Early Building Design: Capturing Decisions for Better Interoperability

K. Meniru
Concordia University, Montréal, Canada

C. Bédard & H. Rivard
ETS – École de Technologie Supérieure, Montréal, Canada

ABSTRACT: Interoperability depends largely on accurate interpretation of data from one form to another. Current efforts (e.g., the IFCs) provide ways to do this, however such solutions are not available when work is accomplished manually. This is unfortunately how work is done today in the most important stage of building design – early building design. The translations that occur when transferring concepts to later stages or when referring to work at this stage entails a high potential for errors that increase cost and delay work. This paper investigates the work process in this early stage of building design and presents requirements for supporting it, a design that satisfies these requirements and a prototype to illustrate an implementation of the design.

1 INTRODUCTION

The building delivery process consists of feasibility, design and construction stages. The scope of work in the design stage is further divided into conceptual (schematic), preliminary (development) and detailed (construction) stages.

Computers have become commonplace in the building design and construction process due to their ability for interaction, recording and recalling data (Rivard et al. 2000b). A recent study of activities and systems associated with managing and exchange of electronic and paper-based data in the building industry reveal inefficient interoperability issues that costs the industry $15.8 billion annually (Gallaher et al. 2004). Most interoperable costs for architects and engineers occur during the design phase, especially the manual re-entry of data that costs 17 times more in the design phase than in the construction phase.

A major part of this excess cost is due to the lack of adequate computer support for the conceptual design stage. The decisions made in this stage are manual-based and work has only recently begun towards understanding it and finding ways to capture it electronically (Cross et al. 1996, Meniru et al. 2003).

This paper discusses how decisions in the early design stage can be captured and shared between all building design teams using a neutral file format like the IFC. The following section presents a summary of issues in the early design process. A section follows with requirements needed for adequate support. The rest of the paper presents a design for supporting these requirements and an implementation for illustration.

2 EARLY BUILDING DESIGN

Building design is complex and its success is most likely when different professionals can collaborate, especially in the early stages (Howard et al. 1989, Bedard et al. 1991). During the resolution of problems encountered in the early design process, the designer does not necessarily complete each issue before moving onto the next. Often, the designer pursues opportunities in the design and may leave incomplete efforts to return at a later time (Goldschmidt 1991, Purcell & Gero 1998, Heylighen et al. 1999).

There are intermittent periods of assessment and reference to the collected requirements when the designer checks the design process against initial established needs (Fricke 1999). Labels are used to substantiate the drawing as reminders or for capturing the intended use of a space. Designers may use stencils or predetermined spatial dimensions but the dependence on precise measurements is typically avoided. Transparent sheets are used in manipulating drawings as these reduce the effort necessary by making it possible to copy from already drawn items. Transparent sheets also support the creation of design alternatives which assist the designer in ultimately producing the perceived best possible solution for the design problem (Atman et al. 1999, Casakin & Goldschmidt 1999, Dörner 1999).

Designer's sketches undergo duplications and transformations (Goel 1995, Mcgown et al. 1998, Verstijnen et al. 1998, Rodgers et al. 2000). During duplication efforts the designer reproduces ideas or sketches already existing, such as a staircase. There are two types of transformations – vertical and lat-

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eral. During vertical transformations, the designer successively details an idea, like adding different spaces to a design such as a kitchen then a bedroom. During lateral transformations, the designer investigates alternate ideas of the same space (e.g. two or more kitchen designs for the same building problem) (see section 3.4 Figure 1).

The next section presents requirements that must be considered in supporting this activity.

3 REQUIREMENTS FOR SUPPORT

3.1 Introduction

Support for early design must cover the essential parts of the process that lead to successful solutions such as the use of vague drawings that stimulate imagination for the creation of alternate solutions. There are five main requirements: appropriate interface between designer and design; proper recognition of items created; collection of alternate solutions; organization of items created and making engineering knowledge transparently available.

3.2 Interface Issues

Drawing is a main part of the early design process. The use of simple graphical forms simplifies the drawing process and leaves the designer's mind free to concentrate on design. This simplicity makes it possible to discard drawings when necessary to explore more than one solution. Support must be provided in a way that encourages the use of simple forms and also minimize the effort in manipulating them.

3.3 Design Item Recognition

The result of using simple forms in drawings is vagueness due to very little definite information. This leads to inconsistent interpretations that may conflict and jeopardize the success of the solution (Fazio 1990). Designers use labels and other text to add more information, however there are design issues that cannot be captured by text and labels are not provided all the time. Some means of consistently recording or capturing design intent is required.

3.4 Collection of Alternatives

Creation of alternatives enhances the possibility for more informed decisions and a successful design. Figure 1 shows two alternatives, solution paths 01 and 02. A solution path is the sequence of recognized design decisions taken in the resolution of a design problem such as shown in “AP01” and “AP02” in Figure 1 (addition of vertical circulation). The second solution path is initiated by the creation of a new version of “AP01” in “SP01” (creation of alternate vertical circulation). In addition, information such as number of steps and riser height is also duplicated from “AP02”. The two solution paths record two solutions for the design problem, “House”.

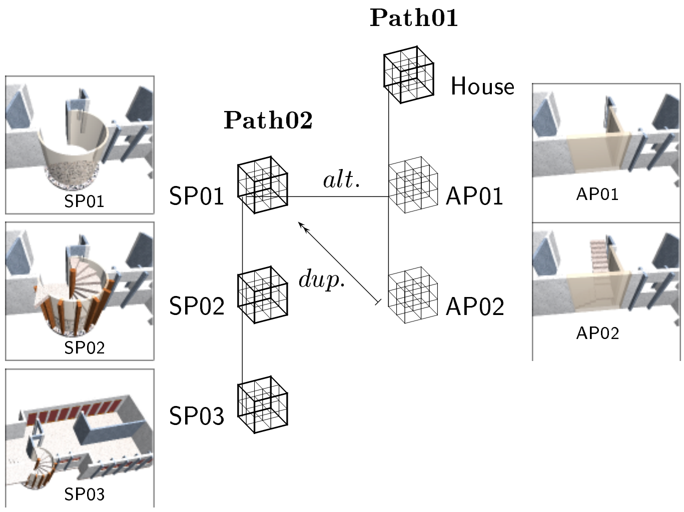

Figure 1. Solution paths

3.5 Design Decomposition

Building parts have a hierarchical relationship in which spaces can be decomposed into their corresponding parts. This forms a natural representation of the connections between them, which provide an intuitive means by which building data can be organized and presented (Rivard & Fenves 2000a). This can be done in many levels of detail. Figure 2 shows the relationship between building levels and the building. Figure 3 shows relationship between spaces and a level.

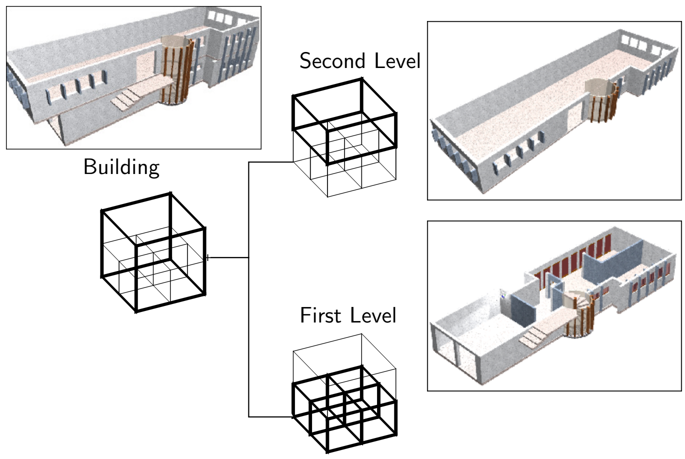

Figure 2. Decomposition of a building

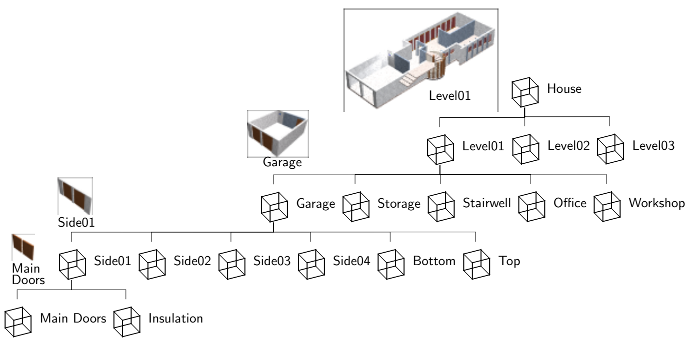

Figure 3. Decomposition of a floor

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This provides the designer an efficient overview of relationships between parts of the building. It also provides direct access with minimum search effort.

3.6 *Knowledge Integration*

The decisions made in the early design process provide a framework upon which all other decisions are built (Cross et al. 1996). The complexity and the personal nature of early design decisions make appropriate collaboration difficult. Designers often revisit decisions made because adequate information was not easily available at the time or was outside the scope of their expertise. Rule-of-thumb knowledge should be available in early design to reduce inappropriate decisions and/or costly amendments.

The next section proposes means to satisfy these requirements.

4 OVERVIEW OF SUPPORT

The concept for supporting early building design in computers is based on the creation and manipulation of two digital objects called Corporeal and Incorporeal design items. Corporeal items denote space usage or space occupied such as a bedroom or a structural column. Incorporeal items denote all other design items such as orientation or direction. When created these items are captured in a way that shows their relationship to all other design items, but to be a part of the solution, first they must be recognized. This recognition process is provided by the Classify function. Once recognized, a design item becomes a part of the design solution and is then collected as a step in the progress towards a solution. Further customization that may make a space more suitable for a particular client, site or budget can then be done through the application of specific knowledge to control behavior or state.

Figure 4 shows an overview of the objects and functions that will provide the required functionality. The draw function makes it possible to create Corporeal and Incorporeal objects. The Classify function makes their classification possible and the designer can also apply knowledge to further configure them. The objects are then captured in a hierarchical view, which occurs automatically, when an object is created. However, they are added to the solution path only when they are classified and can play a specific role in the design.

The next section presents the design of these functions in an attempt to illustrate how to adequately support the process of early design.

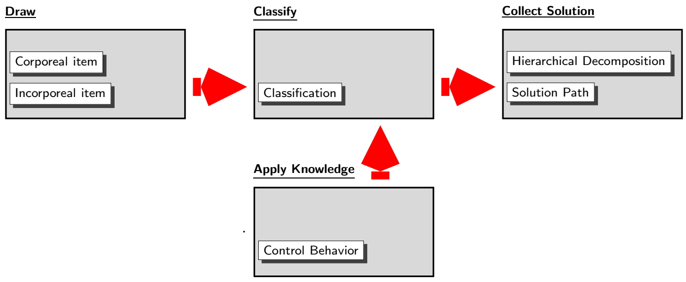

Figure 4. Overview of support functions

5 DESIGNING FOR SUPPORT

5.1 *Introduction*

The illustrations in this section present a visual design session being conducted in a digital environment. The diagrams showing Draw [DW] and Classify [CW] represent windows in which the designer interacts with the support system. The diagrams showing Hierarchy (decomposition) [HW] and (Solution) Path [PW] represent windows that automatically update to reflect the support tools' reactions to the designer's actions.

5.2 *Step 01*

(Figure 5). At the beginning of the session, a blank screen is presented in DW with a list of names for spaces that can be created in CW.

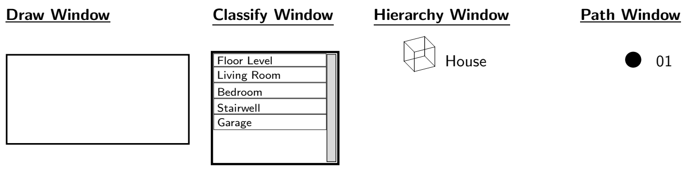

Figure 5. Step 01

The HW depicts the current state of the design session, which is an empty space for solving a "House" design problem. The state of the current solution is captured as a progression of steps in PW, shown here as a first dot.

5.3 *Step 02*

(Figure 6). The designer draws a shape in the DW at (A) and selects the item "Living room" for its classification at (B). The system automatically adds this classified item to the hierarchy tree as shown in the HW at (C) and this progress in the solution of the design problem is shown by the addition of a new step in the PW at (D).

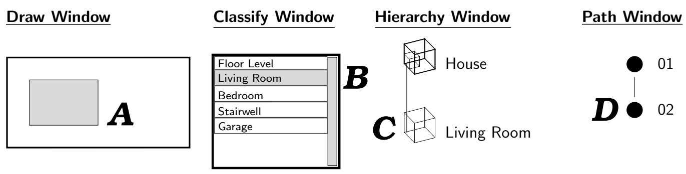

Figure 6. Step 02

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5.4 Step 03

(Figure 7). The designer draws a second shape in DW at (A). Since this new shape is not contained in any other space, the space names offered in CW are similar to those in Figure 6. This new space is added to the hierarchy window as shown in (C) but there is no change in the PW because this new item is not classified and does not provide any obvious improvement or additional feature to the current solution. Designers often draw shapes that may not be used in the final design solution.

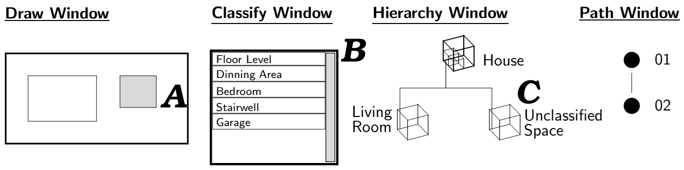

Figure 7. Step 03

5.5 Step 04

(Figure 8). A new space is drawn inside the living room space in DW at (A). The system presents space names in CW. These different choices of names are provided based on the context of the Living room space. The designer makes a choice at (B) causing the system to add the newly classified space in the HW at (C) within the living room space. Finally this progress in the design session is captured in PW at (D).

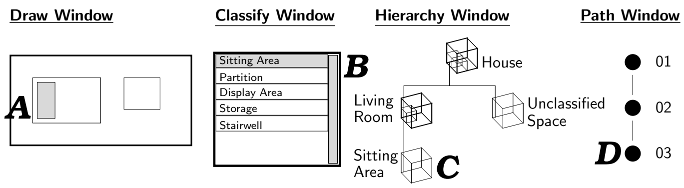

Figure 8. Step 04

5.6 Step 05

(Figure 9). The designer draws a space that encompasses some spaces in DW at (A) and classifies this new space in CW at (B). The system accepts this classification in HW at a higher level (C) than the existing rooms because it is a floor and it encompasses them. The solution path information is then updated in PW at (D).

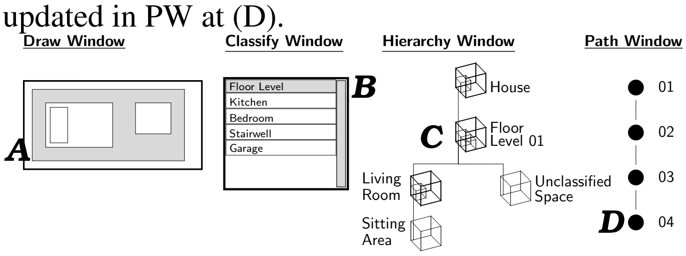

Figure 9. Step 05

5.7 Step 06

(Figure 10). The designer modifies the sitting area in DW at (A) by introducing an alternate version of the solution created in Step 04. No item is classified in this step and the data in HW does not change, however the alternate solution is automatically recorded by the system in PW at (B). The first solution explored is recorded in PW by the path 01–04 while the path 01–03 and 05 records the alternate solution.

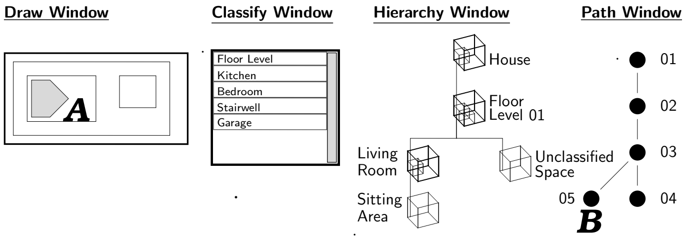

Figure 10. Step 06

6 PROTOTYPE

6.1 Main Window

The prototype developed is called CoBL DT. It presents a main window that is divided into areas in which different activities take place as shown in Figure 11 and as explained below.

The top area presents pull-down menus and toolbars of commands that the designer can use to control the creation and manipulation of design items as shown at A. It provides a location for most of the commands used in CoBL DT.

The second area presents a drawing window shown at B where the designer creates and manipulates the design items. These items are captured automatically by the system and presented in the organization area where the designer can either review or rearrange them with regard to their relationship to each other.

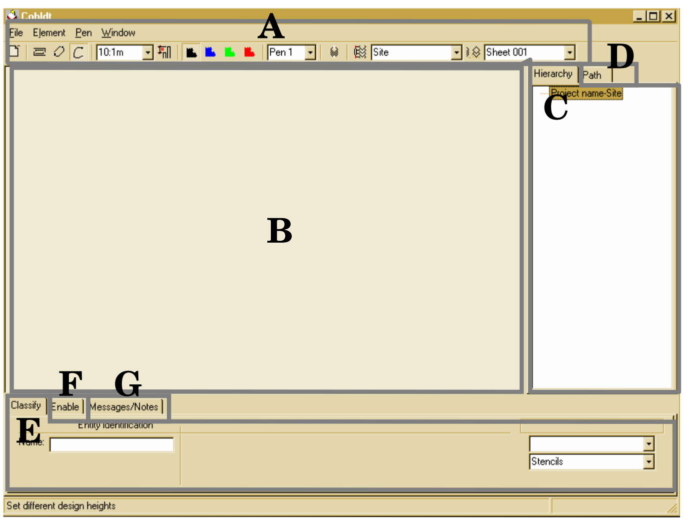

Figure 11. CoBL DT main window.

The third area presents two windows for capturing design items in hierarchies at (C) or capturing design solution paths at (D).

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The fourth area presents three windows. The first two provide the designer with an interface for classifying and configuring design items at (E) and (F). The third window at (G) is used by CoBL DT to provide text-based feedback to the designer about internal operations or consequences of certain interactions. The second region allows the designer to make personal notes.

6.2 *Drawing*

The prototype allows the designer to create generic spaces as Corporeal design items. Generic items are not assigned any role in the design and are drawn with dashed outlines as shown in Figure 12 at (B1). At this time, only the size and orientation is known as shown at (E1). Additional basic function or characteristics can be provided by selecting an option at (E2) to classify the generic Corporeal item.

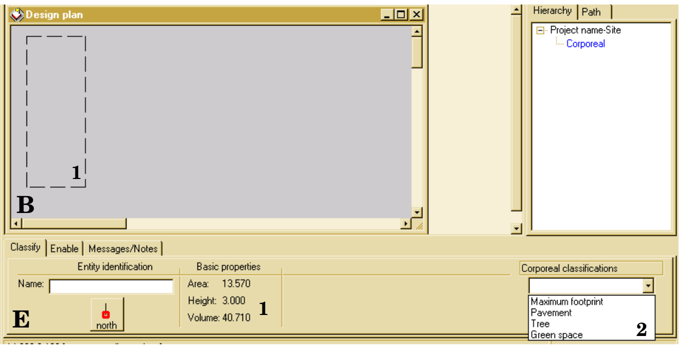


Figure 12. Creating a corporeal design item

6.3 *Classifying*

Classification is akin to labeling sketches in the traditional design process. When classified, the Corporeal item inherits all the basic characteristics and knowledge for the classification as shown in Figure 13 at (B1). The item is then rendered in solid lines and becomes aware of its basic function in the design. Additional options are provided for further configuration and customization at (E1)–(E5) providing one way of applying knowledge in the design.

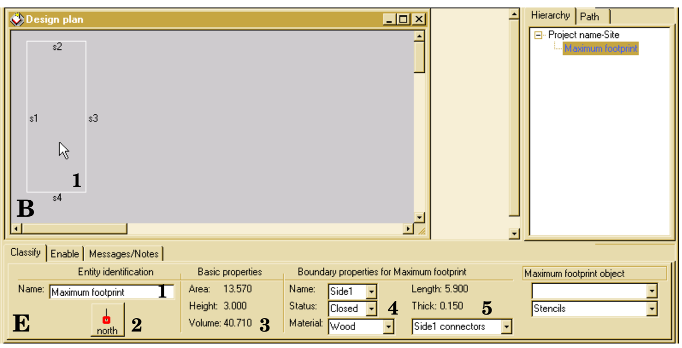


Figure 13. Classified corporeal design item

6.4 *Organizing*

The prototype automatically assists the designer by organizing design items using hierarchical decomposition as shown in Figure 14 at (C). The relationship between all design items is shown and provides an easy access for the designer. Compare with view (B) where items in the current sheet only can be accessed.

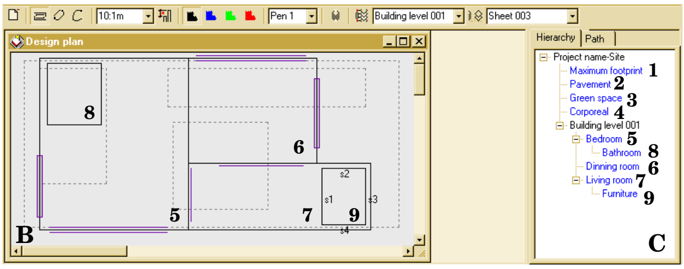
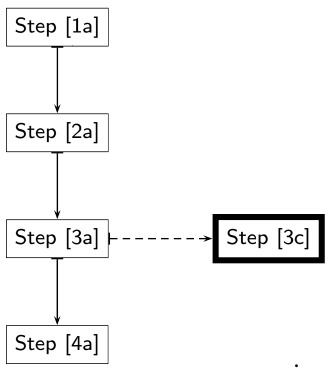


Figure 14. Hierarchical decomposition

CoBL DT can also provide automatic organization by collecting each recognized design item as a step towards a solution (solution path). Figure 15 and Figure 16 show how a new path in the solution is recorded. Solution 01 (Figure 15, Step[1a]–Step[4a]) is automatically captured by CoBL DT. The designer alters this solution at (Step[3a]) to create (Step[3c]). CoBL DT creates solution 02 (Figure 16, Step[1c]–Step[3c]) by duplicating Step[1a] in Step[1c] and Step[2a] in Step[2c]. This is crucial if the designer decides to alter Step[1c], for example. Then it is still possible to go back to solution 01 if desired.



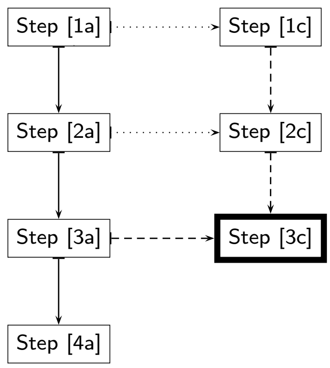


Figure 15. Branch-off point. Figure 16. Replication

6.5 *Application of Knowledge*

Doors and windows are called connectors and are used to establish relationships between spaces as shown in Figure 17 on sides s1 and s2. Connectors are classified in the same way as spaces. They can also be adjusted or removed.

Certain checks can be made as design items are created. For example a minimum size for a space can be provided in which case CoBL DT watches to make sure that this is satisfied. It assists the designer to adhere to requirements. When a violation is detected, a feedback is provided showing approximate

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acceptable size and the creation or manipulation of the item is rejected.

Design aids are also provided such as the use of stencils. Stencils are predetermined sizes for use in design such as automobile sizes for configuring garages or parking spaces.

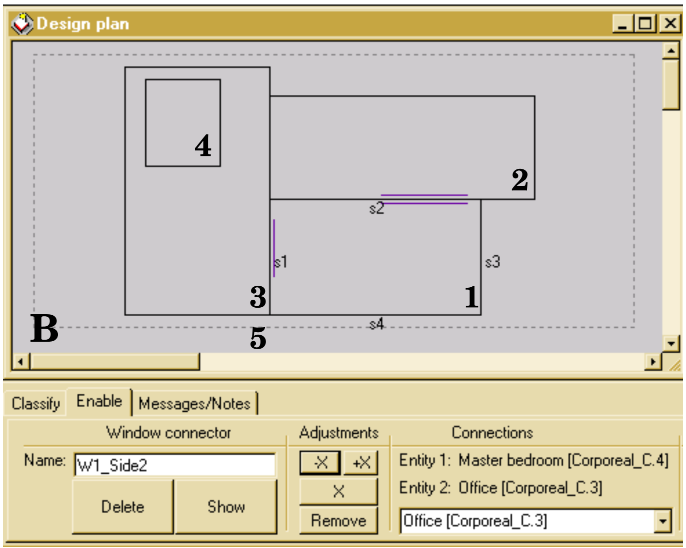

Figure 17. Using connectors

Complex calculations, especially those required to satisfy engineering requirements, can be provided. Figure 18 shows the result of automatic calculations for savings factor in space heating expenses.

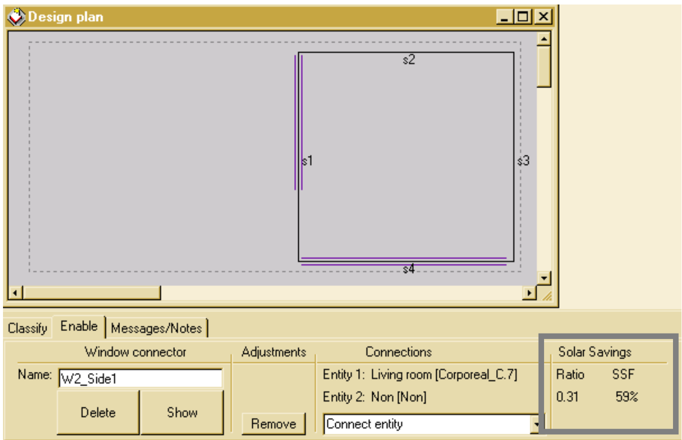

Figure 18. Calculation of solar savings factor

7 SUMMARY

The evidence for more efficient interoperability is compelling and there are new and ongoing efforts to create better formats that existing tools can utilize to transfer data and decisions. These are important efforts however the conceptual stage of design, that provides the fundamental issues which are used by every member of the building team and which relies on the interpretation of decisions made, cannot be supported by these efforts. The reason is that it is not, currently, a digital process.

This paper begins with a description of the early building design process and the requirements for its support. The concept for support in a digital environment is then presented followed by the design for supporting interactions in a digital environment. This includes the development of an appropriate interface for capturing the necessary parts of such a vague process. Finally the main components of a prototype that demonstrates appropriate support based on the concept and design as discussed, is presented. This prototype fulfills the need for interoperability with the ability to capture and transfer early design decisions using the IFCs.

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A multi-floor topology to geometry transformation procedure based on shape functions

G. Zimmermann
University of Kaiserslautern, Kaiserslautern, Germany

G. Suter
Department of Building Physics and Building Ecology, Vienna University of Technology, Vienna, Austria

ABSTRACT: Building floor plans are often outlined as schematics with zero wall thickness. Using shape functions, wall dimensions and circulation areas can be inserted and more detailed drawings generated. This topology-to-geometry transformation does not solve vertical constraints in multi-floor topologies, as for example the alignment of load bearing walls. The paper shows how dissection based rectangular floor plans can be modified by introducing space area extensions to resolve the vertical constraints. Penalty values can be introduced to control the distribution of area extensions. The algorithm is based on defining constraints between nodes of the dissection tree. In the presence of multiple constraints, several passes through the dissection tree may be necessary. The topology-to-geometry transformation is used in every pass to check if the constraints can be fulfilled. The algorithm is demonstrated with an example.

1 INTRODUCTION

The process of generating and modifying floor plans is an important design activity in both architectural and VLSI (Very Large Scale Integrated circuits) domains. A significant body of knowledge has been accumulated and various commercial systems have been developed to provide computational support. Liggett (2000) gives a survey of the approaches to automated layout of facilities. Typical layout systems have a modular structure and are based on a generate-and-test search paradigm (see, for example, Flemming 1989). Generators usually implement a floor plan representation based on the concept of dissection. Topological as well as geometric constraints on dimensions, areas, or aspect ratios of rectangles play an important role in filtering the number of alternative solutions down to a number that is manageable for human designers. Most of these constraints may be characterised as permanent, that is, they are either included explicitly in a space program or defined by a designer up-front, remaining relatively stable throughout layout synthesis.

In this paper, we describe how less static, ad-hoc constraints can be dealt with computationally. Also we are interested in how these could be maintained in the transition from schematic to detailed design. Such constraints are specific to particular floor plans and are informed by structural, energy use, or other performance considerations. For example, in multi-storey buildings it is often desirable to align load-bearing walls vertically on top of each other (*vertical alignment constraint*), or to eliminate minor vertical recesses, which may occur due to discrepancies in floor layouts (*perimeter constraint*). These constraints and related conflicts arise first in schematic and later in detailed design. The transformation from schematic (topology) to detailed (geometry) design representations is non-trivial because the introduction of wall thickness information in detailed design typically causes multiple violations of the mentioned constraints. These might be satisfied in a schematic design, where walls are merely represented as lines.

The paper is organized as follows. First, we review related work, followed by a problem definition and an outline of an algorithm that addresses the problem. We illustrate the description of the algorithm with a concrete example and conclude with a discussion of the limitations of the proposed algorithm as well as potential enhancements.

2 RELATED WORK

The vertical alignment constraint introduced above is related to 'nail' constraints in graphics systems, where the location of an entity may be fixed. Harada et al. (1995) use nail constraints to fix the location of individual walls. Wall alignment across floors, however, is not considered. In the same work, numerical continuous constraint solution is used to determine exact locations, aspect ratios and areas of space rect-

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angles. This approach may be computationally expensive, particularly in large, hierarchical layouts, where analytical area calculations need to be aggregated from leaf nodes upwards toward a root node. The computational effort for the derivation of such analytical equation systems appears realistic only in small problems or in situations limited to local search.

In contrast, shape functions could be useful for more complex layout problems because their derivation and solution is more scalable. In the context of VSLI design, a shape function has been defined "as the lower area bound of all possible rectangles of the cell" (Otten 1983, Zimmermann 1988). A more detailed definition of shape functions and a discussion of different types of shape functions in layout planning is given in Chapter 4.2. Shape functions have been implemented in VSLI and architectural design environments (Zimmermann 1988, Zimmermann and Suter 2004).

In stacking algorithms, the shapes associated with allocating an activity to a floor are usually not considered. Bozer et al. (1994) introduce an algorithm which generates multi-floor layouts. Among the known algorithms for stacking or multi-floor layout, none appears to address the types of constraints mentioned and the consistency problems that occur during the transformation from schematic to detailed design.

In the context of performance-based bulding design, Suter and Mahdavi (2004) describe a procedure that is based on space-boundary offset parameters to control the mapping from schematic to detailed design representations. In that work, however, space area constraints are not considered.

In summary, the work presented in this paper should be viewed as complementary to these related efforts. We believe that the proposed topology to geometry transformation algorithm could be a useful enhancement to automated layout generators or building editors for performance-based design. For conceptual clarity, however, we will explain the algorithm as part of a manual layout generation process.

3 PROBLEM DEFINITION

3.1 *Terminology*

We limit ourselves to orthogonal buildings. L-, U-shaped buildings or other shapes we complement by open spaces to achieve rectangular shapes. Therefore, for the rest of the paper we will assume rectangular buildings.

For floor planning purposes we distinguish two models with different resolution: the *schematic model* describes the *topology* of the spaces of a building with true net areas. The *detailed model* represents spaces with true wall and other dimensions. Geometric representations of schematic models as for example Figure 2 show dimensions for visualization purposes and give an idea of a possible geometry. By changing the aspect ratio, different geometries can be derived from one topology.

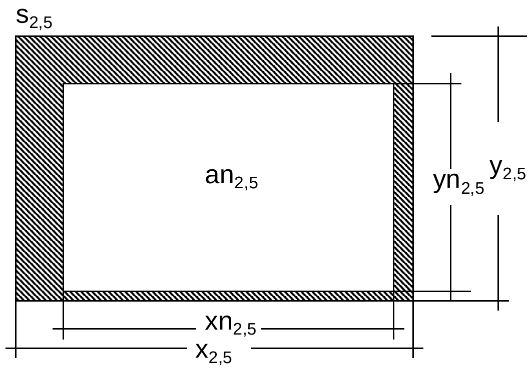

Figure 1. Single room dimensions of a detailed model.

We use an *x*-*y*-*z* coordinate system with *z* as vertical axis. *a* expresses floor area. Suffix *n* denotes net dimensions. Suffix *p* denotes space program dimensions. The space program is a list of all *ap* of net activity spaces plus circulation and other general spaces. The latter spaces are typically not defined by area but by one or two horizontal dimensions. In Chapter 4.2 possible differences between *an* and *ap* are explained.

All dimensions have two indices *i*, *j*. *i* denotes major *sections*, e.g. wings, storeys, vertical shafts, storey, *j* a *space* in a section. Figure 1 shows a single room example.

3.2 *Partitioning*

To generate a schematic model of a building, we interactively partition the whole space of the building recursively by horizontal or vertical *cut-sheets*. We also call this action a *cut*. The cut-sheets are denoted by the direction of the normal vector. The vertical sheets are denoted *x* and *y*, the horizontal *z*. Each cut-sheet dissects a space s_a into two spaces s_b and s_c with

$$an_a = an_b + an_c \qquad (1)$$

We call s_b and s_c siblings of parent s_a. The two siblings have a positional relation to each other, depending on the cut-sheet direction. The following list shows the possible positions with abbreviations in parenthesis:

x:	left(l)	right(r)
y:	front(f)	back(b)
z:	down(d)	up(u)

Partitioning continues until all activity spaces of the space program are positioned. Through careful planning of the positions and directions of the cut-sheets, floor plans for all storeys can be achieved, which even without wall dimensions give a good impression of the final layout. Correct net areas for

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all spaces can be entered into the dissection tool we have described in Zimmermann & Suter 2004, creating a correct topology as starting point for the shape-function based geometry transformation.

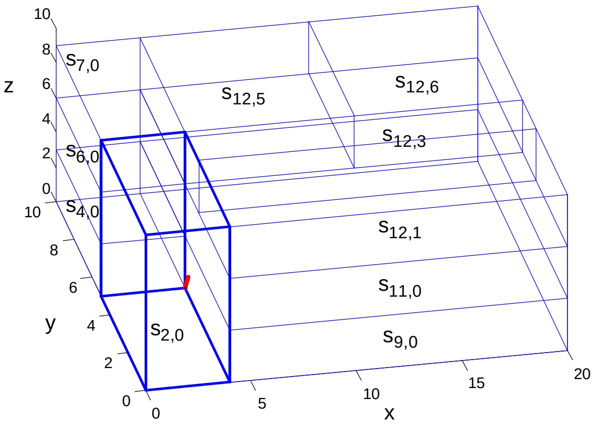

Figure 2. Topology example of a building space $s_{0,0}$ with 3 storeys and a staircase shaft $s_{2,0}$. The top storey $s_{12,0}$ is partitioned into a hallway $s_{12,3}$ and 3 rooms $s_{12,1}$, $s_{12,5}$, and $s_{12,6}$

The partitioning process leads to a binary *dissection tree* representation. Each node in the tree represents a space. We distinguish internal and leaf nodes. Internal nodes represent abstract spaces that are composed of other spaces. Leaf nodes represent spaces required by the space program. Each internal node is also uniquely related to a cut-sheet. Leaf nodes have no cut-sheets. Vertices represent parent-sibling relations. If we denote the nodes in the graphical representation by the positions from the above list, as shown in Figure 3, the cut-sheet direction of the parent nodes can be derived uniquely. A node identifier denotes the space as well as the associated cut-sheet. Figure 3 gives an example. This tree is the basis for all further procedures.

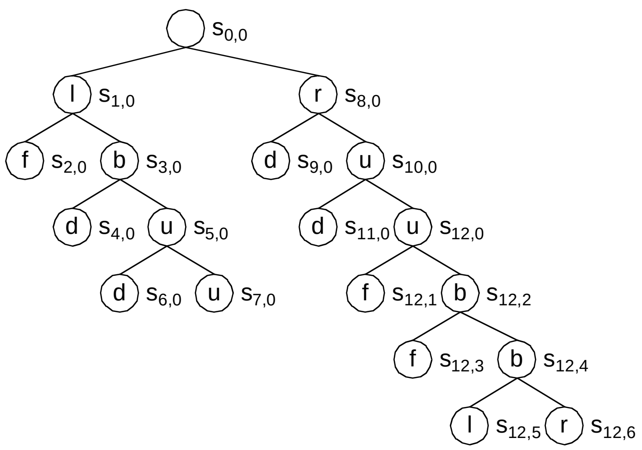

Figure 3. Dissection tree example of the building example in Figure 2

3.3 *Constraints*

Floor planning of multi-floor buildings may be performed floor by floor and by finally matching the layouts where necessary (see Figure 6). We call these necessary matches *vertical constraints*. Horizontal constraints are defined within one floor and are resolved during the topology to geometry transformation (see Chapter 4.2). We distinguish three types of vertical constraints:

The first constraint is caused by the need to align the outer walls of all storeys of a typical building. This means that the perimeters of different storeys have to have the same dimensions. We call this the *perimeter dimension constraint*. If we assume that during floor planning the total area of a storey is determined by the space program for this storey and by the additional areas for walls and other structural objects, the resulting perimeter dimensions will differ from storey to storey, even if a carefully balanced partitioning of the total space program into programs for each storey has been performed. What looks perfectly aligned in Figure 2 will change when the storey spaces $s_{9,0}$, $s_{11,0}$, and $s_{12,0}$ are partitioned and wall dimensions inserted. In this example the constraint can be expressed as:

$$\begin{aligned} x_{9,0} &= x_{11,0} = x_{12,0} \\ y_{9,0} &= y_{11,0} = y_{12,0} \end{aligned} \qquad (2)$$

A similar constraint could be expressed between the three storeys to the left of the example building.

The *wall alignment constraint* stems from the necessity to align load bearing and other internal walls between storeys. Typically the dimensions of such spaces has to be the same in all storeys. In the example this could mean that between the storeys on the left and on the right load-bearing walls exist. The alignment constraint would be expressed as:

$$x_{4,0} = x_{6,0} = x_{7,0} \qquad (3)$$

Shaft constraints guarantee the vertical alignment of shafts for staircases, elevators, chimneys, or utility networks. In the example in Figure 2 the alignment is automatically guaranteed by making the staircase a leaf-space $s_{2,0}$. In other cases this constraint has to be expressed by equations.

It should be pointed out that in all constraint examples dimensions of internal nodes or spaces have been used. The same could be expressed by leaf node dimensions, but the number of equations would increase drastically for most constraints. This is an advantage of the dissection approach and the resulting tree representation. In the following, we outline an algorithm for topology to geometry transformation. The algorithm is especially suited for configurations with floors separated by single cut sheets, such as the configuration shown in Figure 6.

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4 SOLUTION OUTLINE

4.1 *Idea and basic equations*

If the space program would be strictly enforced, the constraints may not always be fulfilled. Some slack is necessary to enlarge or shrink total floor areas or other dimensions. For the purpose of this work we assume that the space program defines minimal net areas or dimensions that have to be fulfilled in any case. On the other hand, spaces can be enlarged if necessary. This will increase the cost but also the utility. We assume that the cost will exceed the utility increase, but this relation will depend on the activity of a space. We will introduce penalty factors p for leaf spaces to control the increase. In general, the total area increase should be minimized.

The basic idea is best explained with the perimeter constraint. Let us assume the example building with three storeys. The equalities of Equation 2 have to be fulfilled. The space areas are nearly balanced across storeys, but the floor plans are different. For each storey the topology has been transformed into a geometry with the same dimension y. This condition fulfills two of the equalities. But the x dimensions differ by a small percentage. If the difference is larger, the space program partitioning should be modified.

Since we assume that all dimensions are minimal, we can not shrink the largest x. We can only extend the x of the smaller storeys. We do this relative to the area of each space and also controlled by the penalty factor p.

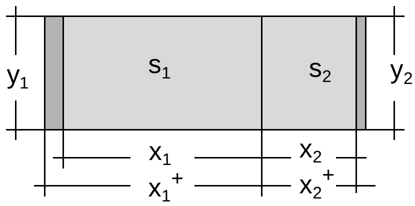

Figure 4. Area extension example

Let us assume two adjacent spaces that are separated by an x-cut-sheet, as shown in Figure 4. If a^+ denotes the extended area, then we define the extension d_i by

$$a_i^+ = a_i \cdot (1 + d_i) \tag{4}$$

If y_i is fixed, the following also holds (for x respectively):

$$x_i^+ = x_i \cdot (1 + d_i) \qquad \text{for } y_i = const \tag{5}$$

Let s_0 be the parent s_1 of and s_2 with

$$a_0 = a_1 + a_2 \tag{6}$$

then for the extended areas we postulate

$$\frac{d_1}{d_2} = \frac{p_2}{p_1} \quad \text{and} \tag{7}$$

$$a_0^+ = a_1^+ + a_2^+ \tag{8}$$

If d_0 is known, we can calculate d_1

$$d_1 = d_0 \cdot \frac{a_1 + a_2}{a_1 + a_2 \cdot p_1 / p_2} \tag{9}$$

and d_2 from Equation 7. This allows us to calculate all extensions starting from the top or from any internal node of the dissection tree down to the leaves of the corresponding subtree. We can imagine this process as a penalty controlled propagation of parent extensions to child extensions. Both children together provide the necessary extension for the parent.

In order to simplify the calculation of the d_i during resolving constraints, the fraction in Equation 9 is calculated and stored in the geometry translation process for all nodes. Since *an* and *at* can be shape dependant, we use *ap* for these calculations. In the case of spaces with x or y dimension constraints, these are used instead of *ap*.

Since we have defined the penalties for the leaves only, we have to give a rule for calculating internal node penalties. We do this from the leaves up, using the same indices as above

$$p_0 = \frac{p_1 + p_2}{2} \tag{10}$$

This basic approach works fine as long as only one constraint is defined in a subtree. If more than one is present, we have to refine our idea. Here we will just outline the idea and explain details in Chapter 5. We start with fulfilling the highest constraint in the subtree. Then we propagate the extensions d with Equation 9 and Equation 7 breadth first down the tree until we meet the next node with a constraint. This may require a larger d than was assigned to the node. In this case we propagate this new d up until it can be met. To get more slack, the extensions are no longer distributed according to the above proportions, but one-sided to the node that requires the larger d. In the extreme case this can mean to even extend the largest storey in the example. Once a node is found with sufficient slack, the top-down propagation continues until the next constraint is found. We assume that during early design phases the number of vertical constraints is small and this “Jo-Jo” process terminates quickly.

4.2 *Shape function based floor plan generation*

Before we can explain the algorithm for vertical constraint resolving, shape functions and their role in floor planning have to be explained. Shape functions have been introduced by Otten (1983) to define the relation between shape and layout area in VLSI designs. Zimmermann (1988) used this definition to

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estimate the effects of routing areas on layout area for chip planning purposes. This technique is closely related to considering wall and other areas in floor planning and led to the current research.

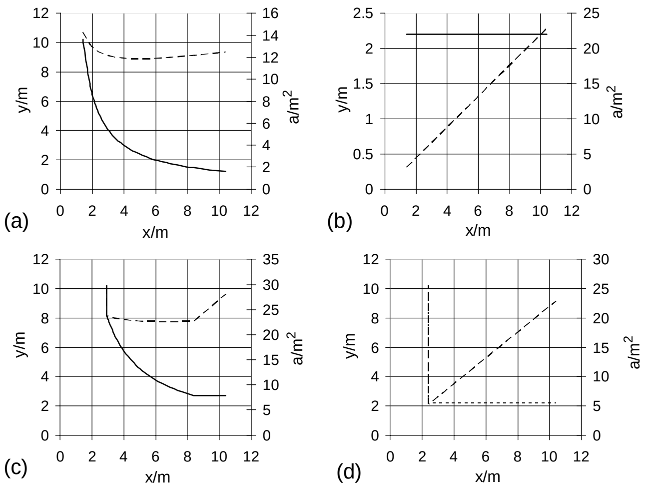

Figure 5. Different shape functions (dashed line = *a*): (a) constant *an*, (b) constant yn, (c) constant an in a limited range, minimum dimensions outside the range, (d) fixed *xn* and *yn*, the dotted line defines empty space

A *shape function* is defined as the relation of *y* to *x* for all possible aspect ratios *y*/*x*. Even if *an* is constant (horizontal constraint), *a* normally varies with different aspect ratios, because the volume of the walls changes with length. Figure 5(a) shows an example of this type.

Shape functions can also express other horizontal constraints. Hallways have typically one dimension fixed and the other variable. Figure 5(b) shows the shape function of a hallway that extends in the x-direction. Other constraints define minimum dimensions of rooms. For example, no office dimension should be smaller than a certain value. Figure 5(c) shows the corresponding shape function. In this case, *an* exceeds *ap* when one of the limits is reached. Instead of hard limits, an can also be continuously increased outside of an ideal aspect ratio. Finally, a space with fixed dimensions is defined by the shape function in Figure 5(d). An example is an elevator shaft. In order to fit such a space to a more flexible space, L-shaped spaces would be created. Here we will introduce empty space by extending the fixed space in one dimension as shown by the dotted lines.

All shape functions have a limited definition range. This is an additional constraint on possible aspect ratios. Also, discrete rather than continuous dimension increments can be expressed. During the topology to geometry transformation, aspect ratio constraints can lead to unsolvable problems. In such a case, the topology, the space program, or the overall aspect ratio have to be changed.

As explained in Zimmermann & Suter (2004), for the purpose of generating floor plans, shape functions have to be defined for all leaf nodes of the dissection tree. This is done automatically by using the space program data and the wall type information. Wall types are either assigned as defaults during the interactive dissection process or can be modified by the designer at any time. External walls are assigned fully to the adjacent space. Internal walls are normally split into two layers and these are assigned to the two adjacent spaces. For this purpose all walls are automatically partitioned into sections with exactly two adjacent spaces. For external walls the surrounding space is the second space.

Shape functions of internal nodes are calculated by adding the shape functions of the siblings. This is a bottom-up process that continues in all branches of the tree until a horizontal cut-sheet is reached. This limit is necessary because the height od spaces (*z*) can not be traded with *x* or *y*. Thus shape functions are always 2-dimensional.

The subtrees that are reached at this point are the major sections that are denoted by the first index (see Chapter 3.1). For each section one total dimension (*xt* or *yt*) for the top node has to be chosen. In the case of several vertically stacked storeys, the same dimension and value will be selected to align one direction of outer walls. With this selection all other dimensions in the subtree are derived from the shape functions and a floor plan geometry without holes or overlaps results. This is a top-down process. The algorithms have been described in Zimmermann & Suter (2004).

The problem remains that the section may not fit together in the free dimension and that other vertical constraints are violated. The basic idea for a solution has been explained in Chapter 4.1 and will be extended in Chapter 5.

5 ALGORITHM

After the introduction of the basic idea and the formulas in Chapter 4.1, the alignment process is straight-forward. We will describe the individual steps of the algorithm in textual form, because a formal language would hide more than it would explain:

Step 1: Plan major sections. Partition space program with the goal to evenly distribute net areas to stacked sections. Sketch floor plan for each section.

Step 2: Mark the cut-sheets in the sketches, compute sums of space areas, calculate total volume and net dimensions of the building. Dissect the building space, major sections first and then each section. This results in a geometric representation of the topology as for example in Figure 2 and the dissection tree as in Figure 3.

Step 3: Identify nodes that result from z-cuts, but do not contain z-cut-sheets in the associated subtree. For each subtree perform the shape-function based geometry transformation. Try to reduce the number

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of vertical constraints by using identical dimensions where possible. Assign penalty factors to leaf nodes.

Step 4: Identify vertical constraints. Enter relations between affected spaces and add constraint equations to the relations. Avoid redundant constraints (if *a*=*b* and *b*=*c*, *a*=*c* is redundant).

Step 5: Traverse the tree breadth-first until the first constraint is found. Find the second node of the constraint relation. Select the node with possible slack. Calculate the extension *d* for this node as defined in Equation 4 and apply *d* to all nodes of this subtree. If *d* extends x, Equation 9 and Equation 7 are used for nodes that result from x-cuts only. For nodes resulting from y-cuts, *d* is copied. For extensions in y, the above is applied respectively. Execute the geometry transformation to check if with the new dimensions a valid solution can be found. If not, which can happen if the valid range of a shape function is exceeded, other modifications as proposed in Chapter 4.2 have to be made.

Step 6: Repeat Step 5 until all vertical constraints at the highest level in the tree have been resolved. This can require repeating the process for nodes that have already been visited, because of the order of the visits. Because we do not reduce the minimal dimensions of the space program and if more than two nodes are directly related, the node with no slack may be visited after the first resolution step.

Step 7: Additional constraints are detected when the subtrees below a resolved constraint are also traversed breadth first. As in Step 5, the second node of the constraint relation has to be selected. Since all subtrees have been processed in Step 5, the extensions *d* of both nodes are known. They can be manipulated by modifying the distribution of the parent extension to the children. In Figure 4, for example, the cut-sheet position can be moved left or right within limits. If both participating nodes have extensions, both will contribute relative to their *d* value and penalty, using Equation 9 accordingly, replacing *a* by *d*. Otherwise, only one *d* is manipulated. In both cases, the *d* of the other child has to be adjusted accordingly.

If the range for modifying the *d*'s is large enough, the process stops here and all involved subtree are recalculated. Otherwise, if the required *d* is larger than what both parent nodes together can provide, the *d* is also distributed to both participating nodes as above, but the parents propagate this extension up the tree until it can be met by a node.

If during this up-propagation other constraint relations are met, these have to be reevaluated in the same way as before.

Step 8: Repeat Step 7 until all constraints have been found and resolved or no valid geometry can be generated.

6 EXAMPLE

In order to be able to show enough details, we had to make the example extremely simple. Let us take a building with 2 storeys, 8 rooms, and a load bearing internal wall in both storeys that have to be aligned. This creates a perimeter dimension and a nested wall alignment constraint.

Step 1: The space program consists of 3 rooms with 20, 30, and 50 m^2 in the first floor and rooms with 25, 30, and 3 rooms with 15 m^2 on the second floor. This sums up to 100 m^2 in each floor. Outer walls are 40 cm, inner walls 26 cm thick. Floor plan sketches are not shown here.

Step 2: The topology result of floor planning is shown in Figure 6 seperately for each storey.

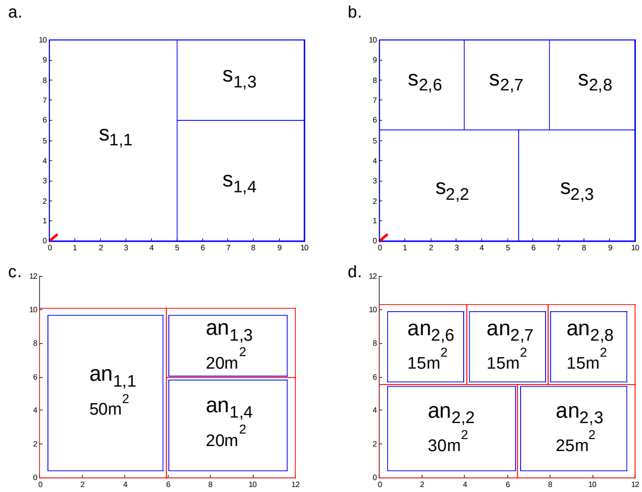

Figure 6. Test building before constraint resolution. a. First floor (schematic). b. Second floor (schematic). c. First floor (detailed), d. Second floor (detailed).

Figure 7 shows the resulting tree structure.

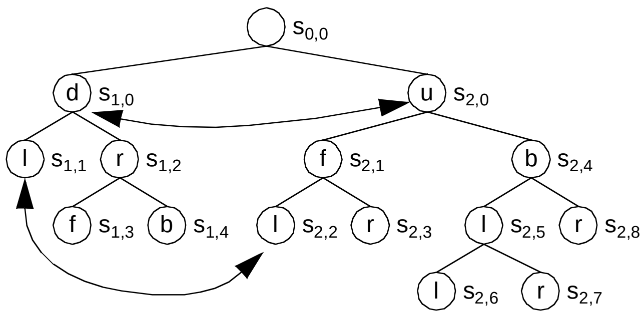

Figure 7. Dissection tree of test building. Arcs with arrow heads denote vertical constraint relations.

Step 3: For the two storeys s1,0 and s2,0 in the detailed model, the same *x*=12m is chosen and the geometry constructed with the results as shown in Figure 6. The transformation results in different y-dimensions of the storeys: $y_{1,0}$ = 10.076m and $y_{2,0}$ = 10.304m. We can also extract the position and dimension of the spaces to the left of the load-bearing walls in the first storey between $s_{1,1}$ and $s_{1,2}$ as $x_{1,1}$ = 5.921m and in the second storey between $s_{2,2}$ and $s_{2,3}$ as $x_{2,2}$ = 6.497m, both measured from the left side of the building. In this step we also

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assign penalty values for the rooms (leaf spaces): $p_{1,1} = 1$; $(p_{1,3}, p_{1,4}, p_{2,2}) = 2$; $p_{2,3} = 3$; $(p_{2,6}, p_{2,7}, p_{2,8}) = 4$. This means that necessary area increases will mostly apply to the larger rooms.

Step 4: We define two vertical constraints: The perimeter dimension constraint $y_{1,0} = y_{2,0}$ and the wall alignment constraint $x_{1,1} = x_{2,2}$. In Step 3 we have shown that both are violated in the geometry in Figure 6. The constraints are shown in Figure 7 as arcs.

Step 5: Traversing the tree in Figure 7 top down, we first find a constraint at node $s_{1,0}$ and the related node $s_{2,0}$. Since $y_{2,0} > y_{1,0}$, $s_{1,0}$ is the node with slack. With Equation 5 we get $d_{1,0} = 0.0226$. By applying Equation 9 and Equation 7 to nodes that result from y-cuts below node $s_{1,0}$, $s_{1,3}$ and $s_{1,4}$ in this case, we finally get new dimensions for these nodes and can apply the geometry transformation again. The result is $y_{1,0}$=10.304m and thus the first constraint is met.

Step 6: No more constraints at the top level are found.

Step 7: Traversing further down from $s_{1,0}$, we find a constraint at node $s_{1,1}$. This is still violated because the x-dimensions have not changed. Since node $s_{1,0}$ has been extended, there is slack in this storey and we try first to use this slack to extend $x_{1,1}$. By minimizing the net area of node $s_{1,2}$ to $ap_{1,2}$, we get $x_{1,1}$=6.061m. To get this result we have to use the shape function of $s_{1,2}$. Figure 8 gives an idea of this process. Still, the constraint is not met. Therefore, we extend $y_{1,0}$ and $y_{2,0}$ in parallel not to violate the first constraint. Again, we have to use the shape functions of the appropriate nodes as above. As a result we get

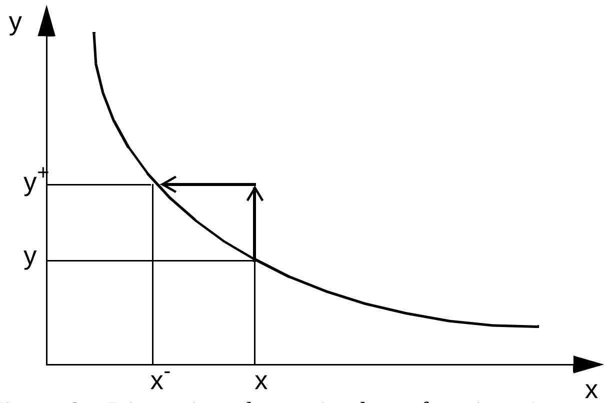

Figure 8. Dimension change in shape function: 1st modification y->y^+; 2nd modification x->x^-

the new dimensions:

$y_{1,0}$=$y_{2,0}$=10.555m

$x_{1,1}$=$x_{2,2}$=6.204m

This result shows that both constraints are met.

Step 8: Traversing further down the tree, no more constraints are found, as expected. Since the generated geometry is valid, the algorithm terminates.

In order not to confuse the reader with too many details we have not shown all intermediate calculations. In practise these are executed by tools, here we used a spreadsheet to do the calculations. The designer only needs a basic understanding of the process to interpret the results and propose modifications.

Matching of the two constraints requires an increase of total building floor area of originally 200m² by 8.75m². The designer can now decide, if he finds this result satisfying or he can either change the space program, the topology, or the penalty factors to improve the result. With tool support these operations can be performed rapidly and allow the designer to experiment in a large design space.

7 CONCLUSION

Mapping procedures such as the topology to geometry transformation algorithm introduced and illustrated above are aimed at improving the information flow in the building design. Although our algorithm is based on several restrictions and assumptions, it is already fairly complex. To further improve its generality, we anticipate work in three areas.

So far, only the 3-dimensional topology planning and the 2-dimensional topology-to-geometry transformations are supported by a prototype tool based on Matlab. Since all extensions are based either on analytical functions or on shape functions that are generated with the existing tool, the extension to full tool support is only a matter of programming effort. No basic problems have to be solved.

We also plan to experiment further with shaft constraints. The idea of the outlined algorithm seems to solve this problem, but we are not certain yet that it works under all conditions. For this purpose we first have to introduce empty spaces into the topology-to-geometry transformation.

Restricting the domain to orthogonal geometries is a significant limitation of the proposed algorithm. This is important particularly in the context of detailed design. We thus intend to incorporate geometry refinement operations, perhaps similar to those described in Suter and Mahdavi (2004). These operations extend the domain to certain classes of non-orthogonal geometries common in building design. Issues related to extending the domain, such as preserving constraints, or adapting shape functions, need to be addressed as well.

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Neural networks in the re-engineering process based on construction drawings

S. Komorowski
HOCHTIEF Construction AG, Bauen im Bestand NRW, Essen, Germany

V. Berkhahn
Institute of Computer Science in Civil Engineering, University of Hannover, Germany

ABSTRACT: In this paper an approach is presented to digitize a drawing, to build up geometric and topologic models, to recognise construction parts and to interpret dimension lines and inscriptions. All recognized parts are transformed into a three-dimensional geometric model which provides all necessary geometric information for a product model. The recognition process of construction parts is based on a line search and topological analysis, which are not suitable for the recognition of drawing inscriptions and hand writings. Therefore, the information of dimension inscriptions has to be neglected in former case studies. Because dimension inscriptions deliver significant information about the dimensions of construction parts, a neural Kohonen network is implemented and adapted in order to recognise inscription text. Finally the gained information about dimensions is related to significant details of construction parts.

1 INTRODUCTION

There have been great efforts in the development of software tools concerning the design and the realization of new buildings. Nowadays, an engineer has access to different kinds of computer based product models and CAD-models. But if he has to deal with the management, reorganisation or recalculation of older buildings, most times there are no digital data available. The only information about the building could be gained from in situ measurements or from paper based drawings, which have to be analyzed manually by the engineer. This is a very time-consuming and boring job hardly supported by effective software tools in general. In order to close this gap between drawings of an existing building and a digital product model an approach is presented in this paper to digitize a drawing, to build up geometric and topologic models, to recognize construction parts of the building and to interpret dimension lines and inscriptions.

Case studies presented by Berkhahn et al. (2003, 2004) are based on a line identification process and topological information about the identified lines. The corresponding topologic and geometric models are used to interpret drawing lines and to identify construction parts. Unfortunately, this approach based on the analysis of topological information is not sufficient for the recognition of inscriptions. Consequently, the information of dimension inscriptions has to be neglected in the corresponding case studies presented by Berkhahn et al. (2004). In these case studies the dimensions of construction parts are gained exclusively by scaling the scanned lines. This approach leads to remarkable inaccuracies for dimensions of construction parts and in some cases the topological correctness of the geometric model could not be assured.

To overcome these difficulties of inaccuracies the inscriptions of drawings have to be interpreted, which is realized by merging the information obtained by a neural network and the topological model. Therefore a Kohonen network (Heaton, 2004) is adapted to recognize standard lettering as well as handwriting in drawings (Komorowski, 2004). The information gained from the Kohonen network and the topological model is merged in order to identify single characters, to combine single characters to inscriptions and finally to relate the inscriptions to dimension lines and construction parts. Finally all recognized parts are transformed into a three-dimensional geometric model which provides all necessary geometric information for a product model.

This contribution is an enhancement of a research paper presented by Berkhahn & Esch (2003) at the CIB W78 conference “Construction IT Bridging the Distance” on Waiheke Island, New Zealand. In this actual contribution theoretical basics and practical applications of merging neural networks and topological models and of the re-engineering process are presented.

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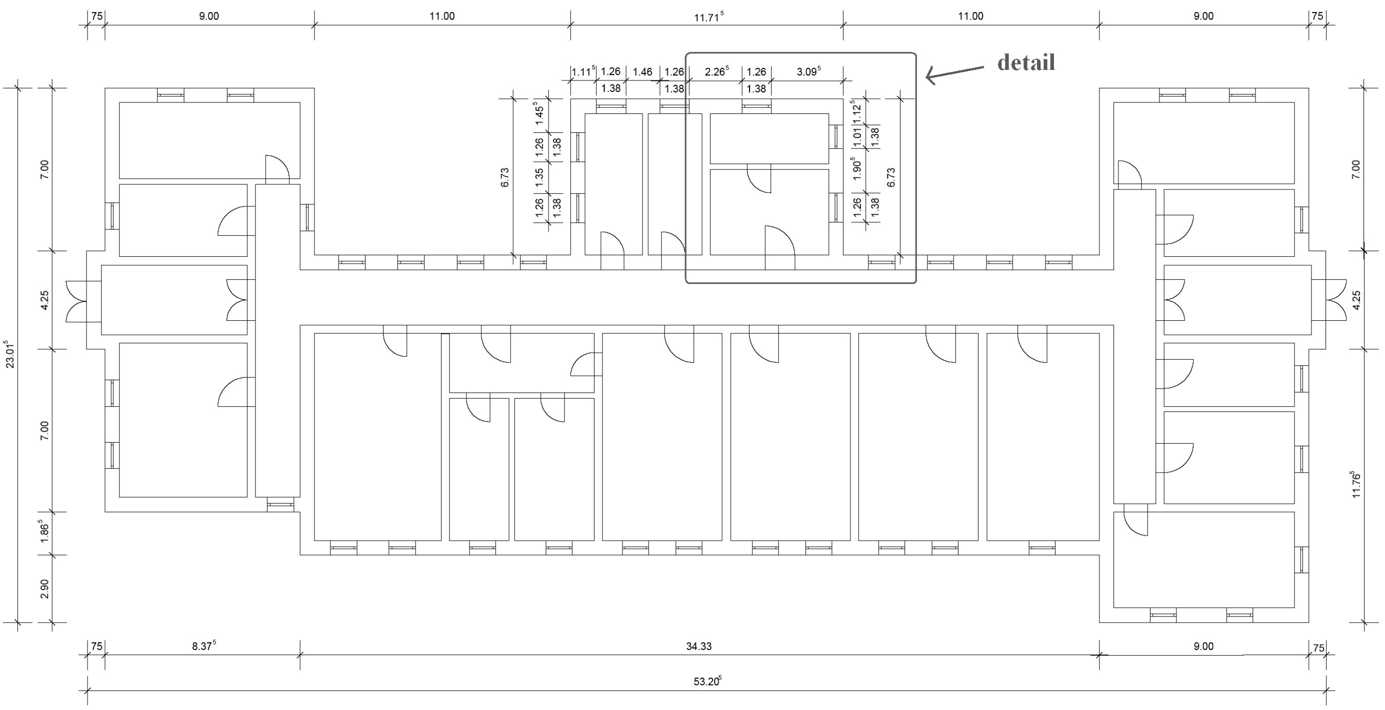

Figure 1. Scanned ground floor plan of the barrack building

All algorithms and methods are implemented with the Java programming language. A case study of an existing building demonstrates the usability and efficiency on the outlined approach. This case study concerns an old barrack build in the beginning of the last century and used nowadays as offices of the University of Hannover. A ground floor plan of the first storey of this building is shown in Figure 1.

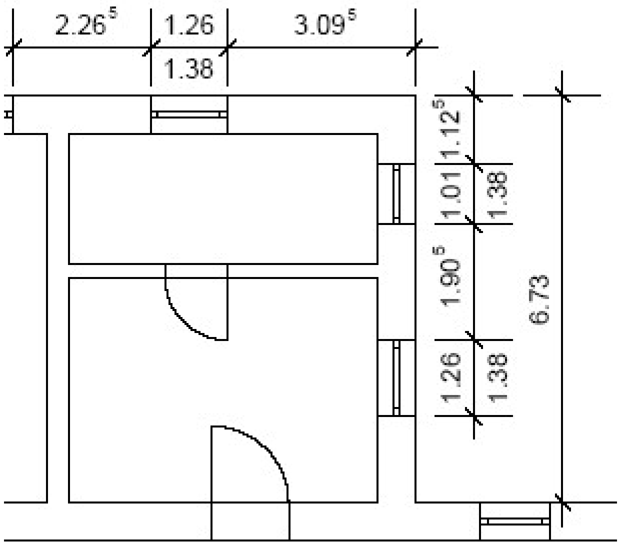

Figure 2. Detail of the ground floor plan

The identified inscriptions, dimension lines and in particularly the corresponding relationship to construction parts are illustrated in detail. For a demonstrative explanation a detail (Figure 2) of the ground floor plan is used. Finally the whole ground floor plan is shown in Figure 14 as result of the identification process after the integration into the IFC-product-model. Product modeling is one of the key issues of the DFG priority program 1103 (DFG 2005) concerning network based co-operative planning processes in structural engineering. Consequently, the actual research work has been considered in strong correlation to this priority program with a special focus to the re-engineering process of existing buildings.

2 NEURAL NETWORKS

2.1 *The Kohonen neural network*

From the multitude of neural networks the Kohonen neural network, which is named after its creator Tuevo Kohonen, suits very well for the recognition of characters. The Kohonen network is a quite simple and fast, but also effective network for this purpose. In contrast to other neural networks the output of a Kohonen network does not consist of the output of several neurons, but it chooses one neuron as a winning neuron. In this way the Kohonen network classifies samples into several groups (e.g. digits or letters). The network only exists of two layers: An input layer which gets information from the outside as well as an output layer which gives information to the outside. When a pattern is presented to the Kohonen network one of the output neurons is selected as a winner. This neuron is the output of the network and corresponds with one of the classified groups. In Figure 3 a simple Kohonen network with three input neurons and two output neurons is shown.

2.1.1 *Determine the output*

By presenting an input vector to the Kohonen network, which contains the values for the input neurons, the network can determine an output for every

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output neuron. The output of the output neurons will be saved in the output vector **y**. The number of components in the input and output vector therefore is equal to the number of input and output neurons. The Kohonen network requires inputs normalized to a range between -1 and 1.

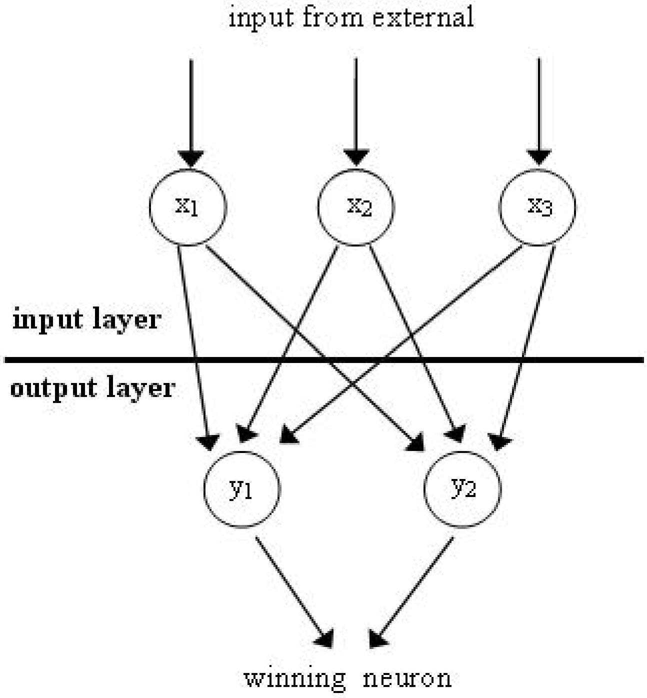

Figure 3. A simple Kohonen network

The normalization factor NF, used in (3), is the vector length of the input vector. Consequently, the value of an output neuron is determined by scalar multiplication of the input vector with the connection weights matrix. For the Kohonen network in Figure 3 the input vector **x** is

$$\mathbf{x} = \begin{pmatrix} x_1 & x_2 & x_3 \end{pmatrix} \tag{1}$$

and the connection weights matrix **w** is

$$\mathbf{w} = \begin{pmatrix} w_{11} & w_{12} \\ w_{21} & w_{22} \\ w_{31} & w_{32} \end{pmatrix} . \tag{2}$$

The matrix **w** consist of components w_{ij} where the index i denotes the input neuron and the index j the output neuron. The output vector **y** is determined by

$$\mathbf{y} = \begin{pmatrix} y_1 & y_2 \end{pmatrix} = \frac{\mathbf{x} \cdot \mathbf{w}}{NF} \tag{3}$$

respectively

$$\mathbf{y} = \frac{\begin{pmatrix} x_1 & x_2 & x_3 \end{pmatrix} \cdot \begin{pmatrix} w_{11} & w_{21} \\ w_{21} & w_{22} \\ w_{31} & w_{32} \end{pmatrix}}{NF} . \tag{4}$$

Consequently, the output values have to convert to bipolar values. Because the input of the network was normalized in advance, only the value of one has to be added and the result divided by two. The winning neuron is the one with the largest value. Thus, the presented pattern is classified in the group which is represented by this winning neuron.

2.1.2 *The training process*

Before a network is able to recognize any pattern it has to be trained. In the case of the Kohonen network this training is unsupervised and quite fast. For the training process training data sets are needed. Every time training data are presented to the network the connection weights are adjusted based on the result of this item of training data. The adjustment of the weights should produce a network that will yield more favorable results the next time the same training data is presented.

A training data set contains of an input vector which holds the pattern of a character and the character that is presented. Because the training is unsupervised, there is no output neuron given in the training data set. The network determines the output neuron itself. This winning neuron represents the classified group representing the character.

The training process consists of repeating cycles. It continues until one of two criteria is satisfied: If the calculated error e is below acceptable level a best weight matrix is found and the process stops. On the other hand, if the error rate has only changed by a very small amount the cycle is aborted, the entire weight matrix is reset to new random values and the training process begins again.

The error e_j is calculated for every training data set and every output neuron as follows

$$e_j = \left\| \mathbf{x} - \mathbf{w}_j \right\| , \tag{5}$$

where w_j represents the j^{th} column of the matrix **w**. The error e_j is not an error in the normal sense of words. It is only a percentage number which gives an idea of how well the Kohonen network is classifying the input in output groups. If the error is not acceptable the connection weights have to be readjusted. The original method for adjusting the connection weights, which was proposed by Kohonen, is the additive method:

$$w_{ij}^{k+1} = \frac{w_{ij}^{k} + \alpha \cdot x_i}{\left\| w_{ij}^{k} + \alpha \cdot x_i \right\|} . \tag{6}$$

The variable w^k is the weight of the neuron, and the variable w^{k+1} is the new weight of the same neuron. The learning rate α is a constant between 0 and 1, which determines the speed of the training process. Setting the learning rate to a larger value will cause the training to progress faster. But a large value could cause the network to converge never.

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Most times the learning rate is set to a value of 0.4 up to 0.5 or it will be set relatively high in the beginning and decreases throughout the training process.

Most times the additive method works quite well. Though, in cases this method fails to converge the subtractive method can by used:

$$w_{ij}^{k+1} = w_{ij}^{k} + \alpha \cdot (x_i - w_{ij}^{k}) \ . \tag{7}$$

This method is used in the program presented in this contribution.

2.2 *OCR in construction drawings with the Kohonen network*

For the optical character recognition (OCR) in construction drawings an existing Java implementation of a Kohonen network (Heaton 2004) is used. This program projects a written character onto a grid with given height and width. This process is called down-sampling and assures that the size and position of the character is no issue. For the down-sampling a frame is drawn around the character, in which the grey scale value of all pixels is determined. Based on this grey scale value a pixel is classified to be part of a digit (= digit pixel) or to be part of the background (= background pixel). The character is projected onto the grid by coloring all caskets of the grid black containing digit pixels. Every casket of the grid stands for one input neuron.

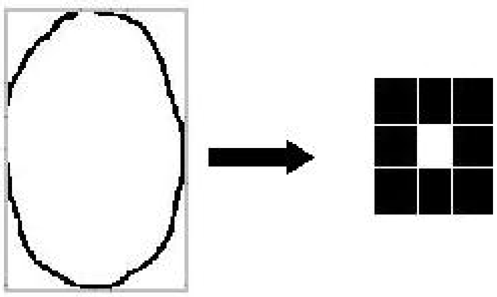

Figure 4. Down-Sampling

The neuron will be assigned a value of -0.5 if it is white or a value of 0.5 if it is black. Thus, the input vector for the grid in Figure 4, which represents the digit 0, will be as follows

$$\mathbf{x} = \begin{pmatrix} 0.5 & 0.5 & 0.5 & 0.5 & -0.5 & 0.5 & 0.5 & 0.5 & 0.5 \end{pmatrix} \ . \tag{8}$$

This input vector is given to the Kohonen network which recognizes this pattern as the digit 0. Because characters in construction drawings normally are not only readable from the bottom, but also from top or sideways, a program for OCR in drawings should be able to deal with this as well. Thus, the implementation is enhanced by these features.

3 DIMENSION MODEL

3.1 *Identification of dimensions chains*

3.1.1 *Dimension values*

For character recognition a Kohonen network is used as described before. But to determine a dimension value it is not sufficient to recognize single digits but the whole number has to be interpreted. This is the point where topological and geometric properties are taken additionally into account.

Most numbers do not consist of one single digit. Therefore, it is necessary to determine how many digits a number contains and how they are arranged. Then the number must be calculated.

To confine single digits the same method is used as for the line identification (Berkhahn et al. 2003, 2004). According to its grey scale value every pixel is either a digit pixel or a background pixel.

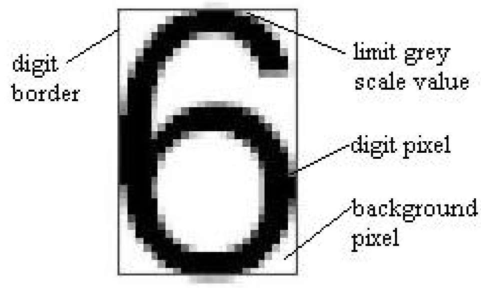

Figure 5. Digit borders and different grey scale values

A well defined area is searched for a digit pixel. Hence, its eight neighboring pixels are examined as well. In this manner all pixels of a digit as well as the minima and maximal pixel coordinates (= digit borders) can be found and saved. The same procedure is done for the next digit pixels. With the pixel borders the digit pixels are presented to the OCR and a single digit is recognized.

All digits of a number will be saved in a vector randomly. For calculating the number the digits have to be resorted. For this purpose the geometrical center of every digit is determined and the right order of the digits can be set. Along with the digits the place of a decimal point will be saved. Also the existence of an exponent is examined. Therefore the centers of the digits are compared to each other. With this information it is quite simple to calculate the value of the number.

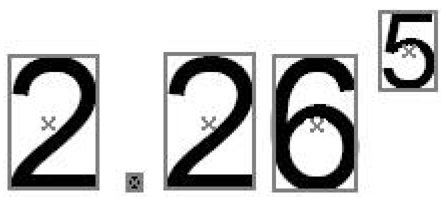

Figure 6. Digit borders and centers

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3.1.2 *Dimension line points and dimension lines*

For the identification of dimension lines the topologic model is used. This topologic model is described in detail by Berkhahn & Esch (2003). Thus, here only a short summary for a better comprehension is given. The topologic model of a pixel-based drawing contains information about the relationship of different lines of the drawing. The model is composed of topologic sections which are bordered by two topologic points. Every topologic section refers to exactly two points and every topologic point refers to all connected sections.

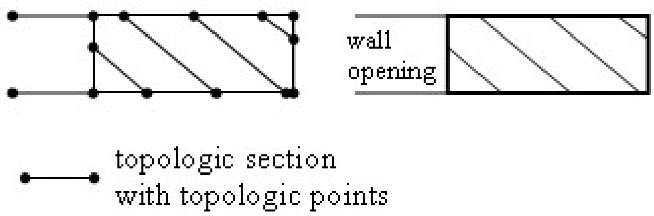

Figure 7. Topologic model

In the topologic model points are searched for which restrain a dimension line, in the following they are called dimension line points. Afterwards the dimension lines between the dimension line points are identified. The dimension model of a drawing is built up by dimension line points and dimension lines.

The ending of a dimension line in a construction drawing is marked by a dimension line termination. In the majority of cases this dimension line termination is a short diagonal slash at the corner of the dimension line and the projection line. By looking at the topologic model of a dimension line termination you recognize four topologic sections (dimension line and projection line), which have a right angle to each other, as well as two topologic section (dimension line terminations) with an angle of approximately 45° or135° to the other sections.

These geometric properties are used to find dimension line points. All found dimension line points are saved in a vector. Every dimension line point refers to one topologic point and a topologic point can only refer to one dimension line point.

After the identification of dimension line points dimension lines are generated. Therefore all topologic sections with the following property are identified: Both topologic points of the topologic section have to refer to a dimension line point. In this case a dimension line with these two dimension line points is created and saved to the dimension model. The coherences between the topologic model and the dimension model are shown in Figure 9.

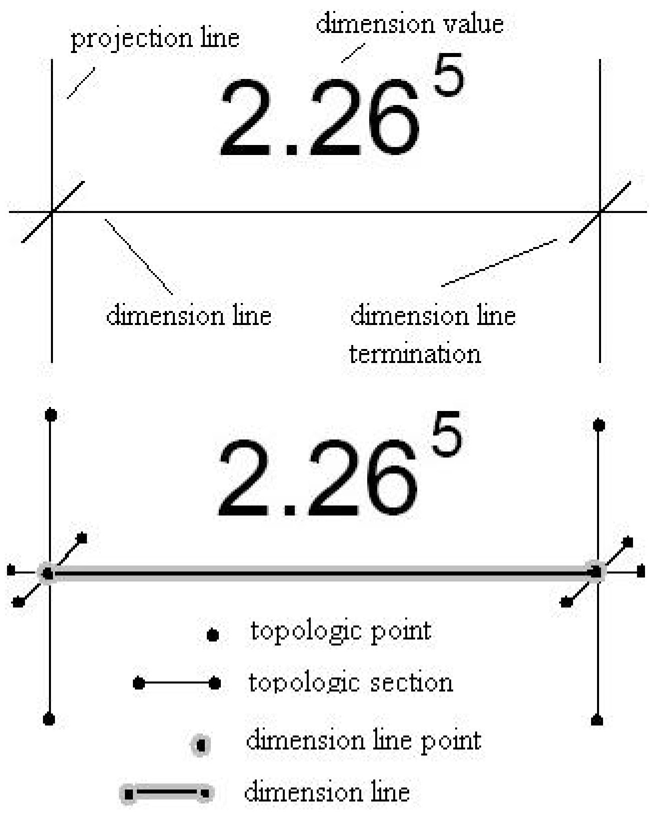

Figure 8. Dimensioning of a drawing with corresponding topologic model and dimension model

Now it is possible to identify the dimension values which correspond to the respective dimension line. Thus, a well defined area on both sides of the dimension line is searched for a dimension value. Depending on the place of the value it will be saved as the length or the height of the measured construction element.

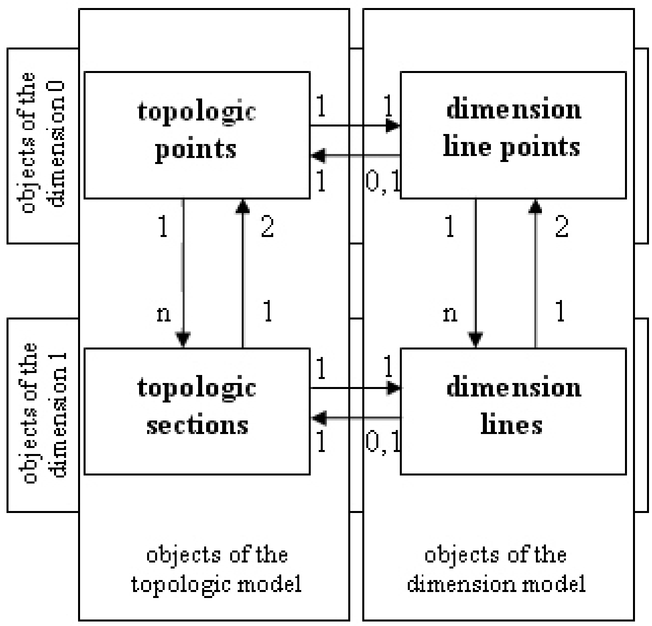

Figure 9. Coherences between the topologic model and the dimension model

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3.2 *Allocation of construction elements*

As described in Berkhahn et al. (2004) construction elements are identified by searching for closed loops of topological sections. These construction elements can be straight walls but also wall corners or junctions. In a second step these construction elements are split up into simple construction elements which has exactly four corner points (= construction element point) and four edges (= construction element sections). This simplification is performed in order to determine quite easily centerlines of construction elements and to facilitate the assembly of independent and dependent construction parts. These later procedure steps are explained in section 4.

Every dimension line holds information about one or more dimension of one or more construction elements. I.e. it corresponds to construction element section of one or more construction elements. For finding the corresponding construction elements of a dimension line in a paper based drawing an engineer will look at the projection lines. Along an imaginary line, that elongates the projection line, all points referring to the dimension line are found. Accordingly the existing construction elements are searched for construction element points, which are on a rectangular line to a dimension a line and cross a dimension line point. Hence, one or more construction element points are found for every dimension line point. An example of this is shown in Figure 10.

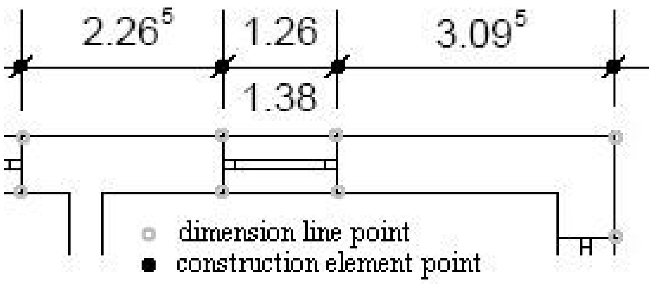

Figure 10. Dimension line points with associated construction element points

The next step is checking out every dimension line and its dimension line points, if a construction element section exists between the associated construction element points. In this case the identified construction element section will be measured by the dimension line and therefore the dimension line now refers to the construction element section and vice versa.

Furthermore, a dimension line may refer to more than one construction element section. In this case construction element sections are searched fulfilling the following criteria: 1.) They are parallel to the dimension line. 2.) They are arranged between the dimension line points of the dimension line and between the construction element points, respectively. The coherences between the topologic model and the dimension model are shown in Figure 11.

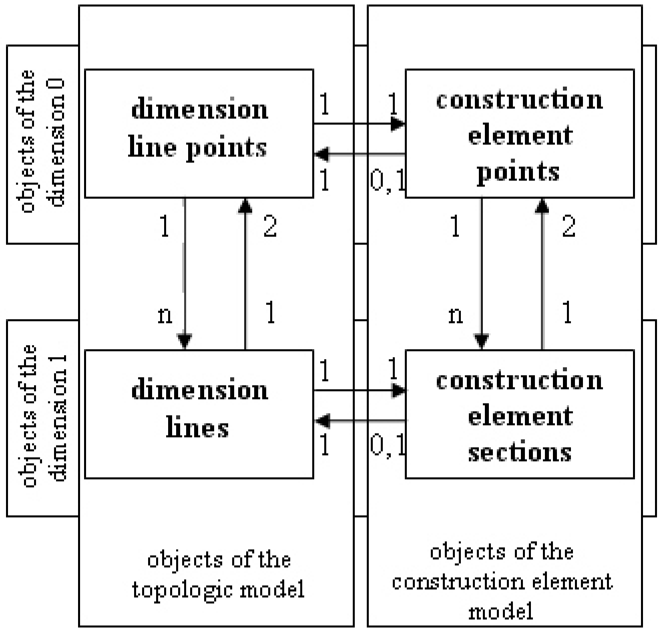

Figure 11. Coherences between the dimension model and the construction element model

3.3 *Inconsistencies*

Finally, the identified dimension lines are displayed in a frame, in which the dimension values are colored. Black values quote that the values are alright, grey colored values quote an error. These indications result from a comparison between the identified dimension values and the user-given scaling factors. In this way all errors resulting from the identification process are recognized. But in the same way inconsistencies in the actual drawing can be determined and made visible to the user. Now the user can correct the errors and the result will be an accurate drawing.

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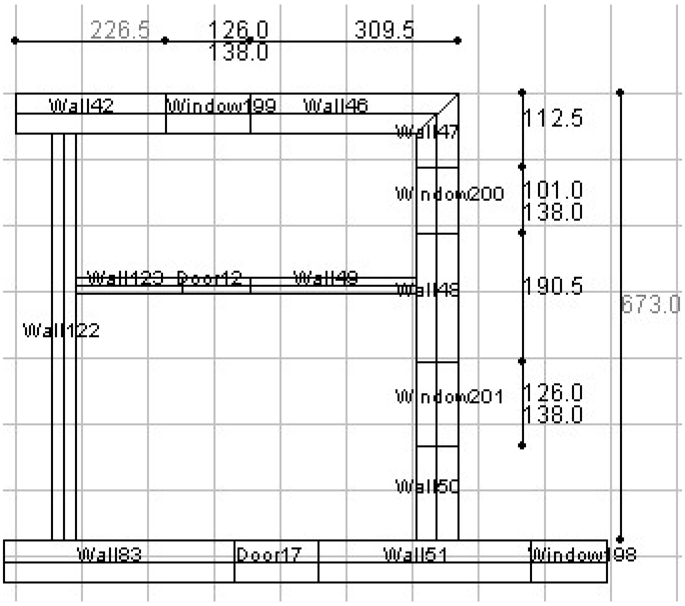

Figure 12. Identified detail of the barrack building

4 IMPORT TO A PRODUCT MODEL

For the import of construction parts into a product model the system centerline has to be determined. This is quite simple for the simple construction elements with its four edges. After the determination of the system centerline of every construction element independent and dependent elements are defined. Independent construction parts exist without any reference to any other part. In contrast to this, window or door construction parts are dependent parts, which are defined by a reference to a wall construction part. A ground floor plan implies only the information about the wall parts beside a window or a door part. For the import into a product model the wall parts at both sides of a window or a door part are merged to one independent entire wall part. The corresponding dependent windows and door parts refer to this entire wall part. The corresponding dependent window and door parts refer to this entire wall part (Figure 13).

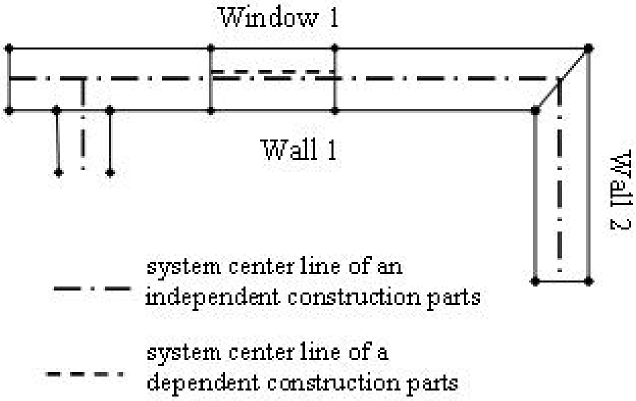

Figure 13. Dependent and independent construction parts

The identified construction parts, defined by their centerline and thickness, are imported into the geometry kernel of a product model. Additional information about the height between floors and the heights of window parapets or of door lintels has to be defined generally for the whole building. Exceptions of the standard heights have to be specified explicitly for the relevant construction parts.

In addition to geometric and topologic data product information of the building is managed by the product model, which is relevant for all states of design, planning, construction, creation and usage.

5 CONCLUSION

The testing of the implemented software tool with a ground floor plan of a real building has shown, that the identification of construction elements and their dimensions and the transfer into a product model is generally possible. Yet hitherto the appropriate criteria for the identification have to be adjusted to the particular drawing. As neuronal networks have been shown very effective within the identification of dimension values, succeeding consideration should involve neural networks within the identification of construction elements. Though construction elements always have the same criteria of recognition, they are seldom exact identically. Therefore, the application of neuronal networks in combination with information gained from geometric and topological models shows a great promise.

Furthermore, the user interface of the software tool has to be adapted to the requirements and conditions of the every day practice. For the different input values sensible standard values have to be provided or appropriate algorithms for automatic determination of the input values have to be implemented. Particularly, dealing with recognized inconsistencies between drawing, dimension and inscription requires fine tuning of user interaction.

6 ACKNOWLEDGEMENT

The authors would like to thank Prof. Ernst Rank and Matthias Schleinkofer, Lehrstuhl für Bauinformatik at the Technical University of Munich, for the fruitful cooperation concerning the data import into a product model. Based on their long experience in product models a common interface was developed and as result the recognised construction parts are visualized within the IFC-product-model (Figure 14).

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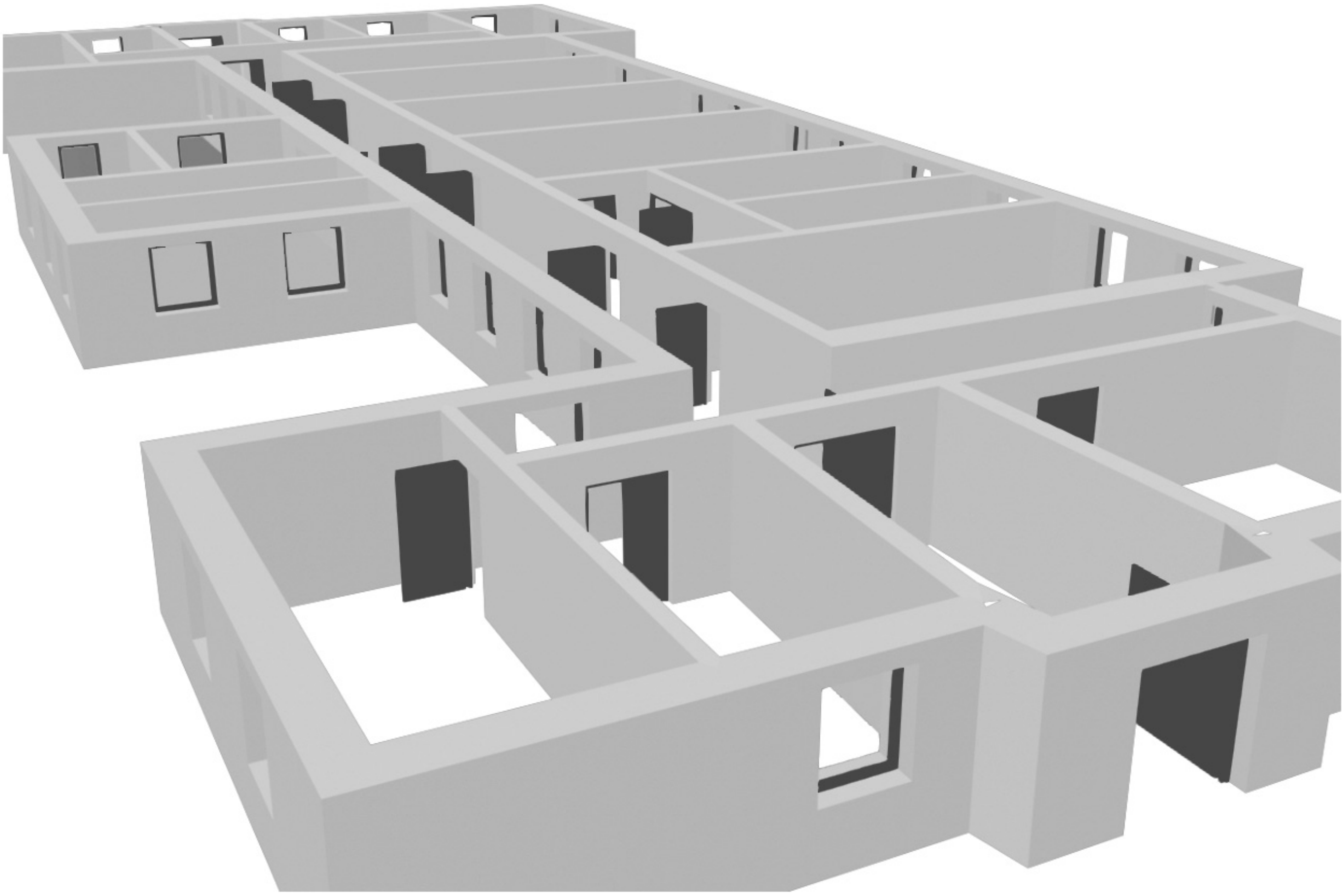

Figure 14. IFC-product-model of the barrack case study

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Prediction of consequences for planning situation based decisions

A. Lähr & K.-U. Bletzinger
Chair of Structural Analysis, Technical University Munich, Germany

ABSTRACT: Consequences of a decision made by a planner (e.g. a project manager, or an engineer) within a collaborative environment can hardly be foreseen. For example, such a collaborative scenario is represented by a planning process in AEC. In particular, during certain planning stages alternatives have to be considered which significantly influence the overall result. Todays AEC planning procedures can be very much improved by predicting simulation methods to judge about the quality impact of certain design or planning modifications. Also, the proper interpretation of data is very crucial to give suitable insight into the characteristic consequences of individual planning decisions. This contribution presents an approach to achieve this goal by discussing needs, problems and implementation for the actual state of our research.

1 INTRODUCTION

Efficiency of a planning process is a prerequisite for the success of a product in AEC. Mistakes or sub-optimal decisions can lead to severe negative influences on the ongoing planning process and therefore on the whole product. As a consequence, prediction of planning decisions would contribute to achieve a better result.

The idea of simulating the planning process is well known in automotive industry. There are many techniques to support designers, which are already implemented. They are frequently used to apply multidisciplinary optimization (MDO). However, in AEC most problems arise on the different working environments of the planning participants. The most important difference is the lack of shared common product data models. Those models are being developed now (see below), but are not yet capable of keeping data consistently for a whole planning process in AEC. Another discrepancy is that in AEC there is hardly any discipline-spanning in-house-manufacturing. Different disciplines are distributed to various companies and therefore locations, which usually don't work together for any longer than the duration of one planning project. Thus, the effort to adjust their systems for co-operation for every new project is usually too high to work economically.

The idea of our research project is to realize the interweavement of the different disciplines participating in a planning process in AEC as depicted below in Figure 1.

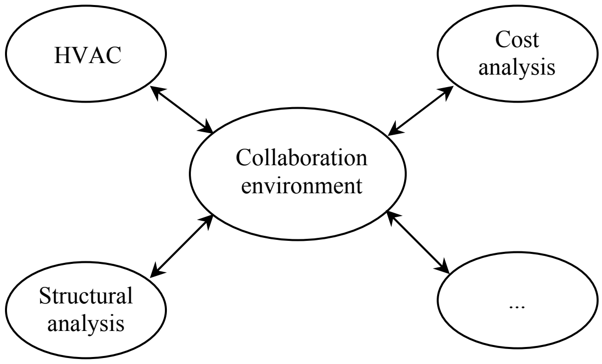

Figure 1. Collaboration schema.

An agent based communication environment allows flexible and scalable implementation of such a co-operative scenario. Furthermore, co-operation with existing agent communication systems is facilitated by using the FIPA standardized Agent Communication Language (FIPA-ACL) for message transfer.

For analysis of planning situations we apply methods from the field of sensitivity analysis, which are typically used in optimization disciplines (e.g. structural or topology optimization). They deal with the question how specific parameters of a system change if certain input parameters vary. Among others, Design of Experiment (DOE) and Response Surface Methods (RSM) are used. Applying these methods the level of impact (consequences) to particular planning parameters can be estimated, which arise by alteration of specified input parameters.

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Predominantly, this affects recurring parts of the whole planning process (e.g. dimensioning of constructional elements) if they are subject to multi-disciplinary involvement.

Communication with respect to data exchange is based on a shared common product model. A promising approach is the Industry Foundation Classes (IFC) because of its standardized data exchange methods (ISO 10303: STEP, SDAI). The potential amount of planner's applications supporting this exchange formats steadily increases.

2 RELATED WORK

The International Alliance for Interoperability (http://www.iai-international.org/iai_international/) released IFC2x2 as the actual version in May 2003. This release has significant changes to the prior IFC2x version (e.g. ST-4 extension for Structural Analysis Model and Steel Constructions, see http://cib.bau.tu-dresden.de/icss/structural_papers). However, only few planner applications implement the actual version of standard, at the moment.

To serve business needs the product model has to be managed by model servers, which are capable of keeping consistency, multi-user access handling, etc. Among others, the EPM Technology (see http://www.epmtech.jotne.com/) company is engaged in implementing these services. Their product, called EPM Data Manager, provides powerful functionality to handle EXPRESS based product models. Also, the Institute of Applied Computer Science in Civil Engineering at the University of Technology Dresden developed a model server along with the iCSS project (see http://cib.bau.tu-dresden.de/icss/) to fulfill the postulated needs.

Extended functionality, like communication between the participants, project management, knowledge based services is obtained by cooperation platforms. Recently, several research projects were involved in developing those constructs. ISTforCE (see http://www.istforce.com/) and iCSS research projects have been finished. ArKos (see http://www.arkos.info/) is a new and actual project of several companies and research institutes.

To find more acceptance in practice much more functionalities have to be implemented in such platforms. For example, the previous services (in particular IFC model servers) were not able to grant access to partial models. Only either individual objects or the whole model could be exported. The Institute of Applied Computer Science in Civil Engineering at TU Dresden developed a global model subset definition schema (Weise et al. (2003)) to define partial models. It is capable of representing a specific view of the model (for example the structural model, or the HVAC model). This is one important step to support collaboration of planners from different disciplines.

Collaboration and co-operation in a planning process implies combining different planner's applications. Data transfer between them can be achieved by using and "understanding" the underlying common shared product model. Unfortunately, the number of planner applications implementing such product models, in particular IFC, is not very high. Most of them support read access from IFC only. Exceptions are, among few others, mainly CAD-applications like ArchiCad (see http://www.graphisoft.de/) or ADT (see http://www.autodesk.com) which produce IFC data in form of a STEP Physical File (ISO 10303-21 IS 1994). However, they usually support the geometric model only.

3 COLLABORATIVE ENVIRONMENT

3.1 *General*

As mentioned in section 2 several projects are dealing or dealt with environments for collaborative work in AEC. However, we develop our own model, because we need additional features like dynamic workflow management or analyzing support for certain parts of a planning process (see below).

A collaborative environment (CE) in our context needs to be capable to include workflow, involved planners and underlying product model data for a certain scenario. Such a scenario is set up by an analyst who defines the product model data and possible changes (variants) to that model. Afterwards, affected planners have to process this information and provide the CE with their results. Lastly, the analyst will pick up the data and do an analysis of that process resulting in an assessment of consequences and pointing out alternatives for the accomplished modifications.

Heterogeneity and different demands of planner applications make generic interfaces highly essential. Therefore, development of an integration mechanism for involved planners is necessary. Furthermore, workflow management should not be handled statically by the analyst himself. A more dynamic workflow as well as product data management model has to be introduced.

In the following an agent based CE is presented, which possesses all the postulated properties.

3.2 *Agent technology*

Agent technology is a methodology for handling network communication on a very high level of abstraction. A software agent is an independent computer program, which is able to autonomously inter-

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act with its environment. Decisions to be made are based on its perceptions and contribute to reach its goal. For detailed information see Woolbridge & Jennings (1995) and Ferber (1999). Furthermore, agent mobility is an important feature in our context. It enables an agent to migrate to other environments. Actually, agents are created on an agent platform, which can be spanned over several computers connected via network. The agent environments on these computers are called containers. Two types of agent mobility can be specified. Intra-platform mobility, which means migrating from one container to another within the same platform and inter-platform mobility for cross platform migration. In foreign containers agents are able to communicate and interact with agents and services residing there. The instrument of conversation is the agent communication language (ACL), a standard released by the Foundation for Intelligent Physical Agents (see http://www.fipa.org/).

So called multi agent systems (MAS) conglomerate several agent platforms and allow the agents to move to other platforms (inter-platform mobility). Such agents are called mobile agents and strongly support collaboration of geographically distributed planners.

3.3 *Integration mechanism*

To integrate the different involved persons (planners and analyst) the class of proxy agents is introduced. A proxy agent (PA) represents the participating person or institution within the agent environment (multi agent system). Accordingly, a PA has to act as an interface to external, planner specific software, which mostly has been approved over a long time. This technique is also known as software wrapping. A software wrapper is a thin software program or module that converts program-specific input and output operations into generic sets of commands that can apply to a wide range of programs.

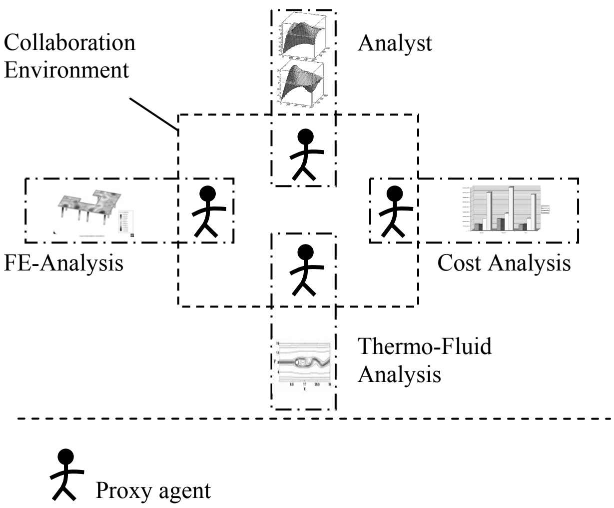

Figure 2. Integration by proxy agents

Furthermore, a proxy agent is immobile and resides in a local container on the same computer as the software to be integrated. The local container is connected to the (main) platform and the proxy agent is able to interact with this environment.

Figure 2 depicts the integration concept. The central rectangle (dotted line) represents the agent environment. Note that there is no distinction between agent container and platform when the term agent environment is used. The dot and dashed line describes a local container (e.g. a personal computer) and contains the proxy agent as well as the application to be integrated.

3.4 *Workflow management*

Typically, complexity of a planning process in AEC renders determination of the planners affected by another planner's decision highly delicate. Furthermore, because within this environment mainly partials of a planning process are to be defined, there is a designated internal workflow management.

There is one central workflow manager, who gets notified if an event happens that affects the workflow of a run. A run in this context is the process starting with initial definition of the product model data and ending when all results from the involved planners are provided to the CE’s data management (see 3.5).

The workflow manager is an immobile software agent. Furthermore, there is no direct communication between a workflow manager and a proxy manager, because there is no static process chain steered by a central institution. A more flexible and dynamic way is letting the planners choose when to contribute to the run. To realize this, another class of agents are introduced, the monitor agents. Monitor agents are mobile agents, which have an owner. As mobile agents they can migrate to the workflow manager’s environment and attach themselves to it. They possess a filter to screen the workflow events of the workflow manager and, in case of interest, inform their owner (proxy agent), who can react on such events.

Everytime the workflow manager gets an event notice, he delegates it to the attached monitor agents. Figure 3 depicts the processing of such an incoming event notice. After delegation to the monitor agents the second monitor agent realizes an event of interest and contacts his owner (proxy agent). An Event notice is sent by a proxy agent when any CE relevant activity finished. Also, the product model agent (see below) is able to initiate (fire) these events.

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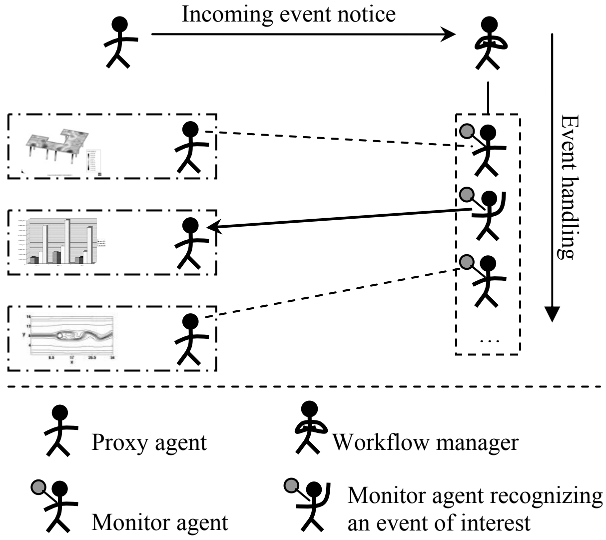

Figure 3. Workflow management

3.5 *Product model management*

The variety of data depends on the definition of the product model. We decided to implement the Industry Foundation Classes (IFC), maintained by the International Alliance for Interoperability because it is widely accepted in this field. Further developments, like the release of IFC2x2 in May 2003 seem to be a step forward to enable integration of the standard in current applications.

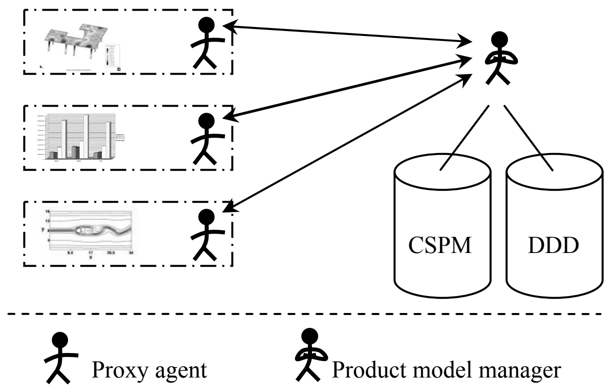

Figure 4. Product model management

Thus, planner application specific data may not be transferred along with the mentioned standardized product data model (IFC). Three reasons are responsible for this:

1 The product model definition is still under development and certain features are not available yet.
2 The planner specific data will not be part of the standardized model, because it is considered to be of no interest for other involved persons.
3 Used planner applications may be unable to write their data back into the product data model consistently.

In particular, for our purpose, planner specific data may be very interesting indeed. This fact leads to the strategy to split the product data into two parts: A common shared product model (CSPM) based on IFC and an extension called dedicated domain data (DDD). If DDD cannot be expressed directly in IFC, it has to be converted to IFC Property Sets. IFC Property Sets are generic data containers, which can be attached to common IFC objects by a link to the global unique ID (GUID).

The question is how to (i) transfer the data to the planner, (ii) modify it and (iii) merge it back to the product data model. Usually, a model server is responsible for accessing and keeping consistency of the global model. This task is fulfilled by a product model agent. The target applications, which will be used, must be able to read the data exchange format IFC as ISO 10303 Part 21 - Step Physical File (SPF) format to realize step (i). Clearly, step (ii) is left to the applications themselves and step (iii) again is to be managed by the product model agent.

A problem arises if DDD gets very large because of the variety or size of the result sets or the domain specific data. Transferring and parsing of such a file can easily lead to severe performance losses. The product model is able to filter corresponding DDD parts to keep exchanged data slim. This means that for every application/domain a certain subset of DDD data can be provided along with the CSPM.

4 ANALYSIS METHODS

4.1 *Sensitivity analysis*

Basically, sensitivity analysis is concerned with the question of how response y of a system varies, due to an alteration of the input parameters x.

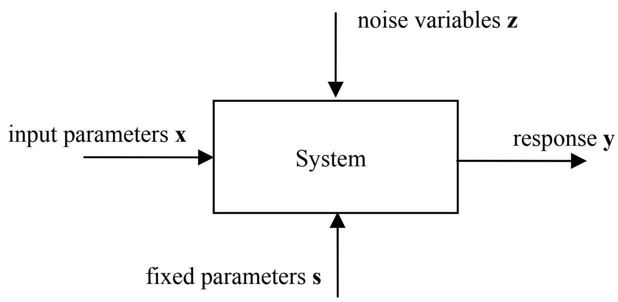

Figure 5. Sensitivity analysis

For completeness in Figure X additional parameters s and z are depicted. Noise variables **z** are non-influenceable, like uncertainties, etc. Fixed parameters **s** are parameters, which remain the same during the whole analysis.

Reasonability of a sensitivity analysis depends on the knowledge of the underlying system. Thus, it can be used to identify an unknown or predict the response of a sufficiently acquainted system.

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Particularly, there is to be distinguished between screening methods, local and global methods. Screening methods are used to identify significant system parameters. One of the simplest applications of screening methods is the one-at-a-time (OAT) method. Their major limitation is the neglecting of parameter interaction (Saltelli et al. (2000)). Local sensitivities of a system are imagined at best as partial derivatives with respect to the input parameters. The system has to be known as a function to directly derive the sensitivities from. Otherwise, methods like finite-difference approximation support obtaining the slopes of the calculated system. Considering "real" systems, an analyst is faced with the influence of noise variables. They are uncertainties, like measurement errors, rounding errors, etc., and can't be controlled directly. Therefore, global methods of the sensitivity analysis are applied to cover the total scope of input parameters. The goal remains the same, namely to analyze the system alteration by variation of input parameters.

4.2 *Surrogate models*

In AEC sometimes a planner's task means high time and effort costs, especially when testing various scenarios with different input parameters. To reduce this effort surrogate models can be created, which processing costs are significantly cheaper than the original ones. Generally, the model cannot represent the real planner's contribution exactly. This is to be faced with the crucial reduction of complexity and effort. The derivation of a surrogate model is realized by applying statistical approximation methods like Kriging to the response data of the tested planner's task. Kriging is a procedure with a statistical, interpolative character and was originally developed by Sacks et al. and presented in Sacks et al. (1989). Further approximation methods are being examined at the moment.

Starting from certain system information and educing to a corresponding function behavior of significant input parameters is a task for Response Surface Methods (RSM). For example, supported by regression analysis, mostly linear or quadratic approximation is used. Furthermore, by application of Kriging these approximations are supplemented by a random process, which allows exact function values at the input sampling points. Aforementioned system information may be of experimental or numerical nature.

4.3 *Design of experiments*

DOE is a methodology to choose the location of the sampling points, used to accomplish statistical experiments. To make an expedient statement of a statistically derived model a certain number of experiments is to be processed. This number can be controlled by using different designs like e.g. full factorial, fractional factorial designs as well as Latin hypercube sampling (see Box and Draper (1987)).

5 APPLICATION

In this section an example of an analysis will be presented. The participating disciplines for this scenario are structural analysis and thermo-fluid analysis. Former is represented by an application from Institute of Computer Science in Civil Engineering at the Technical University Munich (Germany) and the latter is a computer code of the Institute of Computer-applications in Civil Engineering at the Technical University of Braunschweig (Germany). The example arises from a co-operation of our research projects within the DFG priority program 1103.

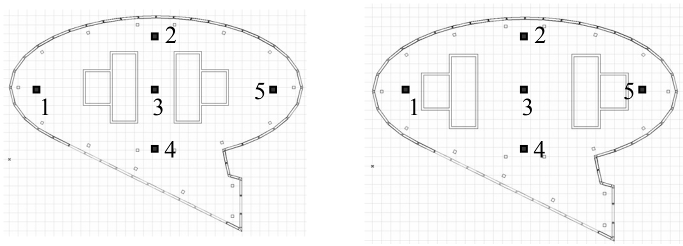

Figure 6. Floor plan. Two variants with different distances between the stairways and locations for the measure points $p_1..p_5$.

Depicted in Figure 6 is a floor plan of an office storey. It is to be analyzed how the distance between the stairways is correlated with (a) the room climate at several measuring points and (b) the maximum deflection of the ground floor. The result of this analysis will be an idea of a beneficial distance between the stairways with respect to a well suited combination of (a) and (b). Furthermore, locations with good climatic conditions shall be estimated.

At first, several (n_i) variants of product models are created by the analyst and provided to a common product model management by using the collaborative environment, described in section 3. The participating planners calculate each variant and send their results back to the CE. Afterwards, the analyst has access to all results of all variants and can begin with the analysis by defining input and output parameters. Input parameters $\mathbf{X}_i$ for this case are the distance of the stairways (x_{i1}) and the position of the measure points (x_{i2}), where

$$\mathbf{X}_i = [x_{i1}, x_{i2}, ..., x_{ik}, ..., x_{in}],\ i = 1..n_i, k = 1..n_k \qquad (1)$$

and n_k is the number of input parameters of a scenario.

The max. deflection of a base plate (y_{i1}), air temperatures (y_{i2}) and velocities (y_{i3}) at the measure points mp_j ($j=1..5$) are treated as the output parameters of variant i.

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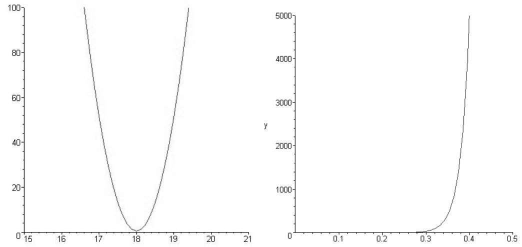
Output parameters for each run are combined to one single system response Y_i for each variant *i*, where

$$Y_i(\mathbf{X}_i) = \sum_{k=1}^{n} f(y_{ik}(\mathbf{X}_i)) \tag{2}$$

Therefore, these output parameters have to be scaled and weighted. Scaling is done by preference functions *p*, which penalize their target for deviation from the considered individual optimum values or exceeding of critical borders by yielding high values.



$$p_i = ay_{ik}^2 + by_{ik} + c \qquad p_i = e^{a(y_{ik}-b)}$$

Figure 7. Preference functions.

Depicted in Figure 7 are two preference functions. On the left hand side a parabolic one, which typically filters optimal values and on the right hand side an exponential one, which filters out values beyond a critical border.

Typically, an analyst needs to assign the importance of single parameters. This is realized by weighting functions like the following.

$$Y_i(\mathbf{X}_i) = \sum_{k=1}^{n} g_i p_i(y_{ik}(\mathbf{X}_i)) \tag{3}$$

After application of preference p_i and weighting functions g_i we obtain dimensionless values Y_i, which are treated as a quality measure. Clearly, this quality depends on the choice of preference and weighting functions and is therefore an individual assessment of the analyst. Due to the definition of the preference function (see above) low quality values denote good quality circumstances and vice versa.

Next, the analyst defines his design space, spanned by input parameters X_i and the response Y_i. Overall, we have $n_i * n_{mp} = 20$ grid points with discrete values. They allow the approximation of a response surface. Depicted below is the resulting surface obtained by application of the Kriging method (see above).

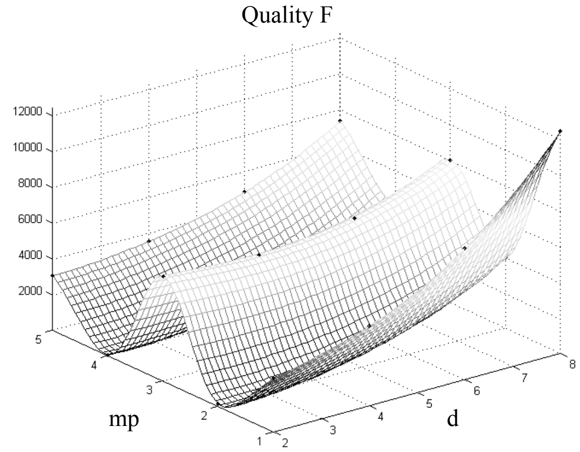


Figure 8. Quality over d and mp.

Here we can see parameter combinations which are beneficial (low values) with respect to our quality definition, as well as unfavorables. Some observations can be done directly out of this diagram:

– A global trend, where quality gets worse the larger the distance of the stairways gets.
– At measure point 3 there constantly is a disadvantageous quality

Sensitivities of the input parameters Xi give even more information. They are partial derivatives of the quality with respect to the input parameters. Figure 9 displays the sensitivity of the stairway distance d:

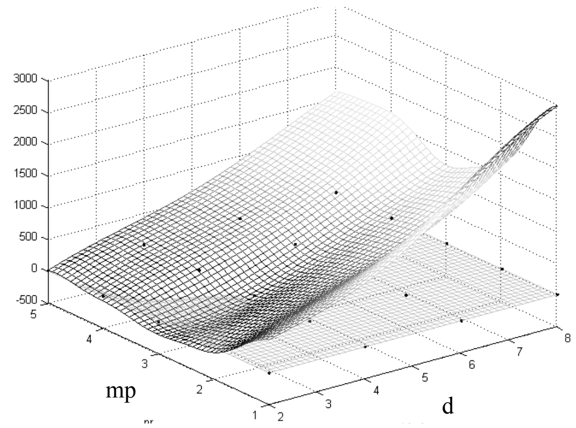


Figure 9. Sensitivity of d.

The most obvious observation here is that in the area around nr=1 and d=8m the sensitivity of d is very high. This means that a modification of d at this input parameter combination will lead to significant changes of the quality. Thus, an analyst may identify areas where a great amount of improvement can be easily achieved.

For completeness Figure 10 depicts the sensitivity of the measure point location, which actually represents the climate at a specified location.

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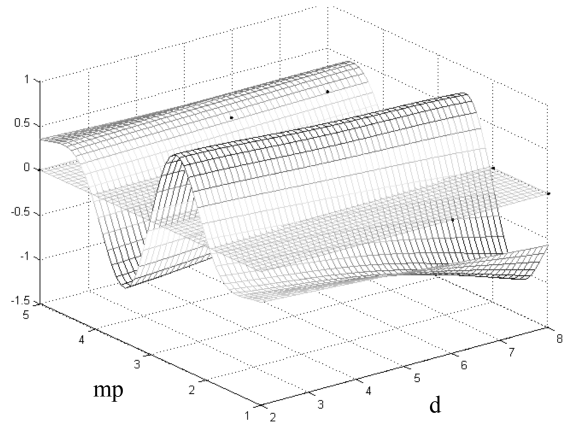

Figure 10. Sensitivity of mp.

An interesting observation can be made if the climate conditions are filtered out and we look on the quality of d only:

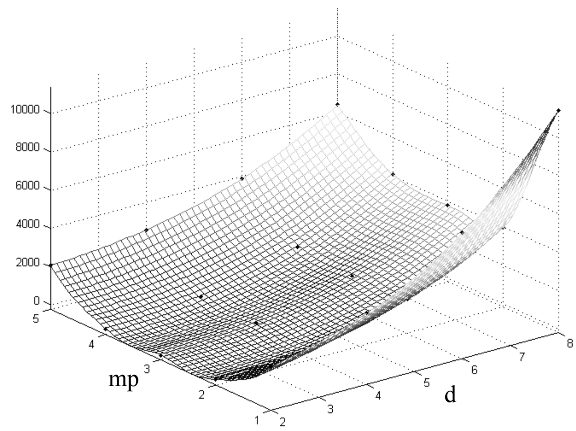

Figure 11. Quality over d and mp without influence of climate conditions.

Here, we can see that the disadvantageous circumstances must be caused by the climatic conditions. Displayed in Figure 12 is the climatic quality, split up in air velocity and air temperature:

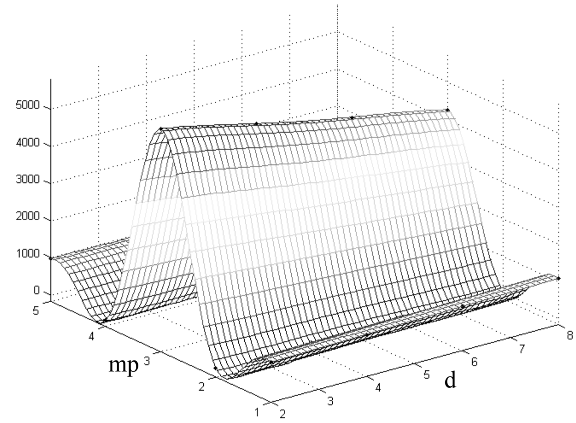

Figure 12. Quality over d and mp for air velocity only.

We find that the air velocity at p=3 gets worse the closer d is, which is a contradiction to the global trend (see above).

It can be seen that the analyst has various possibilities of analyzing and assessing certain scenarios.

6 CONCLUSION

An analysis method was presented to support planning decisions on basis of sensitivity analysis in a heterogeneous planning environment in structural engineering.

Still, product model data management is a difficult problem. Since almost no applications support the check-in of their local data to a common shared product model, our above described DDD concept is used for this issue. For a manageable amount of different planner applications this is applicable, but beyond that the effort to keep track of the variable data format will become very high. Besides that, we seek cooperation with researchers of product model technology to develop a reliable solution for product model data transactions.

During the analysis a response surface is being approximated. Typically, many steps in a planning process in AEC cannot be made without human interaction. This limits the number of variants to be calculated. Thus, the amount of sampling points is relatively low and the approximation of a response surface may be relatively inaccurate. Otherwise, in many cases it would be sufficient to get a coarse idea how to enhance the quality of a product.

After finishing of implementation of the agent based collaboration environment our research concentrates on the analysis methods. Especially the human computer interaction shall be examined. Predominantly, this means to facilitate the usability for engineers or project managers, for example by linking the results to the visualization of a scenario.

Within the next year this method shall be tested and verified on some real case scenarios, especially within DFG funded priority program 1103 (see below).

7 ACKNOWLEDGEMENTS

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Conceptual real-time multiphase flow modeling for complex NAPL remediation systems

I. David & S.B. Anim-Addo
Institute for Numerical Methods and Informatics in Civil Engineering

ABSTRACT: Groundwater data collection is done under statutory supervision and control in catchment. The storage, evaluation and utilization of groundwater and geo-strata information are of importance to the protection of the quality of water for industrial and other uses. The contamination of groundwater sources through immiscible fluids, including NAPLs, is of interest to current research. Equally important is the demand to quickly locate, demarcate and visualize these contaminated areas. This paper provides a structured modelling strategy for digital groundwater data assessment system (DGWDAS) for the 2D/3D visualisation of contaminated areas. This conceptual model forms a basis for a visualization tool for solutions to free-hydrocarbon recovery systems. The tool helps to visualize results of simulations on coupled stratified immiscible fluid flows of NAPL, that satisfy PDEs with coupling conditions on the sharp interface under steady-state flow, based on the assumption of vertical equilibrium. An informative visualization tool based on DGWDAS may also allow evaluation of the discharge, the heads, etc of the recovery system by given heads or discharges in the wells respectively. Additionally, the visualization tool, which is based on the n-Tier Software Architecture, may assist in environmental planning and management in the early stages of assessment of sensitive contaminated areas.

1 INTRODUCTION

The contamination of aquifer, especially with Non-Aqueous Phase Liquids (NAPL), may lead to environmental risks to aligning settlements and protected zones. Relatively accurate groundwater (GW) models for environmental impact assessments may help in early decision making. The source, and accurate use of qualified field data for the parameterization of groundwater models, determines the practical significance of simulation results [Portugal / Den Haag].

The modelling of the coupled flow of free-phase NAPL in groundwater and their remediation using complex multiple well recovery systems (MWNRS) has been discussed elsewhere [1, 2].

Optimizing solutions of the coupled flow and transport processes lead to non-linear and non-convex objective functions with multiple local minima and both nonlinear models and nonlinear constraints. The presence of local minima has implications for the performance and results obtained by optimization algorithms.

The development of these algorithms, however, may have to be preceded by descriptive site-related parameter sensitivity assessments of different remediation scenarios. This procedure for the estimation of the aquifer response for the most important factors of influence, leads to a more suitable definition of the objective functions, scope and constraints required for the optimization of the remediation systems. Achieving a real-time simulation and visualization must take these complexities into consideration.

The paper presents the follow-up steps and methodologies for modeling, simulating and optimizing of multiphase flow and transport of mobile plumes of NAPL in porous media at real-time. Adequate insight is also given on the method of reflection and of superposition of potentials used in the new so-called Bounded Cell Multi-Wells Method for the simulation of NAPL remediation with a grid-based well-field. In particular, emphasis is placed on the various concepts and technologies for handling client-side output, as employed in current on-going research. Practical examples are discussed to underpin the methods discussed in this paper, which may form benchmark solutions for the hydraulic remediation of NAPL-contaminated sites.

2 ESTIMATING GW-MODELING PARAMETERS

The phenomenological approach for modeling GW flow and transport is the assumption of a homogenized structure for continuum models that neglects

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the microstructure. These superimposed continua provide abstraction of the geometrical model and field data for preliminary simulation purposes. The sources of data for the parameterization of these models, however, are through well-targeted site characterization or baseline studies - and standard field measurements using environmental data collection wells or boreholes [1,2]. The spatially weighted averaging method for estimating GW modeling parameters is described in [3]. Hydro-Geological databases are another source of reliable information on soil morphology, especially in inaccessible areas [2, 4, 5, 6, 11].

3 SOIL PROFILES DIAGRAMS WITH CUBIC SPLINE INTERPOLATION ALGORITHMS

A cubic spline is a spline constructed of piecewise third-order polynomials which pass through a set of ***n*** control points. A cubic spline is a spline constructed of piecewise third-order polynomials which pass through a set of m control points. This means that between each two points, there is a piecewise cubic curve. When we string these curves together, we set the second and first derivatives at the endpoints of each piecewise cubic curve equal to that of the adjacent cubic curve's second and first derivatives thus providing for a continuous second derivative. This gives a smooth curve that passes through each point, thus interpolating them.

A polynomial fitted to many data points exhibit erratic behaviour. Splines are smooth and continuous across the interval [16].

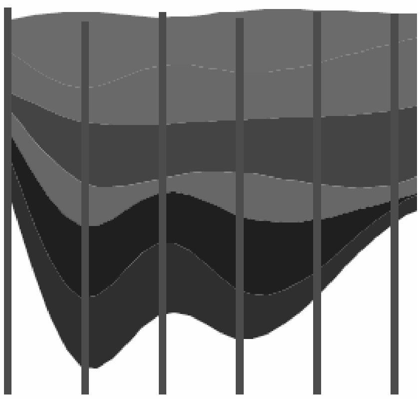

Figure 1. Soil profile interpolation using cubic spline algorithms and SVG.

The use of cubic splines for 2- and 3D Interpolation and graphical visualizations is most suitable, as the resulting soil layers provide the closest approximations to the natural flow of soil layers.

4 REMEDIATION OF NAPL WITH COMPLEX WELL FIELDS

The scheme of the contamination scenario is shown in Figure 1, in which a flow domain of defined boundaries is contaminated with a mobile plume of LNAPL.

Two methods for modeling and simulating the recovery of free-phase NAPL in aquifer are discussed under 4.1 and 4.2. Both methods are suitable for modeling flow and recovery in large domains[1, 12]. While the first method can incorporate the dimensioning of a flexible well-placement regiment of the recovery system [1], the second method allows the more usual practice of well-placements on predefined grids.

4.1 *Remediation of extended domains*

[1] and [2] discussed the theory and implementation of free-phase hydrocarbons on extended domains. On the basis of the practical application demonstrated in these publications, it was shown that most remediation cases may be formulated and modeled.

On the basis of this calculation method, and with the data in Table 1: and Table 2:, it can be shown that the very accurate rasterized piezometric surfaces can be obtained for all nodes(Figure 10ff). Additionally the extraction rates for each well can also be calculated for each time step.

Table 1: Model parameters for LNAPL remediation

Parameter	Value	Unit
Hydr. Cond., light phase (LP), k_{fl}	2,62E-5	[m/s]
Hydr. Cond., dense phase (DP), k_{fd}	9,81E-5	[m/s]
Density, LP	800	[kg/m3]
Density DP	1000	[kg/m3]
Eff. Porosity, n_e	0,2	[-]
Boundary Conditions		
Thickness, DP	11,2	[m]
Groundwater level	12,0	[m]
Thickness LP	1,0	[m]
Domain		
Diskretization	1,0	[m]
Length	100	[m]
Breadth	100	[m]
Wells		
Radius	0,2	Fully penetrating
Type	-	Skimmer well

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Table 2: Coordinates of recovery wells W_i

Well-Point	X	Y
1	30	70
2	35	30
3	45	40
4	60	40
5	65	60
6	70	30

4.2 *Basic formulations of the Bounded Cell Method*

Figure 4 shows a scheme of the so-called Bounded Cell Method (BCM). The concept of this method is to demarcate grid-based areas of influence (cells) for each well in a recovery system (Figure 4), for each of which the boundary conditions can be determined. The number of cells determines the number of wells in the recovery system. Determining the governing equations for this method is done through the super positioning and mirroring of the potentials at discharge point (wells) in the domain on the boundary of the reference cell (Figure 2 and Figure 4).

Potential at a Point M:

The hydraulic potential in the flow domain at any given point is defined as:

$$\varphi = -k_{fl} \cdot \frac{h^2}{2} + c \qquad \text{(Eq.1)}$$

Initial / Boundary Conditions:

From Figure 3, we can define the following initial conditions:

$$\begin{aligned} &h_{li} = h_{la}, \quad i = 1,\dots,n \\ &h_{l0} = h_{lw} \\ &Q_i = Q\,, \quad where \quad i = 0,\dots,n \end{aligned} \qquad \text{(Eq.2)}$$

where:

Q: Discharge in the Well *i* (*i* = 0,….,n), in [l/s]

To demonstrate the calculation method, an equivalent, constant discharge rate Q is assumed for all all wells in the recovery system.

Generated / Induce Potential:

The generated or induced potential at any point of extraction or infiltration is defined as:

$$\varphi_l = -\frac{Q}{2\pi} \ln E \qquad \text{(Eq.3)}$$

where ***E*** is the planar distance between two Well positions in a multiple well recovery system.

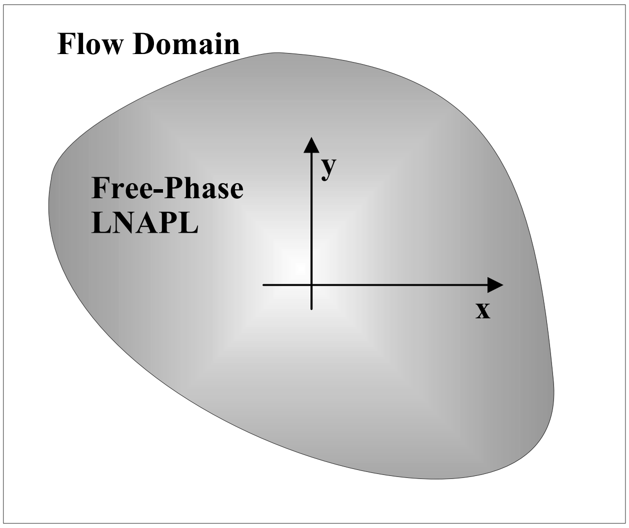

Figure 2. Scheme of the NAPL-contaminated flow domain.

For each of the Wells W_i,th induced potential can be written as follows:

$$\varphi_0 = -\frac{Q}{2\pi} \ln \sqrt{x^2 + y^2} \qquad \text{(Eq.4)}$$

$$\varphi_1 = -\frac{Q}{2\pi} \ln \sqrt{(x-2a)^2 + y^2} \qquad \text{(Eq.5)}$$

$$\varphi_2 = -\frac{Q}{2\pi} \ln \sqrt{(x+2a)^2 + y^2} \qquad \text{(Eq.6)}$$

$$\varphi_8 = -\frac{Q}{2\pi} \ln \sqrt{(x-2a)^2 + (y+2a)^2} \qquad \text{(Eq.7)}$$

The sum of the discharge potentials for ***n*** Wells in the flow domain is:

$$\Phi = \varphi_0 + \sum_{i=1}^{n} \varphi_i \quad ; \quad n = 8 \qquad \text{(Eq.8)}$$

This leads to a general expression for any discharge point, relative to a reference well to be written in the form:

$$\begin{aligned} \Phi = -\frac{Q}{2\pi} \ln \sqrt{x^2+y^2} \cdot \\ &\sqrt{(x-2a)^2+y^2} \cdot \sqrt{(x+2a)^2+y^2} \cdot \\ &\sqrt{x^2+(y+2a)^2} \cdot \sqrt{x^2+(y-2a)^2} \cdot \\ &\sqrt{(x+2a)^2+(y-2a)^2} \cdot \sqrt{(x-2a)^2+(y-2a)^2} \cdot \\ &\sqrt{(x+2a)^2+(y+2a)^2} \cdot \sqrt{(x-2a)^2+(y+2a)^2} \end{aligned} \qquad \text{(Eq.9)}$$

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Piezometric head at any point M:

The hydraulic potential at any point on the piezometric surface of the domain is defined as:

$$\Phi = -k_{fl}\frac{h^2}{2} + c \qquad \text{(Eq.10)}$$

where $h = h(x, y)$, the piezometric head

4.2.1 *Multiphase extraction of only the Light Phase*

To determine the equation for the extraction rates of the light/dense phase (LNAPL/G-Water) and the elevation at any point M on the domain, existing points of known potential and boundary conditions, such as at P_1 and the reference well W_0 may be used. Alternatively, any two points of reflection on the boundary, such P_1 and P_5, satisfy the conditions of equipotentials in the reference Cell (Figure 4).

Equipotentials as Boundary Condition at P_i:

From the Boundary Conditions, the superimposition of the potentials of all wells W_i in the domain on the point P_1 can be expressed as.

$$-k_{fl}\frac{h_{la}^2}{2} + c = -\frac{Q}{2\pi}\ln(975 \cdot a^9) \qquad \text{(Eq.11)}$$

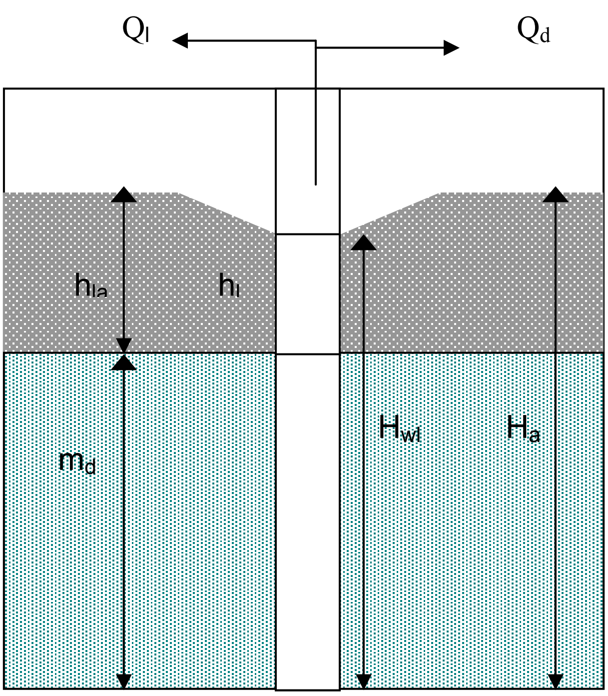

Figure 3. Cross-section of extraction well W_i.

Potentials at the reference Well W_0:

At the reference Well $\boldsymbol{W_0}$, the pressure head h_l can be calculated through:

$$-k_{fl}\frac{h_{lw}^2}{2} + c = -\frac{Q}{2\pi}\ln(1024 \cdot a^8 \cdot r_w) \qquad \text{(Eq.12)}$$

Discharge equation at the reference Well W_0:

At any point on the Boundary, the hydraulic and discharge potentials are equivalent and Equations (9) and (10) are equal:

$$\Phi_\Omega = const \qquad \text{(Eq.13)}$$

Subtracting Eq. 11 from Eq. 12, we obtain:

$$Q = \frac{\pi k_{fl} \cdot (h_{la}^2 - h_{lw}^2)}{\ln \dfrac{a}{1{,}05 \cdot r_w}} \qquad \text{(Eq.14)}$$

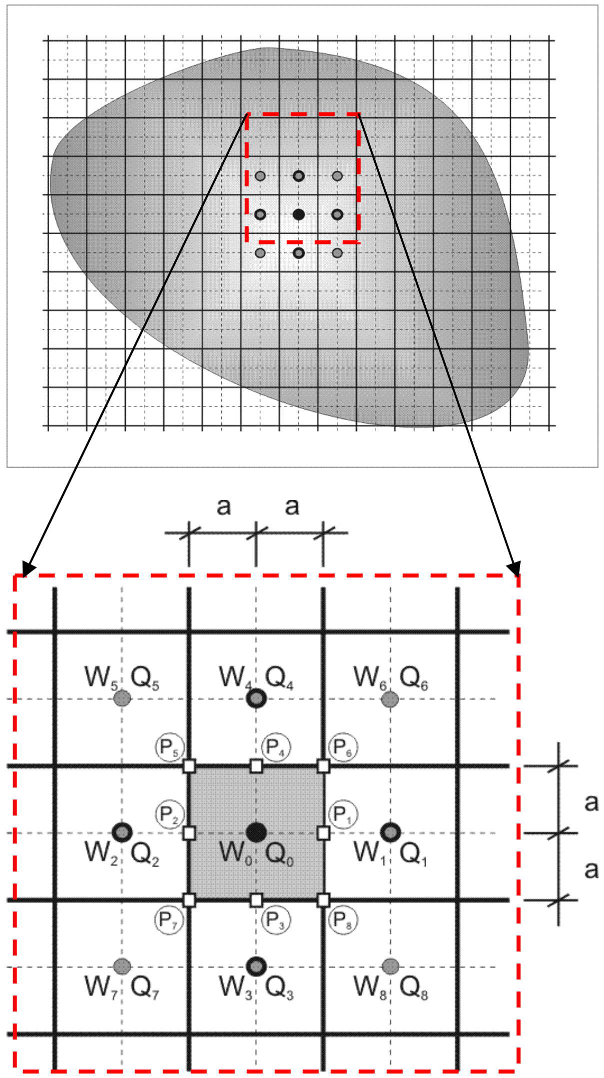

Figure 4. Bounded Cells with Boundary Points P_i.

4.2.2 *Multiphase extraction of both Phases*

As described in [1, 2, 3], it may be essential to simultaneously extract both phases (LNAPL/G-Water).

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From the figure above, it can be deduced that the discharge rate of dense phase can be expressed as:

$$Q = \frac{2\pi k_{fd} m_d \cdot \frac{\rho_l}{\rho_d}(H_a - H_{wl})}{\ln \frac{a}{1{,}05 \cdot r_w}} \qquad \text{(Eq.15)}$$

where

$$A = \frac{H_{lR} - H_{lS}}{H_{dR} - H_{dS}} = \frac{H_a - H_{wl}}{m_d - H_{wd}} \quad \to \infty$$

i.e, $m_d = H_{wl}$ at each time step throughout the duration of the pumping/recovery.

The extraction region is carried out under the prerequisite that the groundwater level remains at constant at m_d in the well.

The simulation results, which compares well with previous bench mark solutions [1, 2], are shown in Figure 6 to Figure 8. By considering the investment and running costs on Figure 8, a break even point for an optimal selection of design configuration of the recovery well can be determined.

5 MODELING TOOLS AND FRAMEWORK

Conception ally, the design of the software components for the visualization of NAPL contaminants should provide functionalities that emulate the procedures and tools used by environmental damage control engineers for planning immediate to long-term remediation work. Increasingly, Geographic Information Systems (GIS) software is providing the functions and tools needed to store, analyze, and display environmentally-relevant information [2].

On the other hand, and to avoid the integration of proprietary modules in existing n-Ter systems (Figure 5), the more platform-independent XML-based libraries such as Scalable Vector Graphics (SVG) provide state-of-the-art cutting-edge methods for most development needs.

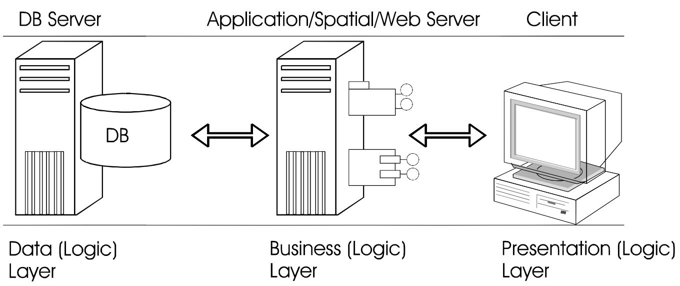

Figure 5. 3-Tier Geosoftware Architecture [2]

For raster-based digital geo-referenced systems (e.g. based on GIS), both multi-well calculation methods (see 4.1 and 4.2) may be suitable for the visual modeling of the contaminated site, and for the 2D/3D graphical output of the simulation and the optimization results on NAPL flow and migration results.

6 AQUIFER RESPONSE TO SENSITIVE PARAMETERS

Results were obtained for *q* in the following situations:

a) Values for *q* for all allowable values of h_d at constant values of h_l.
b) Values for *q* for all allowable values of h_d and h_l for varying influence radii, R.
c) Values for *q* for all allowable values of h_d and h_l, at varying positions of the wells.
d) Maximum and minimum values for *q* for all allowable values of h_d and h_l on different hydraulic coefficients, k_{fl}.

Results from field data in (David et al, 2004, Urban et al, 2004) show significant accuracy for HGPCs through the Spatially Weighted Average Parameter (SWAP) method presented in this Paper. While conventional methods only consider soil layers of relatively large thicknesses, SWAP incorporates all soil layers, thus making the result more representative of the natural flow domain. Confining estimates to only the bandwidth of soil layers directly affected by the contamination can further improve their accuracy through SWAP [2].

7 SIMULATORS AND OPTIMIZERS

The mathematical model described in the foregoing sections of this submission provides the basis for modelling any combination of real world physical contaminant management problems involving NAPL in aquifer. The constraints on the recovery system must include the aspects of cost to the objective function, either as a separate formulation for their optimization, or in conjunction with others. The strategy leads to the formulation of multi-objective functions that require complex optimization algorithms to solve.

Modelers must input data on contamination management models into Simulators such as MODFLOW. Simulators predict how a physical system will respond to an input strategy. The interplay between Simulators and Optimizers may produce management strategy of an assumed management problem.

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Aquifer response is measured through the sensitivity analysis for set proplems. Sensitivity analysis techniques give a way to compute solution uncertainties by using information on the sensitivities of the solution to various parameters. These sensitivities are just the solution derivative with respect to the parameter in question, and equation for them can be derived by differentiating the original model problem. The resulting sensitivity equation is linear and can be solved in tandem with the model equations. First order estimates of solution uncertainties can be developed from these sensitivities with a straightforward additional calculation [8].

8 RESULTS

The results obtained for the two methods of simulating recovery of LNAPL with complex well-fields are shown to demonstrate the effectiveness, and the suitability of the methods, among others, for real-time simulation and visualization purposes. The data are based on bench mark values and parameters discussed elsewhere [1, 2].

8.1 *Results on using the Bounded Cell Method*

Using a well radius of 0,2m and an LNAPL thickness of 1.0m, the following results were obtained for a cell size of 20m (Figures 6ff).

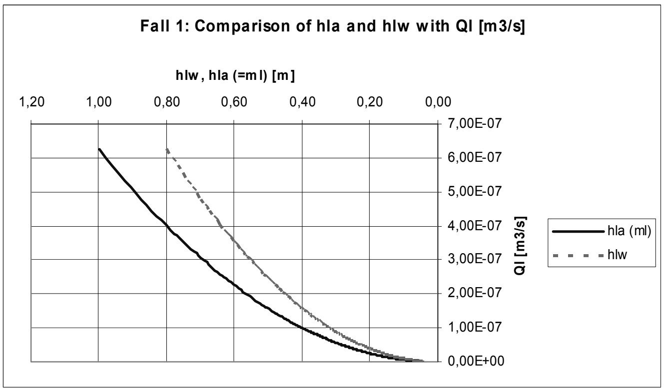

Figure 6. Comparing the effects of the thickness on extraction rates of LNAPL.

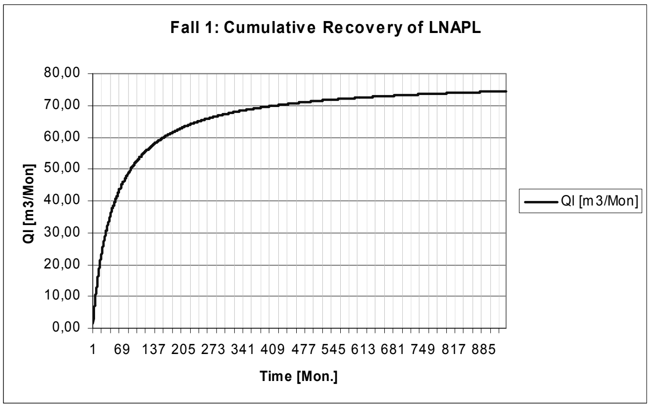

Figure 7. The cumulative recoeverable LNAPL curve shows 80% recovery within 210 months.

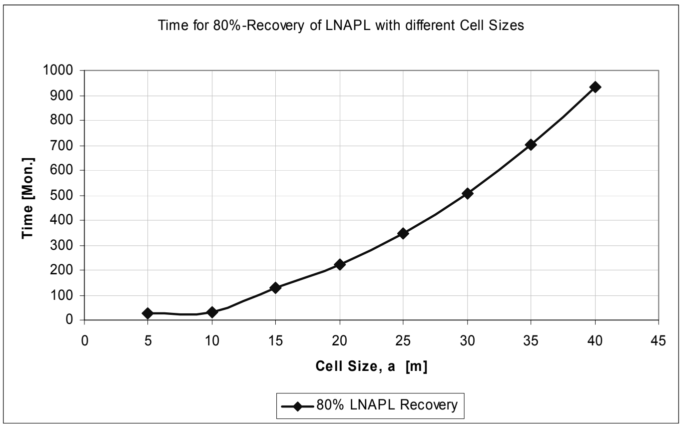

Figure 8. The effects of cell size on total pumping time, yield and well placement.

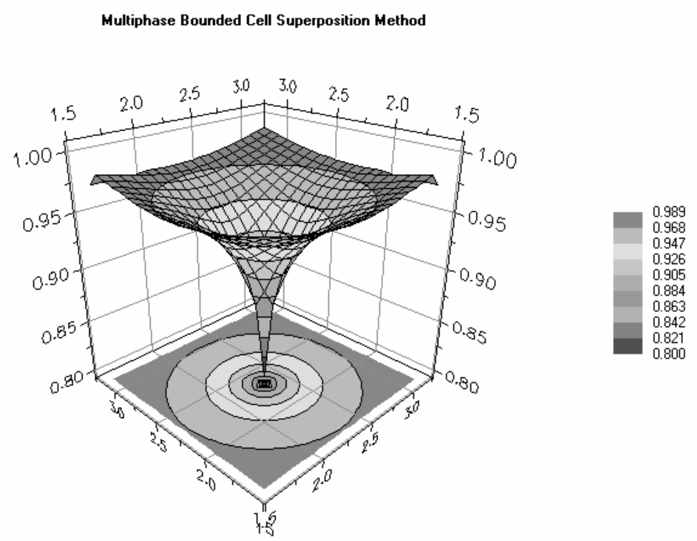

Figure 9. Extraction funnel on simulation of one Well in a bounded cell.

8.2 *Results on using Extended Domain Method*

The simulation of the LNAPL recovery with the system configuration shown in Table 1: and Table 2: yields a minimum discharge rate of 115 [l/d] in Well 4 and a maximum discharge of 207 [l/d] in Well 1. The maximum yield per day is 728 [l/d]. Well 6 remains dry within the initial time step. These values compare favorably with previous results [1,2].

Figure 10 and Figure 11 show the 2D elevation profiles generated by a six well skimmer recovery system for LNAPL. The performance of individual wells can therefore be tracked and regulated externally Figure 11 during the operation. The wells are numbered form 1 to 6 from left to write in Figure 10ff.

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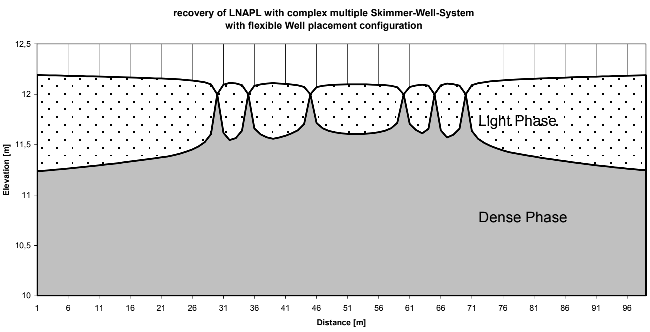

Figure 10. Elevation profile with 6 Wells (Well 1-Well 6, left to right).

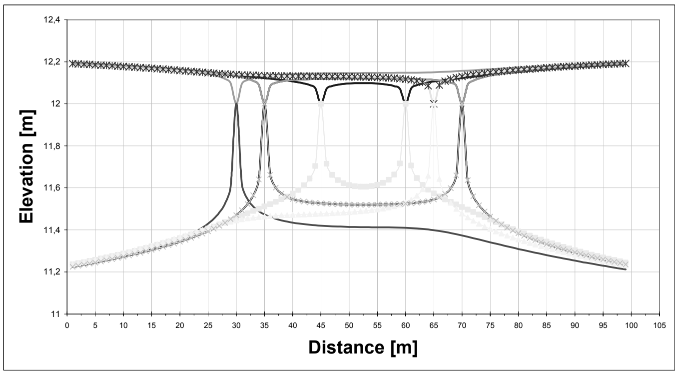

Figure 11. Extractions of individual wells.

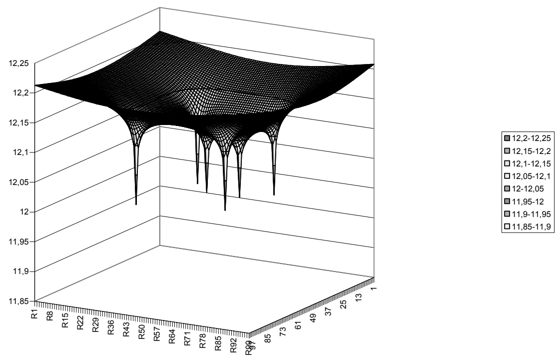

Figure 12. Spatial visualization of LNAPL surface profiles at run-time.

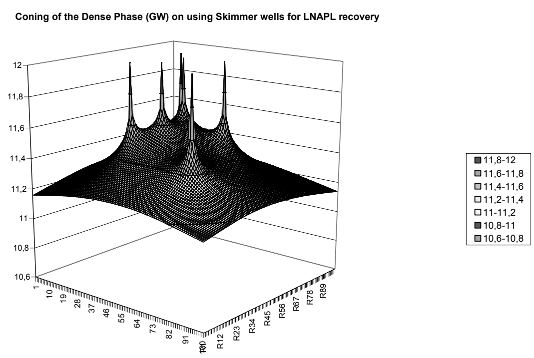

Figure 13. Coned surface profile of the dense phase at run-time.

9 CONCLUSION

This paper has discussed an overview of the underlying methods for real-time modelling of complex coupled multiphase flow and recovery of free.phase contaminants such as NAPL.

Spatially weighted average parameter estimation for groundwater modelling (SWAP4GWM), which is based on qualified source data and Voronoi algorithms, can assist the configuration of mathematical models for first-hand estimates [2, 7, 8, 9, 10].

The simulation of the free-phase NAPL migration and recovery on domains with known boundary conditions on fixed bounded cells or through flexible well arrangements has also been discussed. The simulation results from both methods compare well with other numerical results.

Scalable Vector Graphics (SVG), when combined with the natural smoothening performance of the cubic spline algorithm, provides a state-of-the-art technology for a platform-independent visualization of simulation results in real-time, especially for n-Tier software solutions.

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Implementation of logic for earthmoving processes with a game development engine

H.-J. Bargstädt & A. Blickling
Bauhaus University, Weimar, Germany

In modern industry for example the assembly of a car can be done in different ways or sequences. All may lead to success. Nevertheless manufacturers decide on one specific order of processes for the assembly. This order is designed and managed properly and is the result of deeper studies of the logic of the assembly. In the construction industry experiences on site have shown that logic of processes is difficult to be identified. Although there are areas where a logical order of processes can be presumed. This paper tries to setup logic for earthmoving processes and implement it within a computer game development engine. The result is an interactive computer game that allows the user to play the simulation of excavation in real-time.

1 INTRODUCTION

The rapid development of computer sciences in the last decades brought a lot of ideas about representing the physical reality with machine driven intelligence. However the practicability of the developed tools is yet limited to repetitive process types. Also in the construction area this problem is still being discussed and researched. This paper refers to some approaches for automation and simulation and shows a prototype for an interactive simulation based on computer game technologies.

2 AUTOMATION AND SIMULATION

First approaches for automation and simulation of construction processes assumed that process models could be described with deterministic dependencies. This led to the development of several theories that have been applied so far for representing constraints of processes on a timeline or in a graph. But when it comes to simulating and automating process models in construction it has been shown very early that deterministic approaches might not lead to success. Retik & Shapira (1999) show a VR-based simulation tool for planning site activities with both an integrated intelligent and non-intelligent interface. It indicates that the authors doubt an entirely automated system. Rojas & Mukherjee (2005) discuss some simulation environments developed since 1973 (Fig. 1) and show the relationship to their concept of an educational simulation tool (Virtual Coach). They also argue that the simulation languages used by some of the environments use ´activity cycle diagrams´ (ACDs). These ´discrete event models´ do not sufficiently consider the need for concurrent events in the process model. For this reason they designed ´virtual coach´ to be a ´cycle-based simulation´ with consideration of spontaneous interactions with the process model.

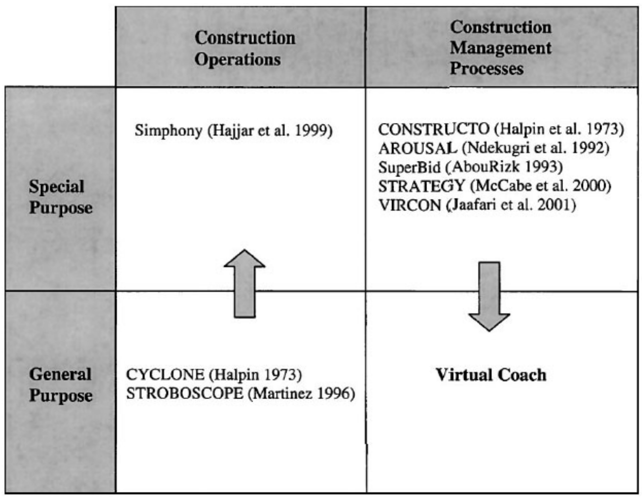

Figure 1. Relationship between virtual coach and other construction simulation environments (Rojas & Mukherjee 2005, p. 84)

From the practitioners point of view the solution suggested by Rojas & Mukherjee is preferable to simulation methods that work with ACDs. The speciality of construction processes is that there are not many ´hard` constraints. Therefore new approaches have to be pursued to develop tools that support the simulation of processes while dismissing logic and offering situational interaction.

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To develop such a solution Bargstädt & Blickling (2004) proposed the use of interactive environments such as game development engines. These tools allow to model logic of processes in a way that users can interact with the model during runtime. An earthmoving process serves as an example. The concept also refers to earlier works on earthmoving processes done by Martinez & Ioannou (1999) and AbouRizk & Mather (2000).

3 LOGIC ISSUES IN SIMULATION

Martinez (1999) showed that the logic of processes for earthmoving could be described with ACDs. In Fig. 2 the boundary conditions of their approach are pointed out.

Conditions needed to start (1)	Activity (2)	Outcome of activity (3)
Pusher at push-point	*PushLoad*	Pusher ready to backtrack
Scraper at cut		Loaded scraper ready to haul
Pusher ready to backtrack	*Backtrack*	Pusher at push-point
Loaded scraper ready to haul	*Haul*	Loaded scraper ready to dump
Loaded scraper ready to dump	*DumpAndSpread*	Dumped soil
		Scraper ready to return to cut
Scraper ready to return to cut	*Return*	Scraper at cut

Figure 2. Activities, Required Conditions, and Outcomes for Scraper and Pusher Operations (Martinez 1999, p. 266).

The process has been divided into five main activities. These are ´PushLoad´, ´Backtrack´, ´Haul´, ´DumpAndSpread´ and ´Return´. Fig. 3 visualizes the concept in a graphical way.

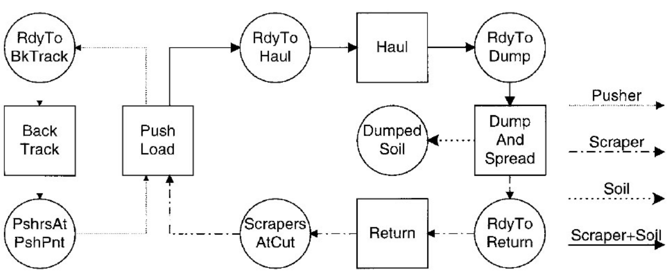

Figure 3. ACD for Scraper and Pusher Operation (Martinez 1999, p. 266).

Rojas (2005) mentioned: *´An activity cannot occur if the condition is not fulfilled and when it occurs it always produces the predicted outcome.´* (see Fig. 2). He further said that *´(..) discrete items change state as events occur in the simulation. The state of the model changes only when those events occur.´* This statement has led the authors to the idea of developing a tool that allows to change the state of the model through user interaction. To assure the most convenient way of deciding when and where the state of the model should be changed the user is supposed to get visual feedback from the virtual environment of the site. Besides he is supposed to ´steer´ the process model using mouse and keyboard.

The logic of the processes was also implemented using ACDs, but on a higher level of detail. The principle of the simulation is shown in Fig. 4.

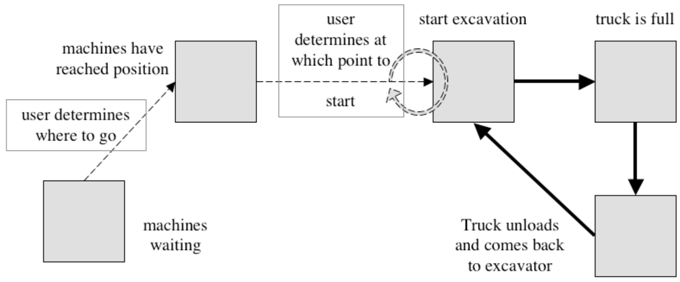

Figure 4. Simulation with user interaction in the virtual environment of the construction site

Before starting the excavation process the logic foresees that the user has to determine where to go with the machinery. This is quite an important question when planning the production process on a high level of detail. Most other research assumes abstract simulation models without reference to the geometry of the site. Associated to this Bargstädt & Blickling (2005a, 2005b) have pointed out that the change to a high level of detail in the process model requires analysis of the impact on simulation.

After the machines have reached their positions the user has to determine at which point the excavation process starts. Here it is necessary to tell the excavator where exactly the shovel should hit the ground if simulation runs on a high level of detail. To assure progress in simulation the interaction with the user is required because otherwise the system will not continue automatically and cannot decide where to continue excavation. This considers that these decisions are not logical but situational.

Following the simulation process in Fig. 4 it can be seen that the process of telling the excavator where to start is an iterative process for the user. After having decided where to hit the ground the excavator fills up the truck without user interaction. After that the next user input is expected. This dialogue game continues until the truck is filled up, which is calculated in the back on the basis of a simple mathematical term. After this the automated part of the simulation starts. The logic foresees that the excavator pauses while the truck drives to a determined place to dump the soil. After coming back the interactive sequence of telling the machine where to work is continued.

The implemented logic is attached to the geometric and material conditions of the virtual site. Changes in the 3D model of the site would result in necessary updates of the logic. If there were a river or other obstacles like marshy ground not only the geometry and material constraints but also the logic of processes need to be adapted.

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A conclusion at this point is that logic of processes in construction can be hardly determined even if simulated on a high level of detail. Experiences from construction sites show that assumptions at an early stage that were explained to be ´logic constraints´ have been proven wrong when it came to execution. In construction processes only a few constraints are purely logic, whereas most ´constraints´ are given by economic consideration. If really needed a column can even be built underneath a ceiling after that ceiling already has been poured.

4 DEVELOPMENT OF A COMPUTER GAME PROTOTYPE

The use of computer game technology for simulation purposes has become more and more popular in the last years because of the progress in hardware development. Applications of these technologies mostly aim at education and training whereas technical simulations are mainly applied in association with collision detection or assembly. Especially the latter is interesting for the simulation of the assembly of a facility.

As a small section of the huge amount of possible scenarios during construction an earthmoving process has been chosen. That problem has been focus of research in many research works.

An idea of how logic can be built in the game development engine gives Fig. 5. It shows the logic that was implemented for the truck. It is only a detail of the whole system where a ´FiniteStateMachine´ was implemented. This pre-defined part of the engine is a Petri Net that runs the behavior of the truck.

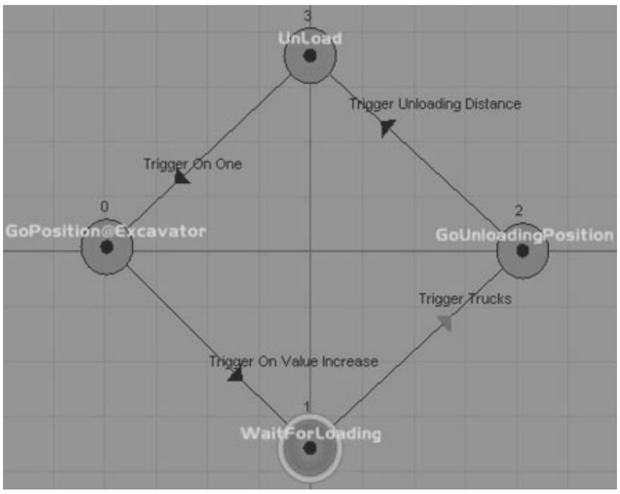

Figure 5. Truck logic in the game development environment

The game is simulated in real-time. The requirements are defined as follows:

1. Truck types, excavator and its equipment are selected out of a machinery database
2. The machinery database contains all detailed data on the chosen machines and equipment, e.g. cost/hour, max. load, weight, etc.
3. The user decides where to start the excavation
4. The virtual time is displayed in the application window as well as the buttons to start and stop duration recording during simulation
5. Input data are collected for later reuse in simulation: an external database is connected to the application so that all process parameters can be saved for later evaluation
6. The virtual construction site provides the user with geometrical data of the site; the objects should appear in a close to reality shape

The prototype requires thorough knowledge of the channel graph logic of the used game development engine. The application consists of several channel groups that merge to one big graph. Here only a few aspects of the graph are discussed.

One task was the implementation of the logic for the determination of the machines to be used for simulation. After the start of the application the system asks for the selection of machine types (see Fig. 6). The user goes through all the machines in the database and thus determines the configuration consisting of a specific excavator with shovel and a truck. The choice is important because there are some parameters (maximum load of truck, performance of excavator) that influence the efficiency of the loading game between excavator and truck. Here the user is free to decide which truck or excavator to choose. But he has to consider the maximum performance possible with the chosen configuration of machines. The selection process is kept open for users` decision.

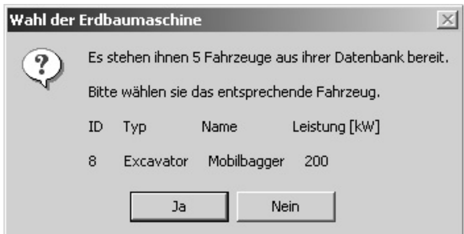

Figure 6. Start-up window with available trucks and excavators

In addition to the truck and the excavator the user can also choose specific equipment of the excavator, for example size and type of the excavator shovel. Only compatible equipment is offered by the database.

In the prototype the user can vary the geometrical position of the working environment. Yet for the time being the shown excavation is only a `play process` because other logic has not yet been implemented. The further development foresees to give a specific point of the virtual construction site. The user indicates the position on the screen and the machine will move to that position.

In Fig. 7 that position is marked with a cube. After having reached the desired position both machines stop and wait for further user input. In the actual construction phase the user can switch from

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hauling (`Umsetzen` in figure 7) to excavation and loading.

Figure 7. Machines proceed to the cube according to user interaction

This switch is important for the database to register that a certain process phase has finished. At the beginning of the next phase the user needs to specify the position of the excavation area. This can be initiated by user input and causes the excavator to rotate the shovel to the chosen position. The excavation is again started by user input. After this the movements of the excavator are animated in real-time what is important for the correct determination of the process duration (see Fig. 8). After having performed all the necessary steps to fill up the truck, the truck leaves automatically and moves to the unloading point. Before that the system changes to phase process-dependent waiting for discharge (Ablaufbedingtes Warten durch Abladen), which is also recorded in the database.

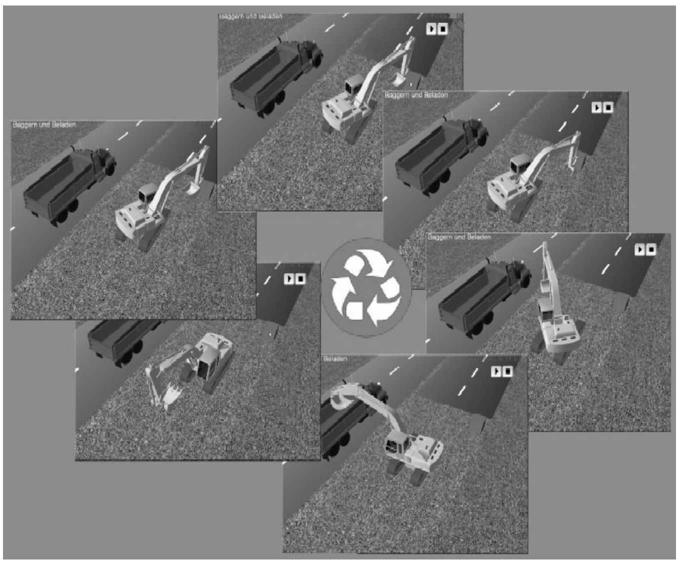

Figure 8. Excavator sequence after user has determined where to start with excavation

The process as described above can be executed in "registration mode" (process durations are instantly written in the database) or offline. Clicking the `play` button starts the registration mode. The actual process phase is identified and written into the database together with the starting/ending time of the process and its ID. The database then calculates the process durations. Fig. 9 shows an example of data written into the database.

Microsoft Access - [Kopie von Prozessdauern : Tabelle]

Datei Bearbeiten Ansicht Einfügen Format Datensätze Extras Fenster ?

ID	StartTime	EndTime	Duration	Process
1	16:44:26	16:45:09	00:00:43	Umsetzen
2	16:45:09	16:47:11	00:02:02	Baggern und Beladen
3	16:47:11	16:48:16	00:01:05	Ablaufbedingtes Warten durch Abladen
4	16:48:16	16:50:16	00:02:00	Baggern und Beladen
5	16:50:16	16:51:21	00:01:05	Ablaufbedingtes Warten durch Abladen
6	16:51:21	16:52:00	00:00:39	Baggern und Beladen
7	16:52:00	16:52:09	00:00:09	Umsetzen
8	16:52:09	16:53:30	00:01:21	Baggern und Beladen
9	16:53:30	16:54:32	00:01:02	Ablaufbedingtes Warten durch Abladen
10	16:54:32	16:56:32	00:02:00	Baggern und Beladen
11	16:56:32	16:57:35	00:01:03	Ablaufbedingtes Warten durch Abladen
12	16:57:35	16:58:32	00:00:57	Baggern und Beladen
13	16:58:32	16:58:41	00:00:09	Umsetzen
14	16:58:41	16:59:39	00:00:58	Baggern und Beladen
15	16:59:39	17:00:39	00:01:00	Ablaufbedingtes Warten durch Abladen
16	17:00:39	17:02:39	00:02:00	Baggern und Beladen
17	17:02:39	17:03:39	00:01:00	Ablaufbedingtes Warten durch Abladen
18	17:03:39	17:03:43	00:00:04	Baggern und Beladen

Figure 9. Example of data written to the external database

5 CONCLUSIONS

Simulation concepts in construction used to be based on common simulation techniques known from other industries. These concepts mostly work with deterministic approaches. This has motivated to search for solutions to bypass deterministic approaches. Thus flexible simulation models have to be developed that consider situational aspects in the process model. The question is, whether a simulation ´interrupted´ by human interaction can still be called a ´simulation´ in its original sense. Integrating human decision making leads to long simulation durations. It is not possible to ´calculate´ the simulation entirely by mathematical terms. For a big project it has been estimated that the total duration of the game might take more than one day. For this reason further research aims to minimize the human part although there will remain some crucial decisions that cannot be taken by computers.

Fig. 10 shows a part of the logic of the prototype. The whole graph is too extent and is therefore omitted. The figure shows the ´start channel group´. This is the starting point of the complete game logic. It gives an overview on the design of the whole application. The ´start project channel` is executed from left to right. The ´GetDatabaseInfo´ on the left side is responsible for the determination of the machinery equipment at the beginning of the game.

In future the representation of a general-purpose virtual construction site with imported geometry and pre-defined construction logic will be one point of interest in research. It has been shown that game development engines can be used for implementing logic of construction processes. However, efficiency in simulating the processes must be increased.

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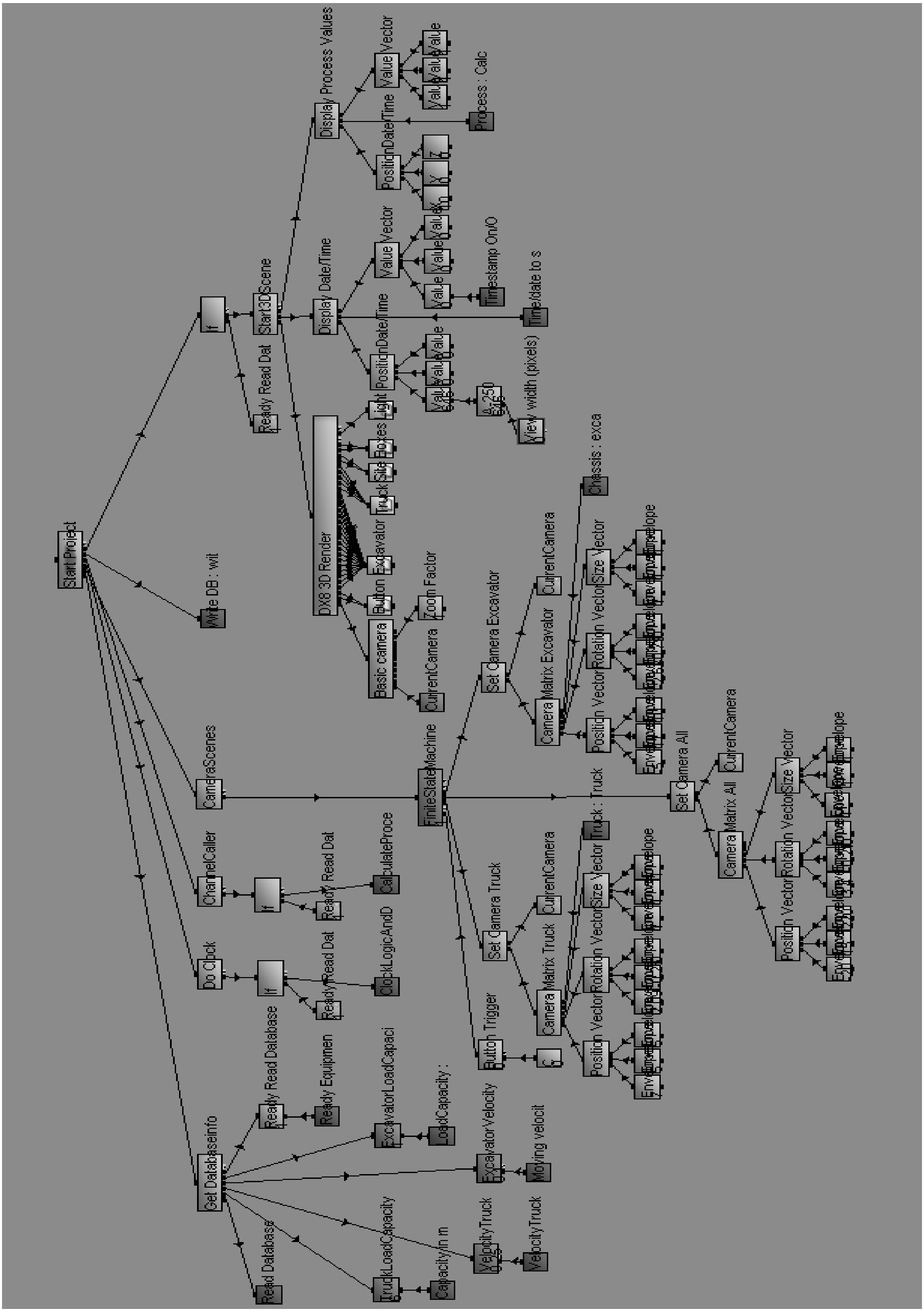

Figure 10. Overview on the concept of the prototype

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Kochonen Neural Model for Destructive Seismic Waves

S. Radeva
University of Architecture, Civil Engineering and Geodesy, Sofia, Bulgaria

D. Radev
University of Rousse, Rousse, Bulgaria

ABSTRACT: The paper is devoted on the problem of real-time earthquake prediction. An approach for real-time prognoses, based on classification algorithm of strong motion waves with neural network and fuzzy logic models is suggesting. As input information for the neural network, build with Kochonen learning rules, are given the parameters of recorded part of accelerogram, principle axis transformation and spectral characteristics of the wave. With the help of stochastic long-range dependence time series analysis is determined the beginning of destructive phase of strong motion acceleration. Developed seismic waves classification gives possibility to determine different kind prognoses models for different king of classified waves. The prognoses of destructive seismic waves are realized with learning vector quantization and self-organizing map.

1 INTRODUCTION

A very promising method in earthquake engineering for protection of height – risk and very important structures against destructive influence of strong motion seismic waves is developing systems for structural control. One of the critical problems there is the problem of forecasting the behavior of seismic waves, in particular in real time for implementation of these prognoses in devices for structural control. Prognoses for further development of the waves can be made from recorded in real-time data for certain part of destructive seismic wave registrated in three directions. These prognoses are based on general, tectonic, seismic and site parameters. During these prognoses is supposed that waves can be classified as destructive or non-destructive and can be taken decision for switching structural control devices.

For such prognoses it can be developed different kind of models, for modeling the behavior of seismic waves main parameters during seismic waves spread in soil layers (Radeva and Radev, 2005). For practical purposes of possible records for displacements, velocities and accelerations as time history, most often accelerograms are used, which are characterized with certain duration, frequency and peak ground acceleration. They are involved in models and systems for estimation of elasticity response spectrum. For each point of registrated accelerogram the parameters of her displacement in soil layer are presented with three components in three directions of the orthogonal axes. The most practical usage in structural engineering and design has their peak values, independently of their sign and direction. That's why the modeling of the behavior of seismic waves is used as input information in the process of calculation of the structural response spectrum (Radeva at all, 2004a).

In this paper is suggesting an approach for real-time prognoses of earthquake excitation, with fast estimation of seismic wave's characteristics with implementation of classification methods and Kochonen neural modeling for destructive part of seismic waves.

2 DETERMINING OF DESTRUCTIVE PHASE FROM ACCELEROGRAM

The purpose of stochastic modeling is the defining of the three phases of the earthquake wave and identification of the main parameters for each phase, such as resonance frequency, damping ratio, peak value. According to implemented stochastic model, each wave is dividing into three separated phases: primary (P- waves), transversal or secondary (S-waves) – on the second phase, and converted and guided waves (C-/G- waves) on the third phase. For evolutionary power spectrum estimation were used the time dependent stochastic principal axes method (Scherer and Zsohar, 1998). According to this method earthquake accelerograms are delivered as representations of the three-dimensional acceleration vector in a Cartesian coordinate system, generally with axes parallel to east –west, north-south and vertical direction, as is shown on Fig.1, where is pre-

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sented registrated records from Loma Pierta Earthquake, 1989.

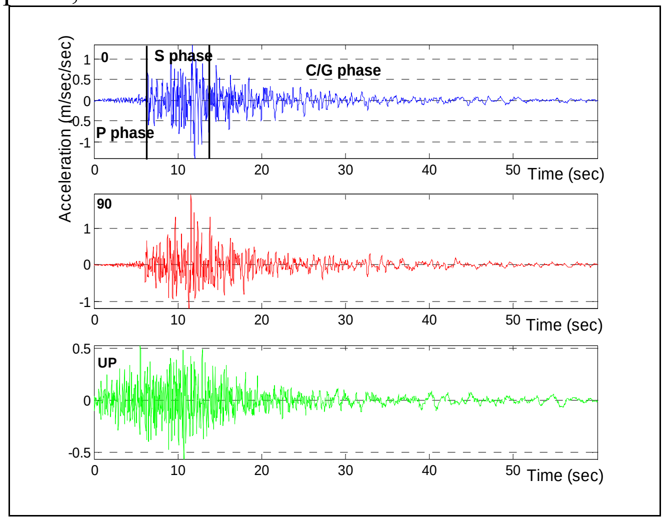

Figure 1. Recorded accelerograms with axes parallel to east –west, north-south and vertical direction.

On Fig 1 is shown as well determining the boundaries of three separated phases, which is realized with scene-oriented model. For determining boundaries between separated classes were analyzed 4300 strong motion seismic records, registrated in Europe and North America and to these records were implemented different stochastic models. We are suggesting the scene-oriented model as best fitting for determining boundaries of destructive S-phase (Radeva at all, 2004b). The scene-oriented model is a modification of simple Markov chain model, where the time series $\{x_t\}$ was transformed into discrete states $\{y_t\}$, where the number of states is the same as the number of target classes, and the size of the model y_i for each state is determined. At the scene-oriented model as three scenes are separated the three phases of the seismic waves. Consider the S-phase as a second scene. The target values in classes of the second scene are determined with (1).

$$SM_j = \frac{\sum_{t=1}^{M} x_t \cdot y_t}{\sum_{t=1}^{M} y_t}, \qquad y_i = SM_j \tag{1}$$

The next step is forecasting the resonance frequency of S-wave on the base of prognoses made with the help of principle axes transformation and further estimation of probability density with neural network and vector quantization.

3 DETERMINING OF DESTRUCTIVE PHASE DURATION AT AXIS TRANSFORMATION

Principle axes transformation is based on composing the components corresponding to the maximum, medium and minimum eigenvalues from all time windows. Consider each accelerogram with her three transformations. Let determine duration of destructive phase according to previous paragraph. Each transformation is a result from different accelerogram time histories that are ordered by seismic energy for every chosen time interval, (Scherer and Bretschneider, 2000). Principle axes transformed accelerograms can be visualized in the coordinate system of the original record. These transformed components, called stochastic principal axis accelerogram T1, T2 and T3 have different duration of destructive phase, as is seen on Fig. 2.

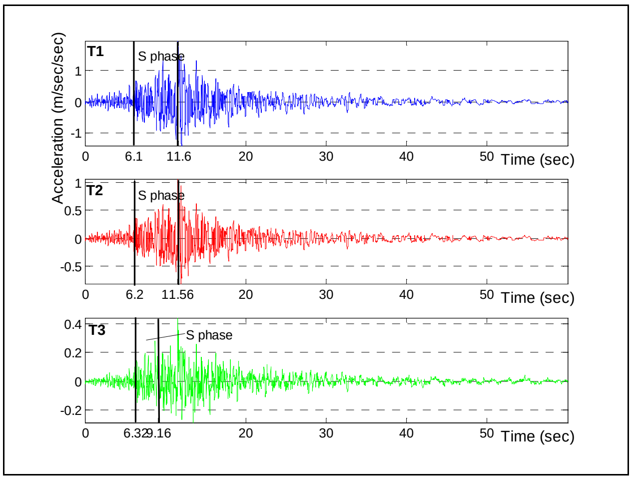

Figure 2. Determining of S-phase boundaries for principle axes transformed records.

Because of this different duration of destructive phase in each transformation, if we will implement one-dimensional vector quantization, it will give different results. That's why for prognoses model here is suggesting two-dimensional vector quantization, based on this time-series transformed records.

This process of time-series transformation gives possibility to use for empirical hazard analyses transformations T1 and T2. As most significant in seismic hazard analyses, for two-dimensional vector quantization and determination of basic classes further are used transformed accelerograms T1 and T2.

4 KOCHONEN NEURAL MODEL FOR 2D DESTRUCTIVE PHASE ESTIMATION

The suggested method for real-time prognoses is developed for fast estimation of strong motion seismic waves on the base of their main characteristics. The fast estimation of seismic waves is based on belonging of prognoses waves to certain class and subclass (Radeva at all, 2004b). The classification helps to select proper prognoses stochastic model for each of selected classes or subclasses.

The proposed real-time classification and prognoses are realized with neural models build on principle of Kochonen learning rules. For different classes and subclasses of seismic waves is suggesting two

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basic kinds of neural modeling - Learning Vector Quantization (LVQ) and Self-Organizing Map (SOM).

For probability density estimation of destructive phase in this research is suggesting a modification of two-dimensional vector quantization, where on axes are absolute values of transformed accelerograms T1 and T2. The main goal of a learning neural model for vector quantification is to determine the probability density function for T1 and T2.

The two-layered neural network for two-dimensional vector quantization consists of competitive and linear layers. LVQ learning in the competitive layer is based on a set of input/target pairs (2),

$$\{\mathbf{x}_1, \mathbf{C}_1\}, \{\mathbf{x}_2, \mathbf{C}_2\}, \ldots, \{\mathbf{x}_j, \mathbf{C}_j\}, \ldots, \{\mathbf{x}_N, \mathbf{C}_N\} \tag{2}$$

with the help of which is trained the neural network. Here $\mathbf{x}_j$ are two N-dimensional input vectors, and the M- dimensional vector $\mathbf{C}_j$ describes the condition of target classes, presented at (3).

$$\begin{aligned} \mathbf{x}_j &= \{X_j^{(1)}, X_j^{(2)}\}, \qquad j = 1,\ldots,N \\ \mathbf{C}_j &= \{S_1, S_2, \ldots S_k, \ldots S_M\}, \quad k = 1,\ldots M \end{aligned} \tag{3}$$

Each target vector has a single 1 and the rest of its elements are 0. The 1 tells the proper classification of the associated input. The hidden neurons from first layer compete via initializing of the weight matrix $\mathbf{W}_{kj}$ and are determining the winner. This is the neuron, which has minimal Euclid distance d_k to the input vectors $\mathbf{x}_j$. Then the corresponding target class receives value 1 and the rest target classes receive 0, as is presented by (4).

$$\begin{aligned} &S_k = 1, \quad for \quad d_k^{\min}, \qquad d_k = \sum_{j=1}^{N} \left(X_j - W_{kj}\right)^2 \\ &S_k = 0, \quad otherwise \end{aligned} \tag{4}$$

The neuron-winner has feedback negative links to the rest of neurons and strong positive link to himself, which is used for learning in linear layer. During the training in the next q epoch are changing the coefficients of all neurons according to Kochonen learning rule, which is summarized at (5).

$$\begin{gathered} W_{kj}(q) = W_{kj}(q-1) \pm \xi\left(X_j(q) - W_{kj}(q-1)\right) \\ 0 < \xi \leq 1 \end{gathered} \tag{5}$$

The coefficient ξ depends on the number of training epochs q and can be adjusted in advance in interval [0,1], where standard is determined equal to 0,1. The sign before the training coefficient ξ is positive for the neuron-winner, and negative for the neighbor neurons. As a result during the process of the training is changed the area of neighbor neurons for the neuron-winner, e.g. decreases the Euclid distances.

With LVQ we determine the function of density distribution with amplitudes, received from the real accelerograms. The vector quantization gives density distribution for each class and redistributes the target values in such a manner to have the same number of target values in each class (Radeva et all, 2004b). The density distribution of the values of time series was received via approximation of the linear target layer of the vector quantization.

For the proper determining of the function of density distribution is necessary to optimize the approximation of the target layer. The network was trained to classify the input space according to parameters of scene-oriented model. With the help of LVQ was determined the optimal number of target classes for destructive phase and prognoses were realized with this number.

Afterward with one layered neural network and self-organizing map (SOM) was determined the function of density distribution with amplitudes, received for transformed accelerograms T1 and T2.

Self-organizing neural networks have one-layered neural competitive structure, which can learn to detect regularities and correlations in the input patterns. The neural maps learn both, the distribution and topology of the input vectors, to recognize neighboring clusters of the attribute space.

Kochonen's network algorithm provides a tessellation of the input space into patches with corresponding code vectors. It has an additional feature that the centers are arranged in a low dimensional structure (usually a string, or a square grid), such that nearby points in the topological structure (the string or grid) map to nearby points in the attribute space.

The Kochonen learning rule is used when the winning node represents the same class as a new training pattern, while a difference in class between the winning node and a training pattern causes the node to move away from training pattern by the same distance. In training, the winning node of the network, this is nearest node in the input space to a given training pattern, moves towards that training pattern. It drags with its neighboring nodes in the network topology. This leads to a smooth distribution of the network topology in a non-linear subspace of the training data. In two-dimensional output space is expected a map, corresponding to the k - dimensional array of output neurons C_j, which can be one or two-dimensional. The connection between n-dimensional input vector and k-dimensional output neural vector is realized with the weight matrix $\mathbf{W}$. At competitive learning for winner is selected the output neuron j^*, which weight vector is closer to the current input according to (6).

$$\begin{gathered} \left|W_{jm}^* - X_m\right| \leq \left|W_{jm} - X_m\right| \\ \forall j \in [1,\ldots,k], \qquad \forall m \in [1,\ldots n] \end{gathered} \tag{6}$$

The Kochonen learning rule is differ from vector quantization rule and is determine by (7).

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$$\Delta W_{jm} = \xi \wedge (j,j^*)(X_m - W_{jm}) \quad (7)$$

The neighborhood function $\wedge(j, j^*)$ is equal to 1 if $j = j^*$, and decreases with increasing of distance between neurons j and j^*in input space. The neurons closer to the winner j^*, changes their weights more quick than remote neurons, for which the neighborhood function is very small.

The topological information contents in the fact, these closer neurons, which are changing almost in the same way and in this manner corresponds to neighbor input patterns. The learning rule (7) attracts the winner's weight vector to the point X_m.

The self-organizing map is supposed to be an elastic set in input space, which wants to be moved maximal closer to the input values. The set has topology of attribute space and it points have as coordinates weight vectors.

Here is suggesting a modification of VQ, with implementation of logarithmic scale and absolute values for T1 and T2. On Fig. 3 is shown modified two-dimensional vector quantization where with black points are depicted weight centers of target classes. We are interesting of last three classes (10, 11 and 12), because for them is observed higher deviation. With Manhattan distance are determined deviations from trajectory of axis and points in corresponding class according to (8).

$$M_j = \sum_{i=1}^{n} \left\| x_{ij} - s_j \right\| \quad (8)$$

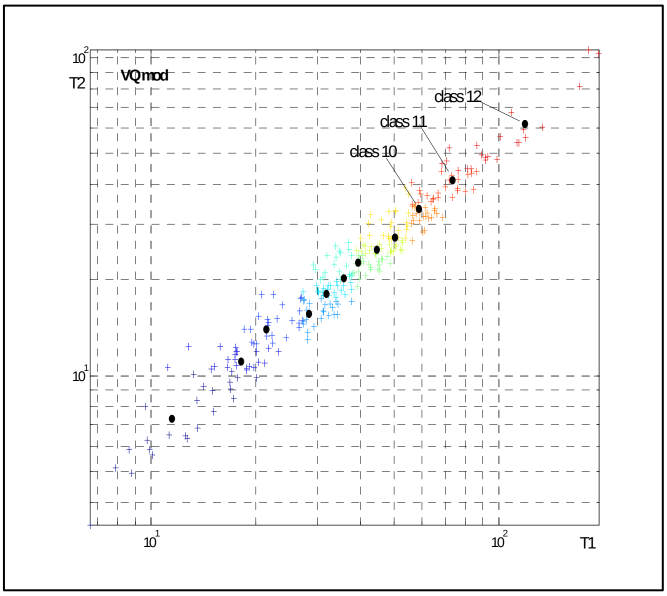

Figure 3. Two-dimensional vector quantization in 12 classes with Self-organizing map (SOM).

In Table 1 is shown estimation of the probability density distribution in each class for S-phase with two-dimensional learning vector quantization and self-organizing map.

Table 1. Estimation of probability density distribution (in percent) with LVQ and SOM

Classes	LVQ	SOM	Classes	LVQ	SOM
1	2.56	7.69	7	12.42	7.18
2	14.72	18.19	8	14.45	14.53
3	4.67	5.05	9	7.62	11.90
4	13.98	7.62	10	3.23	6.01
5	17.95	11.18	11	1.05	2.42
6	7.23	8.14	12	0.12	0.09

From Table 1 is seen, that for last three classes (10, 11 and 12), which are more interesting for prognoses model, there are observing similar results with both neural networks.

5 CONCLUSIONS

An approach for real-time prognoses of destructive phase of strong motion seismic acceleration was suggested, based on classification algorithm of strong motion waves with neural network with Kochonen learning rules. On the base of principle axis transformation and spectral characteristics of the wave, with stochastic long-range dependence time series analyses are determined the boundaries of destructive phase of strong motion acceleration.

For selected diapason of transformed accelerograms was implemented two-dimensional vector quantization with Kochonen learning rules. The prognoses are realized with the help of two-dimensional vector quantization and with self-organizing map. The probability density function for destructive phase was determined with both neural networks.

Received results can be used for analyses of structural response spectrum and in devices of structural control for very important and high-risk structures.

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Integrating evacuation planning into an octree-based CSCW framework for structural engineering

R.-P. Mundani & H.-J. Bungartz
Institut für Informatik, Technische Universität München, Germany

S. Giesecke
IPVS, Universität Stuttgart, Germany

ABSTRACT: In addition to classical topics such as CAD or statics' simulations, design processes in structural engineering often deal with aspects related to the later usage of buildings. One important and not negligible point of view to be examined and to be considered deals with the suitability of buildings during emergency situations as the evacuation of people in case of fire or terrorist activities. Deriving a connection graph from any arbitrary CAD model to be used for shortest-path algorithms, the graph can also be coupled to cellular automata for the simulation of people streaming to the building's exits for evacuation. These kind of simulation reveals bottlenecks of the architectural design. As geometric alterations might interfere with the building's statics, for instance, by integrating aspects of peoples' evacuation into a CSCW framework global consistency between all experts and all different tasks can be assured.

1 MOTIVATION

Within design processes from the field of structural engineering a lot of effort has to be invested to achieve global consistency for shared data, i.e. geometric models, in cooperative working environments. Beside the necessity of sufficient representations for all participating tasks, geometric models fulfilling the specifications of a statics' (CSD) or climate simulation (CFD) might fail according to the requirements for a safe evacuation of persons in case of emergencies, for instance.

In (Mundani et al. 2003, 2004a, b) and (Niggl et al. 2004) we presented a framework for CSCW and process integration for applications from the field of structural engineering, where global consistency among all participants is achieved by octree-based methods. Solving different tasks like CAD, CSD, CFD and visualisation – shortest-path algorithm for guidance systems in buildings – by this framework, we could also show that by embedding CSD into the framework any necessary computations related to modifications of the geometric model, such as the translation of a column, e.g., can be reduced and, thus, the results can be computed much faster due to a hierarchical approach (Mundani et al. 2005).

In this paper, we present the integration of evacuation planning into the framework mentioned above. When considering aspects of peoples' evacuation already during the design process, any modifications initiated to avoid bottlenecks of the underlying geometric model, such as too small doors or columns standing in the way of emergency exits, for instance, can be immediately examined for impacts on other tasks like CSD and CFD. Hence, assuring global consistency between all experts and all applications not only allows a faster processing of the entire tasks, it also provides the necessary preliminaries for setting up customized solutions for specific kinds of problems, so called problem solving environments.

2 GRAPH-DERIVATION FROM CAD MODELS FOR SHORTEST-PATH ALGORITHMS

2.1 *Derivation of a connection graph from arbitrary CAD models*

A general problem for shortest-path algorithms is the derivation of a sufficient graph from any arbitrary CAD model, if possible without manual post-processing. In our approach, we use the graphics card's *z*-buffer for detecting walls, corridors, and rooms before, finally, a connection graph can be derived from that information. Therefore, the model is rendered while being moved forward along the *z*-axis (up-vector), using an orthogonally projection to generate a stack of slices, depending on the chosen discretisation (step) width.

Regarding these slices, walls and, thus, rooms can be found easily by edge detection algorithms. Once all rooms have been identified a graph can be generated, applying distance skeleton algorithms well known from the field of image processing (Jähne

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1997). If the discretisation width is chosen "fine" enough, even stairs and ramps can be detected automatically. Manual corrections aren't necessary, only elevators and escalators are difficult to identify. Here, adding an edge between the corresponding nodes and marking it with an attribute such as ELEVATOR or ESCALATOR, resp., for further processing is everything to be done. For further information see (Drexl 2003).

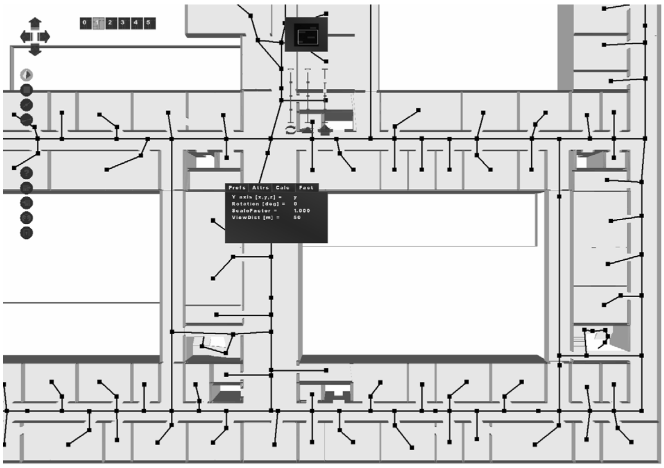

Figure 1. A sample graph – displayed within a tool for graph manipulation – as automatically derived from the CAD model of the computer science building of Universität Stuttgart.

2.2 *Shortest-path algorithms and visualisation*

Once the graph has been generated, applying DIJKSTRA's algorithm (Dijkstra 1959) to the weights stored to the graph's edges – representing the distance between the two nodes bordering an edge – calculates all shortest routes between any two arbitrary nodes. An online visualisation, as VRML application (Fig. 2), for instance, can now be used as guidance system to find any room or location inside a building.

Figure 2. A sample guidance system – here shown as VRML application – based on the graph derived from the computer science building of Universität Stuttgart.

Some more sophisticated routing can be achieved when allowing a dynamic (such as time-dependent) change of the weights – setting them to infinity, e.g. – to prevent the usage of certain routes. Sometimes the route through the canteen might be the shortest, whereas it's not a good idea to choose it at noon during the week. In combination with databases further information retrieval is possible, such as the usage of rooms or names and phone numbers of persons sitting in an office.

The automatic derivation of a graph is also the basis for our evacuation planning where people should find their own way to the nearest emergency exit. As visualisation and shortest-path algorithms are already integrated into the framework, a graph-based pedestrian flow can be easily integrated, too. Thus, peoples' evacuation can be made a part to be considered when dealing with a building's global consistency, allowing some more detailed studies of design processes.

3 EVACUATION SIMULATION

3.1 *Cellular automata*

A lot of research has been done in the field of pedestrian flow and evacuation dynamics (Schreckenberg et al. 2002). For the simulation of flow two different approaches have evolved: continuous and discrete simulation. While the first one (in general) is based on a precise physical model, it often lacks due to large computation times and, thus, is only of limited usage for an evacuation planning in real time. Beside this, for simulating pedestrian flow a precise model is not always necessary. In (Thiele 2001) we have shown that the continuous simulation of pedestrian flow based on the NAVIER-STOKES-equations is far beyond the usability in real time or online applications. Here, online means interactive, thus, an expert has the possibility to change the geometric model while a simulation for studying any impacts related to this manipulation runs.

To overcome that problem, discrete event simulation (Banks et al. 2000) – less precise than continuous simulation but nevertheless sufficient enough for describing pedestrian flow – allows faster computations and, thus, the processing in real time or online applications. Another technique, meanwhile state-of-the-art, are cellular automata that allow fast and efficient computations of peoples' movement. Each cell of such an automaton represents the place for a person – if not empty – being "moved" to one of the neighbouring cells by the state transition function

$$\delta: Q^N \to Q \tag{1}$$

with a set of states Q and a finite amount of neighbours N. Applying this transition function to all cells simultaneously and removing all persons that have reached a final state, i.e. a node representing an exit, an evacuation simulation is done by successively repeating this step until all cells are empty. For further information on cellular automata see (Wolfram 1994), for evacuation simulation based on

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cellular automata see (Hanisch et al. 2003), for instance.

3.2 *Objectives for evacuation dynamics*

In most cases, engineers are primarily interested to check if buildings, planes, or ships fulfill certain security requirements in case of emergencies when processing an evacuation simulation. That means, it has to be proven that it's possible for all people to leave within a given amount of time. In (Klüpfel et al. 2000) it is shown how security requirements concerning peoples' evacuation can be proven for passenger ships, for instance.

In our approach, the main focus does not tend into that direction of proving time-related security requirements, but to reveal any kind of bottlenecks related to the underlying geometric model. By integrating our approach into the framework mentioned above, those bottlenecks can be detected in early steps. Thus, impacts due to geometric modifications of the model on tasks such as CSD or CFD, for instance, can be considered and consistency among all participating experts or applications, resp., can be achieved.

4 GRAPH-BASED PEDESTRIAN FLOW

4.1 *Basic approach*

Here, we want to simulate online pedestrian flow in arbitrary buildings, thus, information about all corridors, stairs, escalators, elevators, doors and exits is necessary. This information is almost given within the connection graph derived from the geometric model. Corridors and stairs are represented as edges, the latter ones as a combination of edges and nodes (Fig. 3). The distance between two adjacent nodes is given by their common edge's weight, automatically retrieved from the geometric model, too. Escalators and elevators can also be represented as single edges with certain attributes, but a different processing – in the sense of additional time for waiting or transportation – has to be considered for pedestrian flow. Both are not included in the current version and will follow within some later extension.

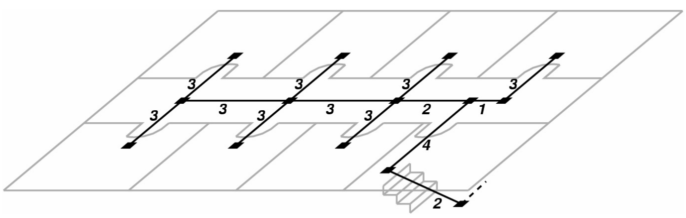

Figure 3. Connection graph with edge weights representing the distances – as measured from the CAD model – between two nodes; the edges on the lower right-hand side are from a staircase to the next floor.

The connection graph can now directly be used as a basis for cellular automata. Therefore, each edge represents one (1-dimensional) cellular automaton with n cells, where n is calculated in the following way. Assuming one person needs the space of a circle with diameter 0.8m for standing on the corridor (information about the height is not necessary as only rooms with a height of more than 2m have been considered within the graph derivation), thus, with

$$n = \lfloor (length / 0.8) + 0.5 \rfloor \qquad (2)$$

for an edge with weight 3 (length of 3 meters) this results to a discretisation of 4 cells, for instance. The corresponding cellular automaton has 4 cells where each cell can represent one person.

As persons should move through the building for evacuation they have to pass over different edges connected via common nodes. That means, tracking one person's route it has to be shifted between the different cellular automata corresponding to these edges. The transition from one cellular automaton to another is done over the common node that connects both of them or the corresponding edges, resp. Hence, a person reaching the border cell of one automaton – left or right border of the 1-dimensional array representing the automaton's cells – can decide in which direction to go (for the case this node connects more than two edges) and, thus, is removed from one cellular automation and inserted in the next one, if possible, by a state transition.

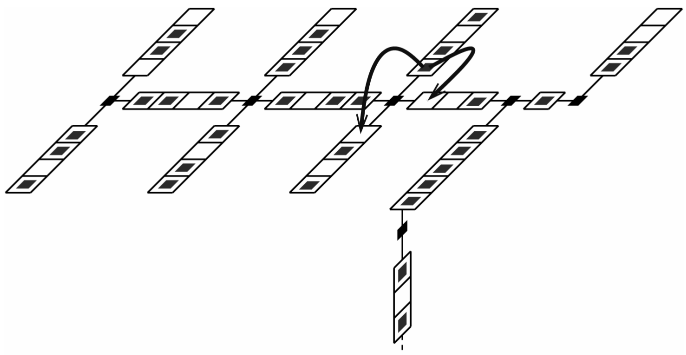

Figure 4. Sample graph-based cellular automata for the connection graph from Fig. 3 with some random states (filled squares indicate people); for one cell the possible directions for a transition are shown (arrows).

The decision which direction to choose in case there are several possibilities is driven by a shortest-path algorithm. As in our scenario people want to evacuate the building, a state transition always looks for the neighbouring cellular automaton or edge, resp., that lies in the direction of the shortest exit—always under the assumption people are following the exit signs, chaotic behaviour is not considered so far. If this transition is not possible as the designated cell is not empty the state transition looks for the next possibility. Only in case none of them is applicable the state transition decides either to wait or to "run back" and try another exit. It's obvious that a wait causes all other people behind also to wait, thus, a congestion appears. Congestions also appear

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at nodes that are connected to several edges, such as a T-crossing, e.g., as always only from one side a state transition can be done. To prevent the "starvation" of one ore more cellular automata, a round robin principle assures an equal distribution of state transitions to all cellular automata connected to a node. In reality this can often be seen at road works on highways where cars (should) merge together from several lanes to one lane like a zipper.

4.2 *Further geometric considerations*

So far, no geometric information about the dimensions of corridors or the width of exits have been taken into account for the evacuation simulation. For a realistic pedestrian flow further data is necessary. Beside the length of an edge (given by its weight) and, thus, the amount of cells n also the "capacity" and "throughput" of an edge are important values. While the first one determines the amount of people that can walk next to each other on the corridor represented by the corresponding edge, the latter one specifies the amount of people that can pass over that edge in a certain amount of time. The capacity can easily be retrieved from the geometric model by examining the width of corridors. Again, Equation 2 computes the correct amount of cells m substituting the width instead of the length (Fig. 5). To simplify the cellular automaton it is still represented by a 1-dimensional array. In contrast to before, each cell can now store more than one person, thus, the cellular automation has n cells where each of them can store m_i persons—$i \in [0, n-1]$.

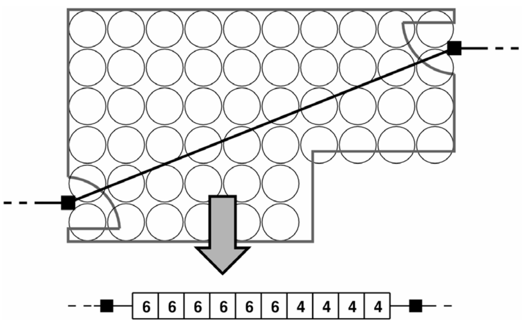

Figure 5. For a sample room the possible amount of persons – according to Equation 2 – is indicated (circles) as well as the corresponding cellular automaton for the drawn edge. It consists of 10 cells where the ones representing the left part of the room can store up to 6 persons and the ones representing the right part up to 4 persons.

Calculating the throughput is a bit more complicated. The amount of people that can enter or leave a room depends on its exits. An office room, for instance, has one exit in the general case, thus, one person can enter or leave. A hallway might have large exits on two opposite sides, thus, several persons can enter or leave at the same time. Hence, for calculating the throughput all available information according to a room's exits has to be considered. From the geometric model the width of a door can easily be obtained. Unfortunately, the geometric model doesn't tell anything about the direction a door can be opened (to the left or right and, thus, in direction of an escape route or against it) or if it's locked at certain times. Here, some context-based data such as attributes for parts of the geometric model could be helpful. For the current state, our algorithm only considers the width of doors or exits, resp., to calculate the throughput. More sophisticated approaches will be examined in future works.

The throughput is expressed as persons/time that can enter or leave. In the sense of a cellular automaton that means how many persons can be moved from one automaton to a neighbouring one over a common node within one state transition. It's value is determined by Equation 2 when substituting the width of a door or exist as obtained from the geometric model. For the example shown in Fig. 5 the throughput is 1 person/transition for both doors. Obviously, this not too much because it would take at least 52 state transitions to evacuate the full room.

4.3 *A prototypical implementation*

To achieve some first results and to test our approach of a graph-based pedestrian flow we have made a prototypical implementation. Our test scenario is the model of a small office building with two floors (basement and first floor). Within this scenario we start from a random distribution of persons inside the building, placing some of them in the office rooms and some on the hallways. There exists one exit to leave the building and two staircases to come down from the first floor to the basement.

When starting the simulation, in each step the algorithm determines for all persons the shortest route to the exit according to their current positions. Once it is known in which direction to go (forward or backward) or on which edge to change at crossings (nodes), the corresponding state transitions for all cellular automata are initiated. Finally, all persons that have reached a final state – i.e. a node representing an exit – are removed and all steps are successively repeated until all persons have left the building (see Fig. 6).

In some cases it might not be possible to evacuate all persons as parts of the building are destroyed and cannot be accessed. This can easily happen if one thinks about fire or – unfortunately not negligible in our times – terrorist activities. To prevent the algorithm from using certain parts of the building during the simulation the corresponding edges or weights, resp., have to be set to an infinite value, thus, the shortest-path algorithm doesn't take these edges into account when calculating the shortest route. As we are interested in an online simulation, in a future release users will be able to select single edges during the evacuation simulation and to disable them manually to pretend an emergency – fire or the detonation

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of a bomb – to perform studies about the impact on security related issues.

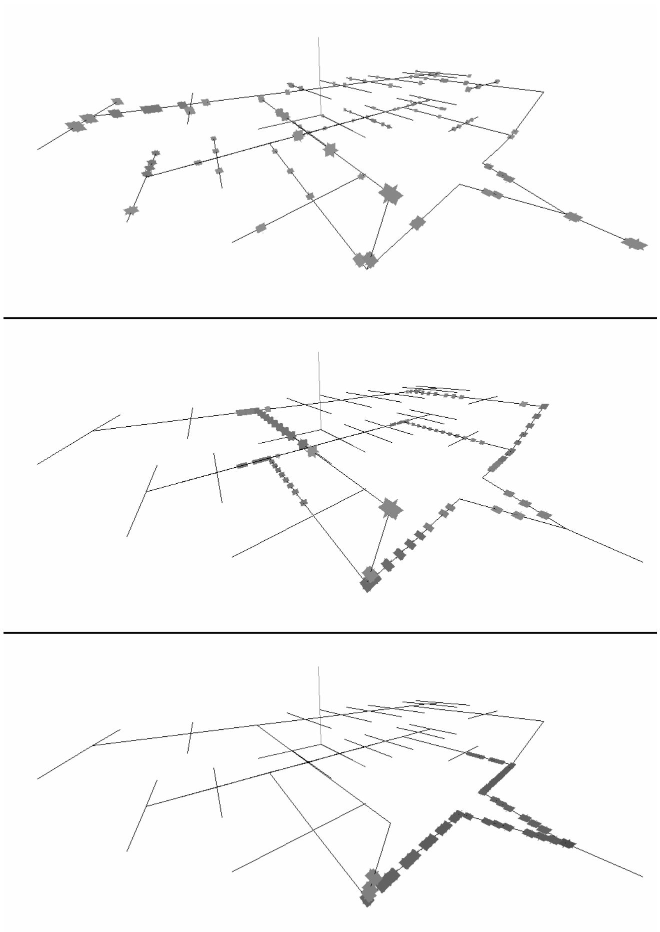

Figure 6. Sample evacuation simulation for an office building with two floors: The topmost picture shows the initial setup (squares are indicating people), the middle picture the state after some transitions, and the lowermost picture the state close to the end. The darker squares are drawn, the more people have to wait before they can move on as it can be seen near the exit (right-hand side).

Nevertheless, disabling an edge and, thus, making parts of the building not accessible might result to isolated blocks where people are running around but they are not able to leave. Such a block has to be removed from the current computations, so the simulation can stop if the rest of the building is empty. Otherwise it would loop forever, waiting that all people have been evacuated. The problem is to automatically identify an isolated block and to stop computations of the corresponding cellular automata.

One possibility determining an isolated block is to try to reach an exit from both sides of the disabled edge. Therefore, from both of the edge's nodes a recursive search is initiated, either stopping when an exit was found or all edges and nodes behind that specific node have been visited. For the case no exit could have been reached all edges and nodes on that side belong to an isolated block. Thus, to prevent further computations and to assure that the simulation stops when all people from the rest of the building have been evacuated, all subsequent edges on the isolated side are disabled, too, and the cells of the corresponding cellular automata are set to zero.

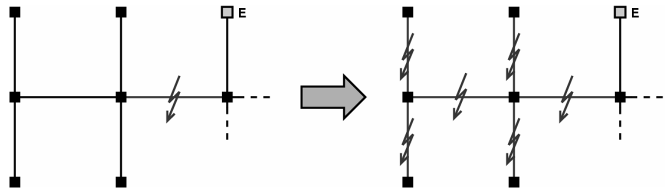

Figure 7. For both nodes of the disabled edge a search for a reachable exit (highlighted node with capital letter 'E') is performed. If no exit can be reached all subsequent edges behind that node are disabled, too.

5 INTEGRATION OF EVACUATION PLANNING INTO THE CSCW FRAMEWORK

By now, we have shown a graph-based pedestrian flow as stand-alone application for evacuation simulation. To exploit the full potential of this approach and, thus, to add a new characteristic to the cooperative working environment discussed in this paper, evacuation planning was integrated into our octree-based CSCW framework. Hence, the results of evacuation planning can be considered in other tasks, revealing any impacts of geometric modifications on the global consistency initiated due to security requirements.

Starting from a CAD building model (IFC) all geometric and related data is stored to a database server. Any access to this server is controlled via services to check-out/in parts from the geometric model to/from the local workspace. Any (local) modifications written back to the server have to pass a collision detection before stored to the database or being rejected in case of failure. Thus, global consistency among all participating experts or tasks, resp., can be assured. Further information about this framework can be found in (Mundani et al. 2004b) and (Niggl et al. 2004).

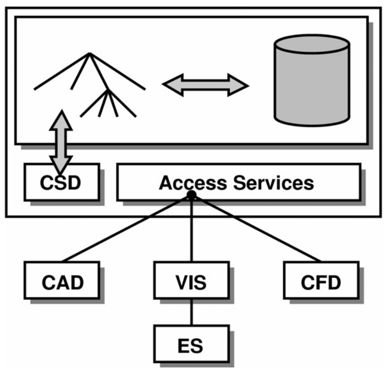

Figure 8. A sketch of our CSCW framework: All shared data is stored to a central database server assuring global consistency via octree-based methods. Already embedded into that framework is the structure analysis (CSD), all other integrated tasks can access the data via provided access services. Here, the component for visualisation and shortest-path algorithms (VIS) is extended by an evacuation simulation (ES), based on the automatically derived connection graph from the central building model.

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Another important property related to global consistency deals with impacts or side effects between all participating tasks. A modification done within one application might interfere with another application – not necessarily based on the geometry itself – and, thus, might entail further modifications until all requirements – such as a room's air conditioning, for instance – are satisfied. The earlier these properties are taken into account, the easier global consistency can be achieved. Integrating evacuation planning into the design process from the start prevents additional iteration cycles at the end when the building evolved so far doesn't come up to security related expectations. Figure 8 depicts a schematic sketch of the current framework also considering evacuation planning.

Whenever one engineer now changes the central data all subsequent applications can immediately react on that new scenario and check if there occur any problems. In case of the evacuation planning another engineer responsible of that can not only check the suitability of the current geometry according to security requirements, he can also reveal bottlenecks when studying further scenarios different from that standard evacuation case. Therefore, he can block certain routes as described above and see if a secure evacuation is still possible. Any suggestions or changes according to more or wider doors, additional staircases, or the translation of columns in huge areas, for instance, can then again be considered within the other applications immediately. Thus, any inconsistent state is easy to detect and necessary measures can be initiated.

Nevertheless, reacting to a different scenario entails manual activities by some engineer. If all tasks would be embedded into the framework, the corresponding applications would run automatically and, thus, only the simulation results would have to be checked. This can safe a lot of effort, as shown in the case of statics' simulation (Mundani et al. 2005) where a much faster and much more efficient processing is possible—especially when one engineer intends to locally study the behavior of different variants without conflicting the global consistency.

6 CONCLUSIONS

In this paper, we have shown how a connection graph for shortest-path algorithms can be coupled to cellular automata to simulate pedestrian flow in arbitrary CAD models for evacuation planning. Furthermore, this evacuation planning can be used to study different emergency scenarios by making parts of the geometric model inaccessible and, thus, revealing bottlenecks of the architectural design. By integrating the evacuation planning into a framework for cooperative work, the results of an evacuation simulation can immediately be used within other tasks to achieve global consistency among all participating experts and applications, resp.

A next step will comprise the embedding of evacuation planning into this framework as already done for the statics' simulation, thus, providing a so called problem solving environment that allows a faster and more efficient treatment of design processes from the field of structural engineering.

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Probabilistic Building Inspection and Life Assessment – a computer program for reliability based system assessment

C. Klinzmann & D. Hosser
Institute of Building Materials, Concrete Constructions and Fire Protection, Braunschweig University of Technology, Germany

ABSTRACT: The collaborative research centre (CRC) 477 explores innovative methods for structural health monitoring. In project field A1, methods and strategies, the modular knowledge-based computer program PROBILAS (Probabilistic Building Inspection and Life ASsessment) is developed. Its main focus lies on the optimization of structural health monitoring measures. One opportunity to optimize the monitoring process is to concentrate the monitoring measures on a few critical weak points of a structure. These critical weak points are identified by using methods of the system and reliability theory. Additionally these methods provide the opportunity to evaluate and to assess the probability of failure of a system. This paper concentrates on the implementation of the described methods into PROBILAS. Especially the database model, its integration into the program modules and the calculation procedure used for reliability analysis are discussed further.

1 INTRODUCTION

The construction of new civil infrastructure used to be the typical business of the construction industry. Nowadays this has changed, because the preservation or renewal of structures has become more and more important. These changes result from the fact that the structures erected in the early 1960´s are now reaching the end of their predicted lifespan of service or show at least serious signs of deterioration. This happens at a time when the need for the reduction of costs in public budgets is always present, which leads to the problem that not every necessary measure of rehabilitation can be carried out. In most cases this does not mean that the overall safety of the structure is endangered, because especially structures erected in former times have been designed with high margins of safety. Until the damage of the structure increases, it can be safely utilized. In these cases, structural monitoring can be used to ensure the required load bearing capability. The structural monitoring process as well as construction and rehabilitation measures have to be cost effective. Finding the optimal and cost-effective maintenance strategy is a field of research, which came up in many recently published papers, e.g. in Frangopol & Liu (2004).

One of the main focuses of the collaborative research center (CRC) "Life cycle assessment of structures via innovative monitoring", funded by the DFG at Braunschweig University of Technology is to optimise methods of structural monitoring. This paper describes the approach of project field "A1" to develop methods for reliability-based system assessment and their integration into PROBILAS. With the help of PROBILAS, the weak points of the modelled structures can be identified and the further developments of the probability of failure of the structure can be predicted.

2 METHODOLOGY

2.1 *Reliability-based system assessment*

The idea of reliability-based system assessment is the combination of methods of system and reliability theory. Before these methods can be used to create a describing probabilistic system model of a structure, all necessary information about the structure has to be acquired. This includes material models and properties of the structure, loads imposed on the structure and resulting failure mechanisms. With the help of event tree analyses, the behaviour of the structure is studied when all the important parts of the structure are subjected to failure one after the other. With the results from these analyses, the most important elements for system reliability are known and a fault tree can be constructed. The fault tree describes how dependencies and relations of subsystems and components can lead to an overall system failure. The interaction between components in a fault tree is described via logical knots known from the system theory. Components can interact in serial

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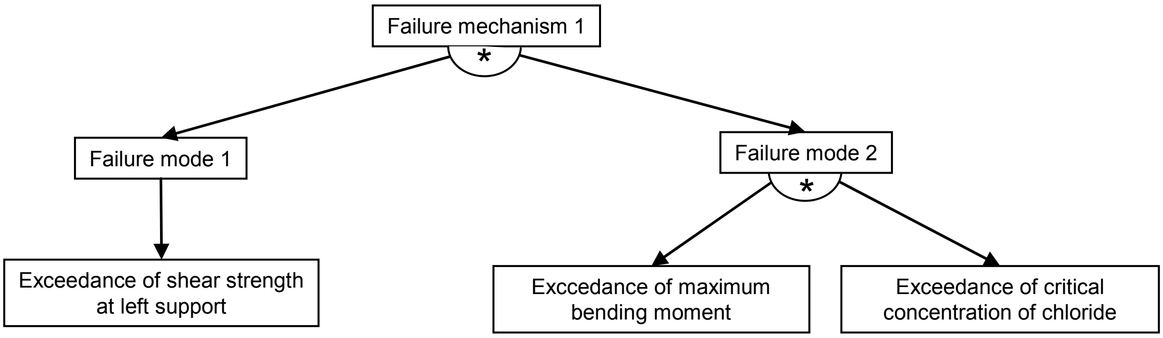

Figure 1. Example for failure mechanism and failure modes for a simple beam on two supports

systems (disjunction), where the failure of one component leads directly to the failure of the system or in a parallel system (conjunction) where the failure of the system occurs only after the collapse of all components. In reality structures normally consist of a combination of both types. The computation of the probability of failure of a structure represented by a fault tree is enabled by the use of limit-state equations. A limit-state equation compares the actions imposed on a structure (e.g. live load) and the resistance of the structure (e.g. material strength). Formula 1 shows its general form.

$$G = R - S \tag{1}$$

The component fails, when the resistance quantity (R) is smaller than the action quantity (S). Both quantities are functions of parameters, which are stochastic and/or uncertain and are generally described with statistical distributions. These equations are often formulated analytically by adapting classic dimensioning equations. The probability of failure of the fault tree is carried out using the first and second order reliability method (FORM/SORM), a method of approximation which has been described by Ditlevsen & Madsen (2003), amongst others. This method has the advantage that apart form the probability of failure p_f and the safety index ß respectively, a sensitivity factor α_i is computed for each parameter in the limit state equation. This sensitivity factor indicates the influence of the parameter on the probability of failure. One of the main ideas of reliability-based system assessment is to monitor only the most significant parameters of the structure indicated by the sensitivity factors in order to optimize the whole monitoring process.

2.2 *Probabilistic system model*

The creation of the probabilistic system model with the fault tree and the limit state equations is the most sensitive part in reliability analysis. Especially the complexity of the fault tree increases severely when structures with numerous components and subsystems are analysed. In this paper an approach for schematising the construction of a fault tree is proposed, which enables the computer able to help users with this difficult task.

2.3 *Failure mode*

Normally structures do not fail completely, when one of their components fails. Most systems are redundant and therefore have the ability to transfer loads to other parts of the structure in case of a local damage. In the schematised fault tree a local damage is called failure mode. A failure mode can be described by rather simple mechanical models (e.g. shear failure) or have to be modelled considering quite complex relations (e.g. bending failure due to chloride intrusion). Examples can be seen in Figure 1. When modelling failure modes serial and parallel systems can be used.

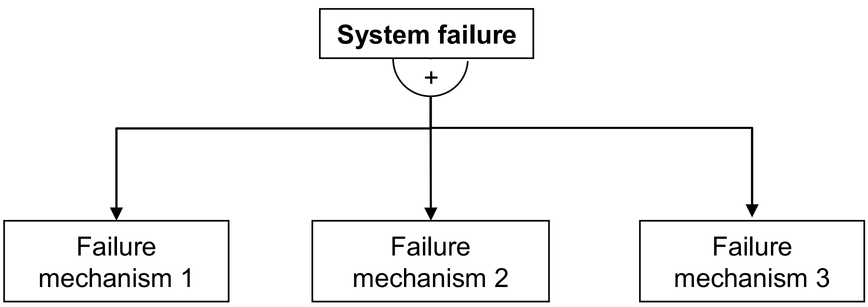

Figure 2. Serial system of failure mechanisms

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2.4 *Failure mechanisms*

A combination of failure modes which leads to an overall system failure can be called failure mechanism. In most cases a structure has several possibilities how local damages together lead to system failure. If all combinations are identified by an event tree analysis, the global system failure can be represented by a serial system of failure mechanisms (Figure 2).

3 THE PROGRAM SYSTEM PROBILAS

The main focus of the computer code PROBILAS is to optimize structural health monitoring measures by identifying the weak points of probabilistic modelled structures and to make lifespan predictions using reliability analysis. The computer code is designed as object-orientated Client/Server application and is written in Borland C++. The application flow of PROBILAS is illustrated in Figure 3.

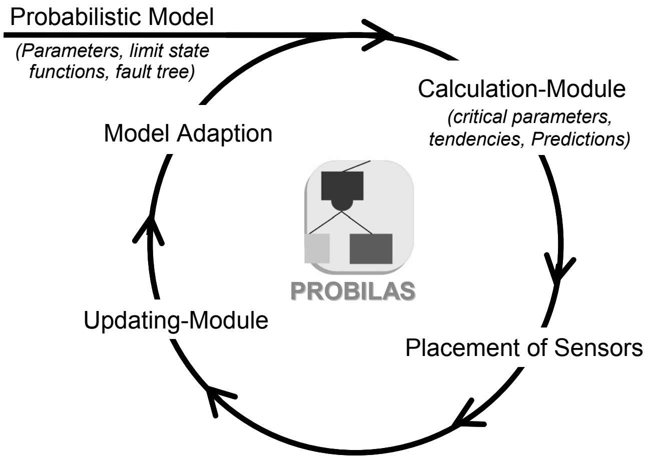

Figure 3. Structural evaluation process of PROBILAS

The primary input data in the program system is the probabilistic model already discussed. The construction of this model is simplified by an intelligent assistant provided by PROBILAS. The architecture of the assistant is one subject of this paper. When the probabilistic system model with fault tree, limit state equations and stochastic model is completed, the calculation module carries out the reliability analysis. In PROBILAS two analysis modes are implemented.

3.1 *Mode for life cycle monitoring*

PROBILAS has the ability to assist the user when life cycle monitoring measures have to be performed. Based on the results of the reliability analysis, PROBILAS makes suggestions and these parameters have to be included in the future monitoring process. After the sensors have been placed, the monitoring process can be started. The data obtained in the monitoring process is afterwards analysed by the updating-module of PROBILAS. The module compares the initial stochastic model of a certain parameter with the measured values and performs likelihood tests. If necessary, the stochastic model is updated using methods of Bayesian statistics. With this procedure, one pass of the structural evaluation procedure is finished. If a model update has been performed, a re-evaluation of the system becomes necessary. Especially changes of the standard deviation of parameters with high sensitivity values have a large impact on the probability of failure. In cases where the sensitivity value decreases significantly after a model update, the parameter may be excluded from the monitoring process. On the other hand it is also possible, that parameters which have not been monitored before become more important after the update. In this case PROBILAS indicates that the parameter should be included in the monitoring measures. Additionally the performance of the structure is assessed by evaluating the development of the probability of failure over the time. When the probability of failure descends below a predefined threshold, the user is informed.

3.2 *Mode for service life prediction*

Every structure is subjected to deterioration in the course of time. The simulation and the assessment of this fact are difficult and they are the objective of many publications (e.g. Gehlen 2000). For practical purposes the time variant problem can only be solved by simplification and approximation (Faber 2003). Examples are the use of Monte Carlo Simulation or of reliability index profiles formulated by Frangopol & Kong (2003). In this paper, a different approach is discussed which uses a time-step approximation procedure. This procedure is currently integrated into PROBILAS.

The purpose of this procedure is to estimate the development of the probability of failure and predict the lifespan of service of structures when they are subjected to deterioration. The process of deterioration has a direct influence on the probability of failure of a structure. Therefore deterioration functions are formulated for selected parameters of the probabilistic model. Assuming that the fault tree of the structure does not change significantly over time, a reliability analysis using the first and second order reliability method (FORM/SORM) at discrete time steps can be carried out. The result of these computations are time-dependent curves of the safety index β or the probability of failure p_f. Figure 4 shows exemplarily a time-dependent reliability curve for the collapse of the support of a clamped steel beam subjected to a bilinear corrosion function. Further examples can be found in Schnetgöke & Hosser (2005).

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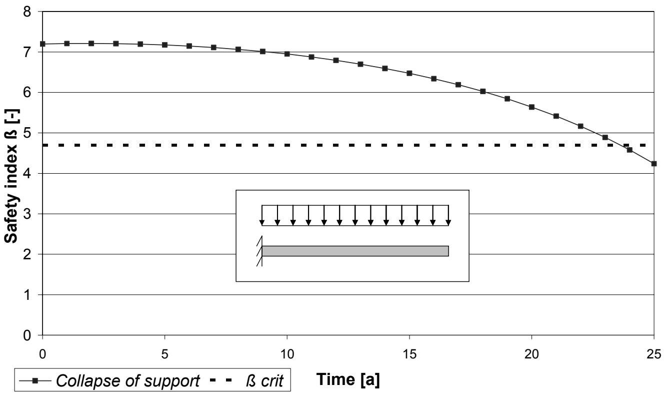

Figure 4. Example of a time-dependent reliability curve

It must be kept in mind that this procedure only leads to a rough estimation of the time-variant development of the safety of a structure. Additionally it must be stated that the model is highly dependent on the accuracy of the deterioration functions. With ongoing research in this area, the accuracy of the predictions can be improved. But even the information provided by the actual model can be helpful in the process of planning a structure or to estimate the ideal time for rehabilitation or maintenance.

In PROBILAS the time-variant deterioration functions are formulated depending on a reserved variable t_{pre} which is varied by the program between two calculation steps. Prior to every calculation, the amount of deterioration is evaluated for each parameter in the limit-state equation. As long as the deterioration function is of deterministic nature, the parameter is modified before the calculation for the next time step is carried out. Probabilistic deterioration functions will automatically be integrated into the probabilistic model of the structure.

3.3 *Database structure*

PROBILAS is designed as knowledge based system, which means that the user is not only able to carry out the reliability calculations but he has access to a database structure which provides useful help when designing the probabilistic system model of his structure. Apart form simple material properties the database will also contain information about typical limit states and failure mechanisms for certain types of structures. Additionally, after completion of the calculation the user is able to include his failure modes and mechanisms in the example database for further use. The database consists of several parts, which are described in the following. The relations between the components are illustrated in Figure 5. Every probabilistic model is highly dependent of the type of structure and of the used building materials. Therefore all data in the databases is stored in relation to these two restrictions.

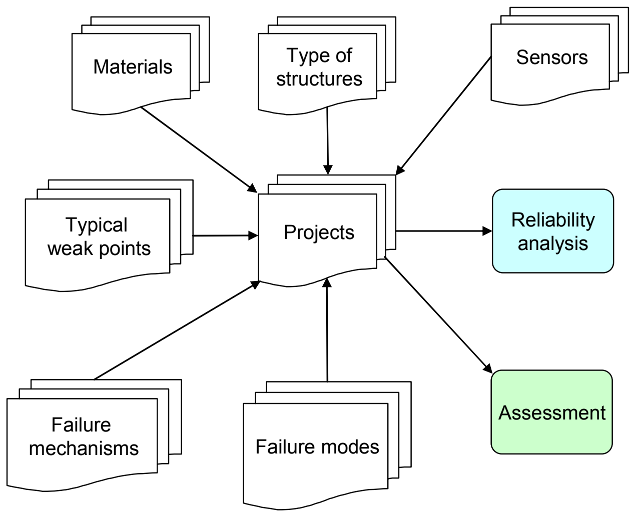

Figure 5. Relation of components of the database

3.3.1 *Database with typical weak points and deterioration functions*

Structures constructed out of different materials show different types of damage. Therefore PROBILAS will contain a database with typical weak points sorted by material and type of structure. The necessary data is entered into the database on the base of literature (e.g. Scheer 2000) or by importing already modelled structures. Additionally this database will contain some deterioration functions. This information can be improved based on ongoing research to ensure the maximum accuracy of the predictions and other calculation results.

The main intent for this database is to show the user which parts of his structure require a closer look when creating a probabilistic system model.

3.3.2 *Database with failure modes*

The smallest unit of a fault tree is the failure mode. The database stores samples of failure modes which can be reused when new models have to be created. These samples are called templates.

A template of a failure mode which is stored in the database can consist of a description, the corresponding fragment of a fault tree, the parameters for the components and a limit-state equation. The fault tree and the description are a required input value. Limit-state equations are normally closely linked to the specific mechanic model of the structure and therefore it is not necessary to include them in the template. In these cases, the description should provide the necessary information which is needed for the formulation of limit-state equations. Alternatively probabilities of occurrences can be entered as a component of the fault tree instead of a limit-state equation. Failure modes can be imported from existing projects.

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3.3.3 *Database with failure mechanisms*

In this database templates for failure mechanisms are stored. Example datasets for failure mechanisms may also be quantitative if they describe only textually which failure modes result in a system collapse. In this case the user has to define the corresponding failure modes by himself. A failure mechanism can also be created from existing objects in the project database.

3.3.4 *Project database*

After the probabilistic system model of the structure is created via the assistant, all data is saved in the project database. If templates from the example databases are used, only copies are created in this database. In addition to this data, the project database contains all data related to former projects. This includes all calculation results and measured data from the structural monitoring process.

The calculation module only accesses the project database, which assures a great data security and flexibility in case of an extension of the template database.

3.3.5 *Material database*

In the material database typical values for different materials are provided. These values and the related distributions are derived from literature (e.g. JCSS 2002) and serve as knowledge base when formulating the limit-state equations. During the monitoring process the values of parameters are updated using the data from the measurements. To prevent the original material values in the database from being modified, a copy of the original material is created in the project database. After an analysis the updated material values can be imported into the material database to provide new material values for future projects.

3.3.6 *Database with parameter categories / sensor database*

One main aim of PROBILAS is to assist engineers to plan monitoring and rehabilitation measures. This includes the choice of sensors and their placement on the structure basing on the calculation results. Therefore a sensor database is needed which will be built in cooperation with the other subprojects of the collaborative research centre 477. In the sensor database, different properties of sensors for building monitoring are stored. This includes the selection of measurands which can be monitored by a sensor and the general requirements for the related measurements. Additionally the sensor database assigns parameter categories to sensors. When each parameter of the limit-state equations of the project are equally linked to these categories, the calculation module can recommend the appropriate sensor for every important parameter of the probabilistic model.

In case the sensor database cannot be filled with enough data, every parameter is allocated to the information whether it is measurable or not.

3.4 *Constructing the probabilistic system model*

Probabilistic modelling of structures is not a common task for civil engineers. Helpful support for the construction of the probabilistic system model is provided by an assistant for the users of PROBILAS. The application flow of the assistant is shown in

Figure 6. The assistant uses the template data provided by the databases described above.

The first step when building a model is a thorough

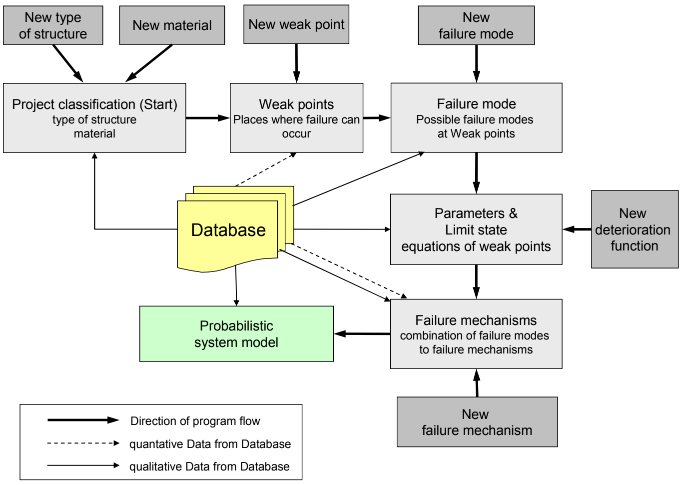
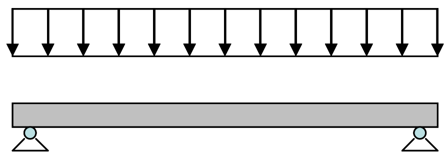


Figure 6. Program and data flow in the assistant

analysis of the static system. After the classification of the structure, PROBILAS can provide information on typical weak points depending on the specific material and the type of structure. After having selected or entered the weak points of the structure, the appropriate failure modes have to be defined. The assistant shows all templates of failure modes which are appropriate for the current structure. If required, the user can define new failure modes with a partial fault tree and description. Afterwards, he has to assign failure modes to the weak points. The example in Figure 6 shows the weak points and failure modes of a beam on two supports.



- left support (shear)
- right support (shear)
- mid span (bending)

Figure 7. Weak points for a simple example

The simple illustration shows the necessity of a separation between weak point and failure mode. It

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can be seen, that it in this case failure mode “shear” has to be used on two weak points, the supports on the left and right side of the beam. On the other hand it would be possible, that more than one failure mode has to be assigned to a weak point (e.g. shear and bending failure at the support of the beam in Figure 4).

After having selected or designed all failure modes, the limit-state equations and additional parameters of all components are defined. When the calculation mode for lifespan prediction will be used, a deterioration function has to be defined for the accordant parameter. After all input data has been entered, the user can combine the failure modes to failure mechanisms. With the help of event tree analysis he can decide, whether one failure mode alone or the combination of multiple failure modes would lead to the collapse of the whole system.

This knowledge is necessary for the automatic generation of the system fault tree, which is the last step of the assistant. With this step the probabilistic model of the structure is saved into the project database. Following this procedure the creation of complex system fault trees is schematized and simplified. In the calculation module a hierarchical view of the fault tree allows final checks of the probabilistic model.

3.5 *Future developments*

The main focus of future work lies in the development of decision guidance for the users of PROBILAS. This includes further help during the creation of the model and in the evaluation and assessment of the results of the reliability calculations. Further help will be provided in selection and placement of the sensors.

Another important field of work is the implementation of typical weak points, templates for failure modes and failure mechanisms of complex structures in the database of PROBILAS.

4 CONCLUSION

In this paper the methodology behind the modular computer code PROBILAS and its approach to the optimization of structural health monitoring is presented. This includes the concept for the schematisation of the fault tree, the database structure for the knowledge-based part of PROBILAS and the explanation of two possible calculation procedures. The application of the described methods is shown by Schnetgöke & Hosser (2005) in another article in this proceedings.

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Application of reliability-based system assessment using a bridge example

R. Schnetgoeke & D. Hosser
Institute of Building Materials, Concrete Construction and Fire Protection, Braunschweig University of Technology, Germany

ABSTRACT: Structural health monitoring during the life-cycle of a structure is necessary to ensure permanently the bearing capability and the serviceability respectively. Differences from the designed properties can be assessed consequently and therefore rehabilitation measurements can start. For the minimisation of the structural health monitoring measures and the cost involved, the monitoring measures must be concentrated on the critical weak points of the structure. Therefore the knowledge-based system PROBILAS (PRObabilistic Building Inspection and Life ASsessment) is developed. By the combination of recognized procedures of reliability and system analysis in PROBILAS a continuous revaluation of the building and the identification of the failure-relevant parts is possible. This article illustrates the building assessment process with PROBILAS using a bridge as an example. The process includes repeated evaluation of the system and the focussing of both the stochastic an the physical models on the failure-relevant parts of the system.

1 INTRODUCTION

1.1 *Motivation*

The life time oriented design of structures includes maintenance strategies. Structural health monitoring is essential to evaluate these strategies in such way that the bearing capacity, serviceability and the durability remain ensured and the costs of rehabilitation are limited.

The aim of structural health monitoring is the continuous monitoring and assessment of the present state of the structure. The outcome of this is the base for the optimisation of further measures.

The main focus of the collaborative research center (CRC) „Life cycle assessment via innovative monitoring" funded by the DFG at Braunschweig University of Technology is to optimize methods of structural monitoring. In the following a part of the work of project field A1 of the CRC for the reliability based system assessment is described. The developed methods are able to identify critical weak points and failure paths. The monitoring measures will be concentrated on these points. This leads to a maximum benefit with respect to safety and information with limited investments.

1.2 *Reliability-based system assessment*

The first step in reliability-based assessment is to acquire all necessary input data describing the structure. In the next steps the structure is analysed with methods of system theory. By combining these methods with methods of reliability theory, a describing model of the structure is created. The reliability analysis starts with the identification of the different sources of risk of the structure. Afterwards, the system has to be discretised in causally connected components and subsystems. These relations are summarized in a fault tree. The fault tree regards all possible causal sequences of component and subsystem failures that lead to system failure. For all components in a fault tree a limit-state has to be defined. The limit state is described by quantities that represent the resistance of a structure (e.g. material strength) and by quantities, which represent the actions imposed on the structure (e.g. live load).

For the reliability analysis the first/second order-reliability method (FORM/SORM) (Ditlevsen & Madsen 2003) is utilized. In these calculations a probability of failure (p_f), a safety index β ($p_f=\Phi(-\beta)$) and sensitivity values (α) for each parameter can be calculated from the limit state equation. For the calculation of the system reliability the computer code STRUREL (RCP 2004) is used. With the help of the system reliability analysis the weak points ("hot spots") of the structure can be identified. On the basis of the calculated values, the failure path with the highest probability of occurrence can be found. Especially the parameters of the limit-state equations within this failure path should be investigated further.

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These methods are implemented in the knowledge-based system PROBILAS (PRObabilistic Building Inspection and Life ASsessment) (Klinzmann & Hosser 2005, Hosser et al. 2004).

2 APPLICATION OF THE RELIABILITY BASED SYSTEM ASSESSENT

The function of a building regarding the bearing capacity and serviceability is to be guaranteed over the intended service life without substantial loss of the usage characteristics. The necessary measures for reconditioning of a building may not become inadequately large at this. The detection of safety-relevant deviations from planned properties requires an optimized structural health monitoring. Consequently the service life is ensured with a minimum of rehabilitation. The main focus in this article lies on the ultimate limit-states of the bridge structure with consideration of a corrosive damage of the tendons. The structure is a single span plate girder bridge with two girders and a span width of 25 m (Fig 1, 2).

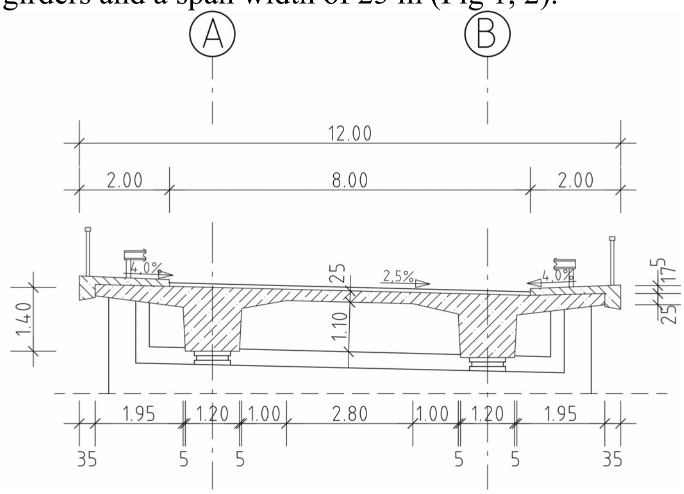

Figure 2. Bridge example, section

The bridge is pre-stressed with post-tensioning tendons. The width of the driving lane is 10.5 m, since the bridge is dimensioned for short-distance traffic.

3 PROBABILISTIC MODEL

3.1 *Fault tree*

The first step is the development of the fault tree with the assistant of the knowledge-based system PROBILAS. After the classification of the type of building and the used structural materials, typical weak points can entered. These weak points should be considered in the fault tree. Failure modes like shear failure at the support or flexure failure at midspan for example are weak points to be inspected. These obvious examples are as well part of the structural analysis. Furthermore environmental influences have to be considered. Corrosion of reinforcement due to chloride attack or carbonating lead to decrease of the bearing capacity of reinforced concrete structures. This interaction of individual components represents a subsystem failure in the overall fault tree of bridge failure. The subsystem failure is called failure mechanism. These failure mechanisms are stored in PROBILAS as sample data sets. Once all failure modes and failure mechanisms are specified for the building, PROBILAS generates the fault tree for the complete structure (Klinzmann & Hosser 2005).

Among other things the following points where taken into account to ensure the bearing capacity of the bridge. On the one hand the shear failure at the support and on the other hand the flexure failure at midspan is to be analysed first. The failure of the transition joint, the penetration of de-icing salt linked with the consequence of a chloride-induced corrosion of the tendon anchorage assembly is a possible failure mechanism at the support. The prestressing is useful for the shear capacity at the support and can not be considered if the tendon anchorage assembly fails. For this reason the shear failure risk increases. If the transition joint does not fail,

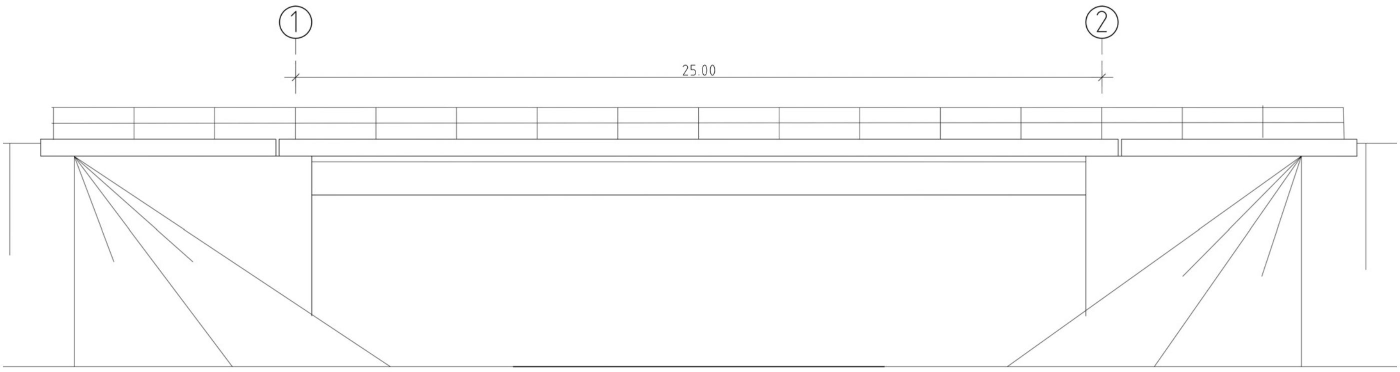

Figure 1. Bridge example, elevation

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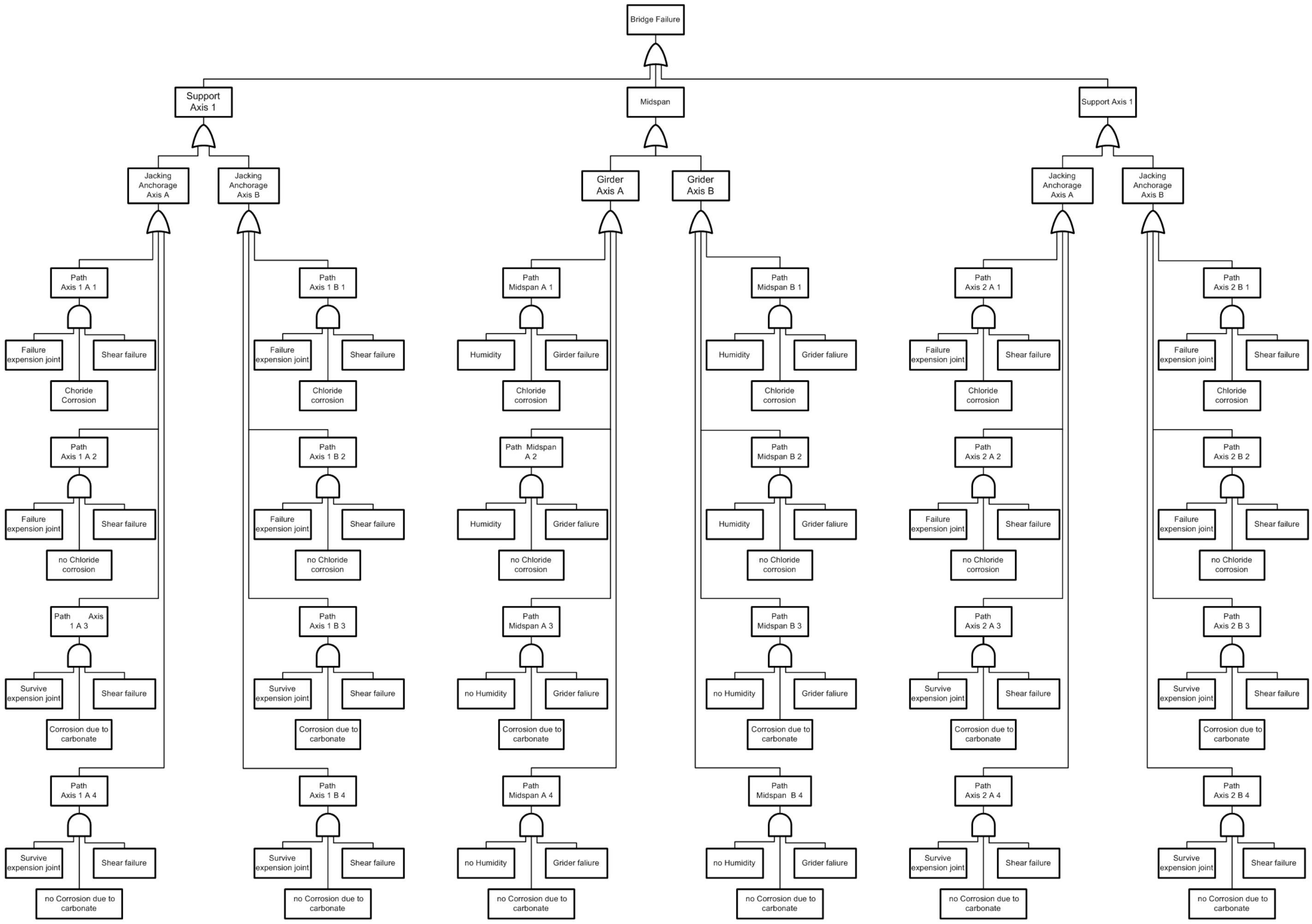

Figure 3. Fault tree

there is no chloride-induced corrosion due to missing of de-icing salt. For this case a corrosion is considered due to the carbonating of the concrete. In midspan the structure can fail by exceeding the flexure capacity or by fatigue fracture of the prestressing steel.

A corrosive degradation of the reinforcement here also leads to a reduction of the bearing capacity. Therefore either chloride-induced corrosion of the reinforcement or corrosion due to carbonating are taken into account in the failure mechanisms for midspan. The chemical and/or physical processes in the concrete do not exclude the simultaneous occurrence of chloride-inducing and carbonating. The transport of chloride in the concrete requires a moisture penetration of the concrete, which restrains again the carbonating process. Thus the independent view of both procedures in the reliability-based system assessment is a meaningful simplification.

For the structural health monitoring with special consideration of the bearing capacity the resulting fault tree is represented in Figure 3. Every component in this fault tree represents a limit-state. The modeling of the limit-states functions on this basis for the shear failure at the support, the flexure failure and the fatigue failure in midspan will be described in this article.

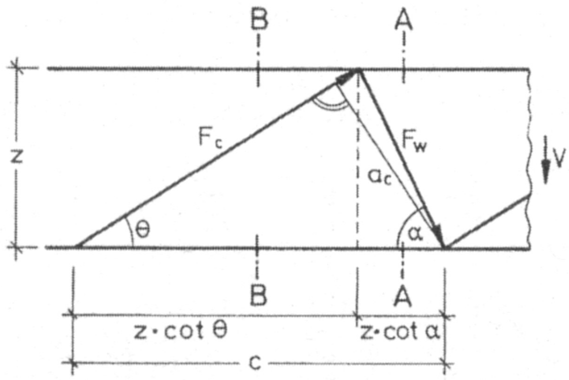

Figure 4: General truss model (Zilch & Rogge 2004)

3.1.1 *Limit-state for shear failure*

A general truss model describes the shear properties (Fig. 4). The capacity of the ties is to be analysed with equation (1) and the capacity of the concrete compression struts with equation (2).

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$$V_{R1} = A_{s,sti} * f_y * (\cot\theta + \cot\alpha) * \sin\alpha \qquad (1)$$

$$V_{R2} = \sigma_c * b_w * z * (\cot\theta + \cot\alpha) * \sin^2\theta \qquad (2)$$

with $A_{s,sti}$ = shear reinforcement per unit length, f_y = reinforcement yield strength, z = moment arm of the internal forces, θ = angle of concrete compression struts, α = angle of shear reinforcement, σ_c = compression concrete strength and b_w = girder thickness.

The shear action (V_S) due to dead load and life load stands against the shear resistance according to the equation (1) and (2) respectively. The pre-stressing decreases the shear action. At first, the reliability of the structure against shear failure is computed on the assumption of an intact anchor and with consideration of the pre-stressing.

The model uncertainties due to idealizations in the mechanical model and the load effect were taken into consideration by model uncertainty factors following (JCSS 2002).

The limit-state equations can be written in the general form Z = R – S. The component fails, when the resistance (R) is smaller than the action (S).

Table 1. Stochastic model for the shear failure

Basic Variable	Symbol	Unit	Distribution	Mean	Standard deviation
Compression concrete strength	f_c	MN/m²	log-normal	38	2.28
Yield strength	f_y	MN/m³	log-normal	560	30
Girder depth	h	m	constant	1.40	
Concrete cover	nom c	m	Beta	0.05	0.009
Shear reinforcement	$A_{s,sti}$	m²/m	constant	0.015	
Angle of shear reinforcement	α	°	constant	90	
Angel of concrete compression struts	θ	°	rectangular	45	8.66
Length	l	m	constant	25	
Dead load	g	MN/m	GN	0.098	0.00275
Live load	TLKW	MN	GN	0.406	0.065
Pre-stressing force	P	MN	GN	15	0.3
Tendon gradient	χ	-	constant	0.096	
Girder thickness	b_w	m	constant	1.2	
Uncertainty of resistance	θ_R	-	log-normal	1.0	0.1
Uncertainty of load effect	θ_S	-	log-normal	1.0	0.1

In this case the limit-state equation for shear failure results in:

$$Z_1 = \left(A_{s,sti} * f_y * (\cot\theta + \cot\alpha) * \sin\alpha\right) * \theta_R - V_S * \theta_S \qquad (3)$$

$$Z_2 = \left(\sigma_c * b_w * z * (\cot\theta + \cot\alpha) * \sin^2\theta\right) * \theta_R - V_S * \theta_S \qquad (4)$$

The stochastic models of the parameter are listed in Table 1.

3.1.2 *Limit-state for flexure failure*

Another component in the fault tree illustrated in this chapter is the flexure capacity of the bridge. The flexure capacity for the bridge section can be calculated by the equilibrium of internal forces (Fig 5).

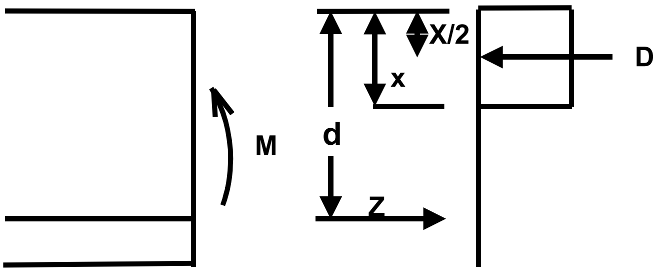

Figure 5. Internal force in case of bending moment

The associated equation for the flexure capacity can be described as follows.

$$M_R = A_s * f_y * d - \frac{1}{2} * A_s * f_y * \frac{A_s * f_y}{b * f_c} \qquad (5)$$

The resisting moment according to equation (5) will be compared with the acting moment due to dead load and life load.

A design vehicle (TLKW) with a middle weight of 400 kN as single load in midspan is simply assumed for the life load. The action–effect is calculated in equation (6).

$$M_s = \frac{g * l^2}{8} + \frac{TLKW * l}{4} \qquad (6)$$

This results in the limit state equation for flexure failure:

$$Z = \left(A_s * f_y * d - \frac{1}{2} * A_s * f_y * \frac{A_s * f_y}{b * f_c}\right) * \theta_R - \left(\frac{g * l^2}{8} + \frac{TLKW * l}{4}\right) * \theta_s \qquad (7)$$

The stochastic model for the related parameter in equation 7 are listed in Table 2. In the reliability analysing also a model uncertainty factor is kept in mind.

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Table 2. Stochastic model for the flexure failure

Basic Variable	Symbol	Unit	Distribution	Mean	Standard deviation
Compression concrete strength	f_c	MN/m²	log-normal	28	2.28
Yield strength	f_y	MN/m³	log-normal	1610	30
Reinforcement	A_s	m²	constant	0.0134	
Girder depth	h	m	constant	1.40	
Effective width	b	m	constant	5.00	
Moment arm	d	d = h-a			
Length	l	m	constant	25	
Dead load	g	MN/m	GN	0.098	0.00275
Live load	TLKW	MN	GN	0.400	0.065
Uncertainty of resistance	θ_R	-	log-normal	1.2	0.15
Uncertainty of load effect	θ_S	-	log-normal	1.0	0.1

Furthermore the limit-state for the flexure failure also includes a corrosive degradation of the reinforcement. Due to penetrating chloride or the carbonating of the concrete corrosion of the reinforcement can occur. A probabilistic description of the processes in concrete are available in the literature (Gehlen 2000). An analytical description of the corrosion progress of the reinforcement is pretty difficult up to now.

The calculation module of PROBILAS makes a prognosis of the reliability. Therefore a time-step procedure is used. In this limit-state the linear decrease of the reinforcement cross section is assumed to 10 % during 10 years after initial corrosion.

The result is a trend for the reduction of the reliability with respect to flexure failure. Newly measured values for the corrosive degradation adapt the prognosis to the current state.

3.1.3 *Limit-state for fatigue failure*

Apart from the bending capacity also the limit- state for fatigue failure of the tendons in midspan is to be analyzed.

The describing model for fatigue failure is based on the Palmgren-Miner-hypothesis. This hypothesis means that alternating loading of the construction causes damages of the materials, which adds themselves until a critical damage value is reached. With the exceeding of this value fracture occurs. The damage progress of the tendon is described by the dimensionless damage factor D.

$$D = \sum_i \frac{n(\Delta\sigma_i)}{N(\Delta\sigma_i)} \tag{8}$$

In the equation is $n(\Delta\sigma_i)$ the number of load cycle with the stress difference $\Delta\sigma_i$. $N(\Delta\sigma_i)$ is the maximum number of alternations for the stress difference $\Delta\sigma_i$. This maximum number can be read off directly from the S-N curve. Per definition the fatigue failure occurs when the dimensionless damage factor D reaches the value 1. On basis of the Palmgren-Miner-hypothesis one can define a limit-state equation for the fatigue failure (Buba 2004).

$$Z = D_R - D_S \tag{9}$$

In the context of the first building assessment the number of $0.5*10^6$ trucks is assumed as the annual volume of traffic. The annual volume of traffic is associated with the fatigue load model 4 (FLM) from Eurocode 1 (EN 1991-3 2003).

Based on a sharpening of the stochastic model for the traffic load as a result of structural health monitoring a re-evaluation of the structure is possible

The chosen load model includes five load steps which are substitutional for a damage-equivalent volume of traffic. For each load step the stress difference results from equation (10).

$$\Delta\sigma_i = f_{M\text{-}\sigma}(\max.\ M) - f_{M\text{-}\sigma}(\min.\ M) \tag{10}$$

The function $f_{M\text{-}\sigma}$ is the relationship between the bending moment and the stress in the tendon. The bridge is pre-stressed with 8 tendons per girder (Fig. 6). The post tension system using strands Dywidag AS-140mm² is installed. Figure 6: General truss model (Zilch & Rogge 2004)

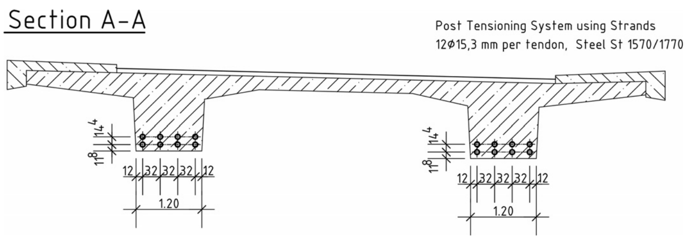

Figure 7. Bridge section

In the limit-state for fatigue failure only the prestressed tendons are considerd. Therefore the relationship ($f_{M\text{-}\sigma}$) in Fig 7 between bending moment and the stress in the tendon for bridge section (Fig 6) results.

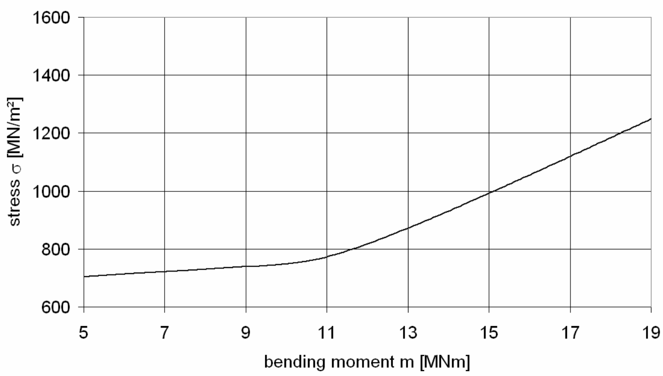

Figure 8: Moment stress curve ($f_{M\text{-}\sigma}$)

With the stress differences determined in this way the maximum number of alternations can be read the S-N curve.

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The used S-N curve is leaned against the representation in the Eurocode 2 (EN 1992-1-1 2004). For curved tendons in steel ducts the function for the maximum number of alternations is $N = e^{28,179} * \Delta\sigma^{-3}$ for a stress difference of $\Delta\sigma > 120$ MN/m² and $N = e^{47,323} * \Delta\sigma^{-7}$ for a stress difference of $\Delta\sigma < 120$ MN/m². The values are assumed as 90-percentile. Further the coefficient of variation for the maximum number of alternations is assumed as 30 %.

In the analysis for the fatigue failure the same damage function as in the analysis for the flexure failure, i.e. a cross section decrease of 10% during 10 years, is used to prognose the reliability. This is considered both for the relationship between bending moment and stress in the tendon and in the S-N curve.

4 RESULTS

4.1 *Limit-state for shear failure*

The reliability of the component shear failure is analysed with and without consideration of the pre-stressing. The analysis was independent from other components in the fault tree for the assessment shown here.

The results of the FORM/SORM reliability analysis are shown in Fig. 7. Thus it appears that the bridge is very durable in the support range. The safety index β is sufficient in the limit-state for the failure of both the ties and the concrete compression struts.

After a failure of the tendon anchorage assembly the beneficial effect for the shear capacity by the pre-stressing can't be considered.

The FORM/SORM reliability analysis for this case shows that the structure has still a large safety margin concerning shear failure at the support.

4.2 *Limit-state for flexure failure*

The FORM/SORM reliability analysis for the flexure failure was accomplished on the assumption of a corrosive degradation of the reinforcement.

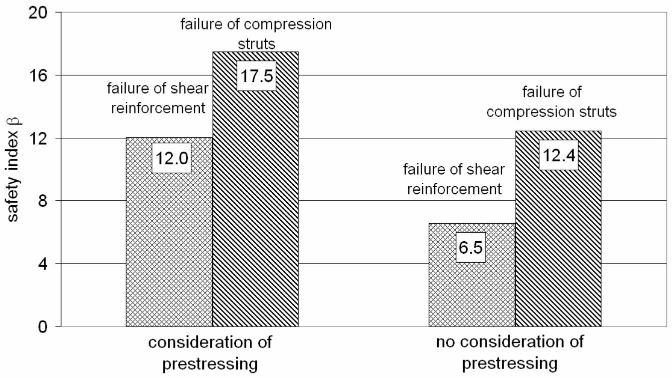

Figure 9: Shear failure, FORM/SORM results

Under these conditions the results explained in Fig. 8 can be obtained. The figure shows the trend for the safety index β and the probability of failure p_f (p_f=Φ(-β)) for 10 years after the initial corrosion. The safety index β (probability of failure p_f) is perfectly sufficient at the beginning and decreases hardly in the regarded time frame. With these results a sudden failure by exceeding the flexure capacity is not expected.

4.3 *Limit state for fatigue failure*

According to the view of the safety level for the flexure capacity during a defined duration also the safety level against fatigue failure was prognosticated.

The safety index β and the probability of failure p_f (p_f=Φ(-β)) are shown in Fig 9 for a time of 10 years.

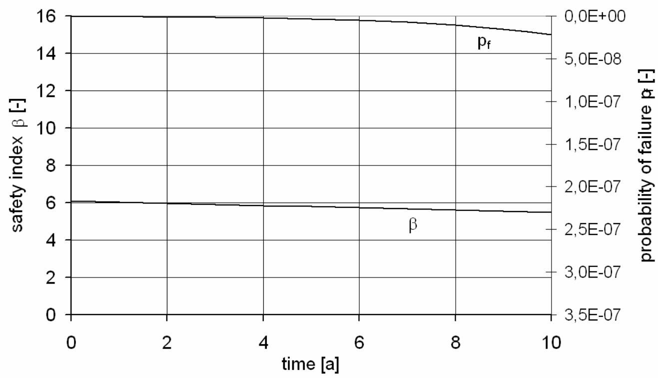

Figure 10: Flexure failure, FORM/SORM results

By increasing the load cycles the damage factor D grows and consequently the safety index β decreases. Without consideration of a damage or additional actions for the tendon the value of the safety index β and respectively the probability of failure is acceptable not only for the time of 10 years but also for 100 years.

With consideration of the represented damage it comes to a reduction of the safety level, which leads to the fact that after 10 years rehabilitation measures are needed. Due to the strong reduction of the safety level it appears meaningfully to start with preventive rehabilitation measures earlier than after 10 years.

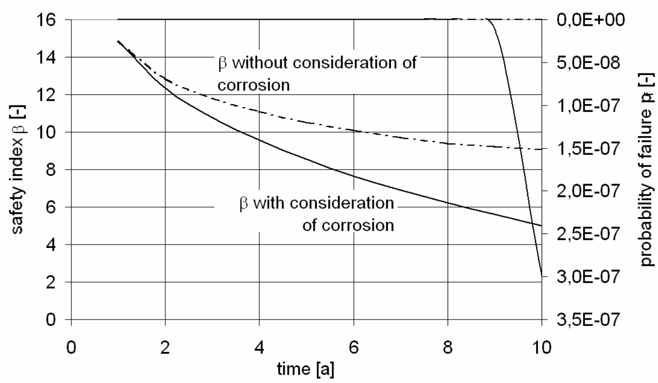

Figure 11: Fatigue failure, FORM/SORM results

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Beside the consideration of a damage for the prognosis of the safety level of individual components, a building evaluation with continuously measured values from the structural health monitoring is necessary, in order to make further decisions concerning the monitoring and maintenance.

4.4 *Evaluation of the results*

On the basis of different components in the system bridge, the modeling and reliability analysis of limit-states was shown. Due to these few results consequences for the further structural health monitoring already become apparent.

After an assumed failure of the tendon anchorage assembly the safety index β for shear failure decreases, however an acute danger does not exist.

The decrease of the safety level for flexure failure was very small, so that a sudden failure does not have to be assumed. Here it is meaningful to use decision making aids to define measuring intervals, in order to compare the prognosis with the current building condition

With the limit-state for fatigue failure the comparison between the prognosis and the current building condition is necessary, since the safety index β drops very strongly.

5 CONCLUSION

In this contribution the application of the building inspection and assessment system PROBILAS using a bridge as an example was shown. Especially the durable bearing capacity is regarded.

First the probabilistic model of the building in form of a fault tree was generated and subsequently the modeling of the limit-states was shown at selected components.

For the set up of the limit-state equations and the specification of the stochastic model for the parameters the system PROBILAS will reproach sample data sets. These example data sets can be adapted user-specifically. Beside the specification of the limit-state equations the probability of failure, e.g. for the failure of the tendon anchorage assembly, can be indicated directly as numerical value.

The independent assessment of individual components was possible under the precondition that the individual components are not correlated.

From the results the weak points can be identified, which have to be monitored with priority. Due to the prognosis represented here measuring intervals can be specified using decision making aids which will be developed. These decision making aids are Part of PROBILAS just like sample data sets and will help to optimize the structural health monitoring.

6 ACKNOWLEDGMENTS

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Risk assessment in disaster recovery strategies development

A. Galach
Polish-Japanese Institute of Information Technology, Warsaw, Poland

Z. Kotulski
Polish Academy of Sciences, Institute of Fundamental Technological Research, Warsaw, Poland &
Warsaw University of Technology, Faculty of Electronics and Information Technology, Warsaw, Poland

ABSTRACT: The paper describes the model for selecting disaster recovery strategies for information system. The risk assessment covers the threats and vulnerabilities related to the problem of losing the availability of information processes in the particular information system model. The analysis takes under consideration the relationships between the components of information system in order to find the risk of availability lost propagation within the system. That is the basis for finding the candidate disaster recovery strategies, which have to fulfil these basic requirements. Such an approach allows sifting these ones, which are basically not suitable for the security requirements of the information system. The preliminary accepted strategies are to be analyzed regarding to the estimated cost of implementation and maintenance. The next phase covers the detailed analysis of confidentiality and integrity risks in the candidate strategies. The level of risk related to the confidentiality and integrity of information processed in the disaster situation using given strategy is to be estimated.

1 INTRODUCTION

The business continuity management is recognized as the very important success factor for the nowadays organization. The need for planning the business operations in the disaster scenario, when there is a lack of some of basic resources availability, was recognized especially after September 11th, 2001. According the survey conducted in Australia during 1999 and 2000 (HB221 2003) 65% of business organizations and 71% of councils reported, that the acceptable downtime is shorter than 24 hours. That data can be extrapolated on the organization outside Australia as well, remembering, that the survey took place before the WTC disaster, so nowadays the awareness of the business continuity need may be much higher.

The contingency of business processes relies very strongly on the availability of information and the ability to process it. The information system is the bloodline of the nowadays enterprise, therefore the assurance of the system services availability is absolutely critical. The reported case of Omega Engineering (Gaudin 2000), where the disgruntled administrator destroyed the data stored in IT system leading to the $10 million loss and the layoff of 80 workers. It should be noted that these disaster caused the significant problem for the company, its employees and customers. It is hard to imagine what the impact could be caused by similar disaster in the information system supporting utilities or the SCADA system supporting powerplant steering.

The facts described above lead to the conclusion, that nearly every organization shall consider undertaking the activities increasing the abilities to survive the disaster situation. The result of these activities shall include implementation of the strategy allowing to continue business and recover the company from the disaster, as well as the plan describing what to do in the disaster situation to continue the critical processes and recover the company. Generally, the strategy describes the approach of the organization to the business continuity and recovery issue, while the plan precisely describes the activities, which shall be undertaken in the disaster situation. The plan depends very strongly on the strategy, therefore choosing and implementing the proper disaster recovery strategy is a vital part of business continuity management.

2 DISASTER RECOVERY STRATEGY

The aim of the disaster recovery strategy development and implementation is to assure that it will be possible to rebuild the ability of the organization to conduct processes if the disaster happens. Analysing the possible solutions for the disaster recovery strategies (Hiles 2004) the four basic options, presented on the diagram below, exist:

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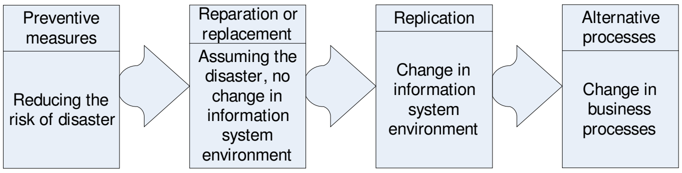

Figure 1. Relations between the approaches to the disaster recovery strategy.

Considering the disaster recovery strategies for information system the additional factor depicting the information protection requirements shall be analyzed. According the ISO/IEC 17799 standard (ISO 17799 2000) the data security consists of three elements: confidentiality, integrity and availability. Basically, the disaster recovery strategy assures the availability of information and the information processing. However, the strategy choice and further implementation shall assure the confidentiality and integrity of the information on the level, which is acceptable from the organization point of view.

3 MODELING THE SYSTEM AVAILABILITY

Further analysis of the disaster recovery strategy selection process requires defining the model of the information system availability, which could allow modelling the strategy. Such a model can be based on a reliability network concept (Dhillon 1999).

In the following part of the paper we will semi-formal define the serial, parallel and independent (being an extension of pure reliability network) elements of the network depicting the information system. Every unit of the network may depict the asset in the information system, as listed in (ISO 13335-3 1998).

Definition 1. Let us take the reliability network R for the given information system I. We say that two units U_1 and U_2 are serial and U_1 is over U_2 when A_2 can be available if A_1 is available where U_1 represents the asset A_1 and U_2 represents the asset A_2.

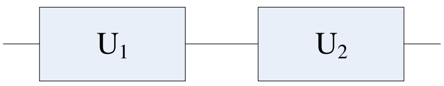

Figure 2. An example of serial units

Definition 2. Let us take the reliability network R for the given information system I. We say that two units U_1 and U_2 are parallel when the A_1 can be used instead of A_2 and vice versa where U_1 represents the asset A_1 and U_2 represents the asset A_2.

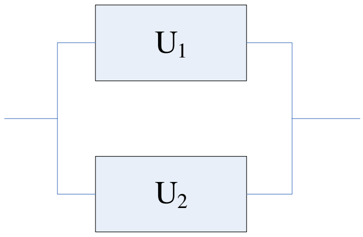

Figure 3. An example of parallel units

Definition 3. Let us take the reliability network R for the given information system I. We say that two units U_1 and U_2 are independent when they are neither serial nor parallel.

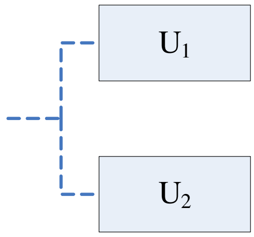

Figure 4. An example of independent units

The next issue would be to analyze the recovery time of the system depicted by the reliability network required in the case failure of the network unit. In the case of serial network $R_s=P(U_1 \ldots U_i \ldots U_n)$ the time for the network recovery $t_R(R_S) \leq \max\, t_R(U_i)$ where $i=1 \ldots n$, if the failure of the particular unit does not cause the failure of other unit.

Definition 4. Let us take the reliability network R for the given information system I. Let the network R consists of two units: U_1 and U_2. Let unit U_1 represent asset A_1 and unit U_2 represent asset A_2. Let U_1 and U_2 be serial and U_1 be over U_2. We say that U_1 propagates failure to U_2 if in a case of failure of A_1, the failure of A_2 occurs.

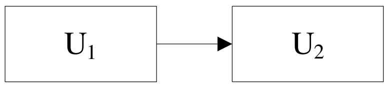

Figure 5. An example of failure propagation

Definition 5. Let us take the reliability network R for the given information system I. Let the network R include the unit U_1 representing asset A_1. We say that unit U_1 is confidentiality oriented if A_1 is either a safeguard protecting a confidentiality of information or includes safeguard protecting a confidentiality of information.

Definition 6. Let us take the reliability network R for the given information system I. Let the network R include the unit U_1 representing asset A_1. We say that unit U_1 is integrity oriented if A_1 is either a safeguard protecting integrity of information or includes safeguard-protecting integrity of information.

Definition 7. Let us take the reliability network R for the given information system I. Let the network R include the unit U_1 representing asset A_1. We say

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that unit U_1 is information unit if A_1 is an information or set of data.

Definition 8. Let us take the reliability network R for the given information system I. Let the network R include the unit U_1 representing asset A_1. We say that unit U_1 is information processing unit if A_1 process the information.

Definition 9. Let us take the reliability network R for the given information system I. Let the network R include the unit U_1 representing asset A_1. We say that unit U_1 is supporting unit if A_1 is neither information nor set of data nor process the information.

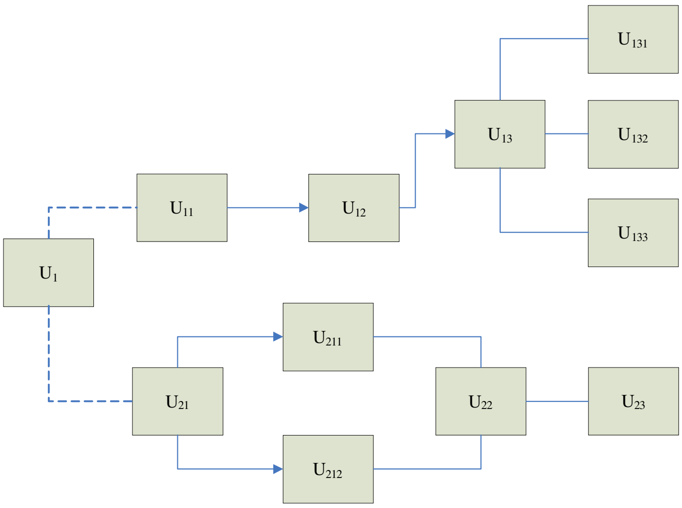

Figure 6. An example of more complex reliability network

4 MODELING THE DISASTER RECOVERY STRATEGY

The disaster recovery strategy describes the approach of the organization toward the recovery of the critical information processing in the disaster situation. The possible solutions within a disaster recovery strategy are described in chapter 2 of this paper. Here we consider how the model described in the previous chapter could be used to represent the disaster recovery strategy. If the strategy bases on the replication the reliability network could directly represent that as the parallel units.

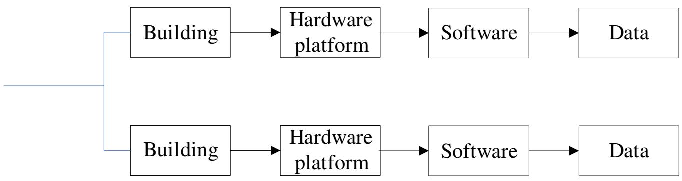

Figure 7. An example of replication strategy description

The replication, although the safest from the availability point of view, could lead to some risks, including:

– The situation, when the back-up infrastructure is not able to take over the tasks of the basic infrastructure
– The problem with data replication, leading to the lack of consistency, which makes the integrity loss
– The problem with confidentiality protection – the data shall be protected according the confidentiality requirements in the basic system as well as in the back-up system
– Another problem with confidentiality protection – the data has to be replicated, that makes the requirement of protecting the confidentiality of the data between the basic and backup infrastructure

If the replication strategy is taken under consideration the switching time between the basic system and the backup system shall be analyzed. It is also worth to note, that in our discussion we consider backup centre as dedicated to take over the tasks of basic infrastructure in a case of disaster. It not necessary has to be true: you can imagine the situation when the backup centre is in practice used in non-disaster situation for supporting some processes and, in a case of disaster, these processes are either suspended (and backup is used to support most important processes) or continued (and backup is used to support both groups of processes). That can have a significant impact on the performance of the whole system, however, that case will not be further analyzed in that paper.

Reparation or replacement as the disaster recovery strategy does not have a direct impact on the reliability network presenting the system. However, the following issues shall be analyzed

– The time required for the reparation or replacement
– The risk related to the reparation or replacement, describing the unsuccessful activity or the situation when the activity is not possible
– The risk related to the loss of confidentiality or integrity of information. That can be caused by various factors, including lack of competences, untrusted staff, etc.

Analyzing the reparation or replacement strategy from the availability point of view the time required for the reparation or replacement shall be considered.

Another strategy bases on the possibility of performing some business processes in other way. In fact, that means, that in the disaster situation another resources can be used to enable process performance. This strategy can be depicted as switching from one reliability network to the other reliability network, while some elements of both networks are common. Let us call the reliability network depicting the resources used in the non-disaster situation as the basic network and the resources used in the disaster situation as the alternative network.

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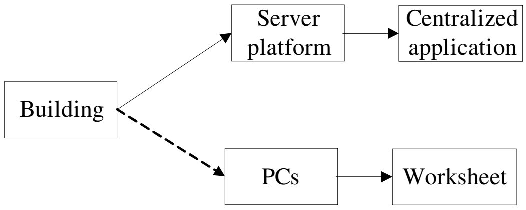

Figure 8. An example of basic and alternative network

This strategy can lead to some risks, including the following:

- The switching time between the basic infrastructure and alternative one can be not acceptable from the organization's point of view
- The alternative resources may not be able to take over the tasks of basic one in the disaster situation at all
- The data has to be replicated to the alternative resources, that can make additional problems with integrity, especially because the other platform is used
- As the provisional resources are used, the confidentiality safeguards may be much weaker than in case of basic resources - in fact the confidentiality protection may be not relevant to the requirements of the organization
- Some integrity assuring mechanisms present in the basic resources may be not present in the alternative ones (an example could be the relational database system, where the integrity is assured by built in mechanisms, which can be replaced in the disaster situation by worksheet personal application where the integrity assurance mechanisms are hardly comparable

The last approach to the disaster recovery strategy presented in the chapter 2 is using the preventive measures. They reduce the probability of the disaster, however considering them the following issues shall be analyzed:

- The impact of these measures on the system performance (it may appear, that, although the measures reduce the disaster probability, they have the negative impact on the system performance, and therefore are not acceptable from the availability point of view)
- The impact of these measures on the confidentiality and integrity of information – if this impact is negative and the level of confidentiality and/or integrity protection is below the acceptable one either another measure shall be considered or the additional one improving the confidentiality and/or integrity shall be implemented.

The issues initially described above include the problems related to the availability of the system services and information, confidentiality and integrity of data resources. However, the disaster recovery strategy selection shall take under consideration the cost of strategy implementation and maintenance. This could include:

- Solution analysis
- Implementation analysis
- Integration with the existing infrastructure
- Environment assurance
- Preparing business contingency plans basing on the selected strategy
- Training
- Data synchronization
- Technical components maintenance
- Monitoring and change management
- Upgrading

5 FINDING THE OPTIMAL DISASTER RECOVERY STRATEGY

The proposed method of finding the disaster recovery strategy for the given information system uses two stages of risk assessment process and the calculation of the cost of implementation and maintenance for the strategy. The strategy selection process can be therefore described in the following steps:

- Risk assessment stage 1 – stress on availability
- Cost assessment
- Risk assessment stage 2 – stress on confidentiality and integrity

Let us assume the information system I which is described by reliability network R. Due to the tasks performed by the system I it is assumed that maximal tolerable downtime for the system I is T.

Definition 10. Let us take the reliability network R for the given information system I. Let the network R include the unit U_1 representing asset A_1 which can be either repaired or replaced. The t_1 is the reparation time for unit U_1 if A_1 can be either repaired or replaced within a time not greater than t_1.

Definition 11. Let us take the reliability network R for the given information system I. Let the network R include the parallel units U_1 and U_2 representing assets A_1 and A_2. The $t_{1\to2}$ is the switching time if the A_2 can fully take over the tasks of A_1 in the time not exceeding $t_{1\to2}$.

Definition 12. Let us take the reliability network R for the given information system I. Let the network R include the unit U_1 representing the asset A_1. The p_1 is the downtime probability for the U_1 if the probability that A_1 is not working is p_1.

The aim is to find the availability requirements for the system I. In order to analyze such requirements we make the following assumptions:

- The reparation or replacement capabilities for any two assets are independent, what means that resources for reparation or replacement are not limited
- In the case of failure propagation, the time t_p between the failure of asset A_1 propagating the failure to asset A_2 and the failure of asset A_2 is such that $t_p \to 0$.

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Now the availability for various information systems is analyzed.

Case 1. Pure serial network

The case which is analyzed at first is the situation when the network R representing the system I is the serial one. There are neither parallel units nor independent units in the network. We also assume there is no failure propagation in the network R. For every unit U in the network R the risk function F(p,t) is defined, where p is the downtime probability for unit U and t is the reparation time. If $F(p,t)>F_R$ where F_R is the acceptable availability loss risk level, than the disaster recovery strategy shall cover reducing the risk of availability loss of unit U or define the way of conducting processes such, that unit U is not required. Summing up, in a pure serial network the result of availability analysis in risk assessment stage 1 is the list of units for which the availability loss risk level is above the acceptable level.

Case 2. Serial network with failure propagation

This case covers the situation when at least one asset propagates the failure to at least one other asset. This can be described using the reliability network R. Let the unit U_m propagates the failure to units U_{sk} where $k\in\{1,..,n\}$. Let p_m is the downtime probability for the unit U_m, t_m is the reparation time for unit U_m, t_{sk} is the reparation time for unit U_{sk}. As in Case 1, the risk function F(p,t) is defined for every unit U, that is $F_m(p_m,t_m)$ for unit U_m and $F_{sk}(p_m,t_{sk})$ for unit U_{sk}. If

$$\max\{F_m(p_m,t_m), \max_{k=1}^{n}[F_{sk}(p_m,t_{sk})]\} > F_R,$$

where F_R is the acceptable availability loss risk level, than the disaster recovery strategy shall cover reducing the risk of availability loss of unit U_m or define the way of conducting processes such, that unit U_m is not required.

Some remarks regarding the reliability network with failure propagation shall be described here. The analysis presented above allows finding out if the given unit propagating the failure shall be covered by the disaster recovery strategy. Such an approach forces to review all units on which the failure is propagated; however that could be optimized in real life implementation. The another point is the fact that the formula presented above is the recursive one, which allows to find the units which must be covered by disaster recovery strategy, which are both the propagating ones and on which the failure is propagated.

The approach described above assumed it is sure that the failure of U_m causes the immediate failure of U_{sk}. However, such a situation does not have to happen. The value $p_{m,sk}$ can be defined as the probability of situation that unit U_m fails and unit U_{sk} fails as well. The condition $p_{m,sk}\leq p_m$ is obvious. The formula presented above shall be changed to the form:

$$\max\{F_m(p_m,t_m), \max_{k=1}^{n}[F_{sk}(p_{m,sk},t_{sk})]\} > F_R.$$

Case 3. Parallel units

The parallel network case could be the most interesting one because it describes the situation of assets replication, which is quite often used as a basis for the disaster recovery strategy. The analysis shall cover the following issues:

– The time necessary for switching between the units (when the unit takes over the tasks of failed parallel one)
– The time required to process the information if one of the parallel units is failed
– The risk of failure of some or all parallel units (worst scenario)

Let the reliability network R represent an information system I. There are two parallel units U_1 and U_2 in the network. The unit U_2 is able to take over the tasks of U_1 within the switching time $t_{1\to2}$. If p_1 is the downtime probability for U_1, than the availability requirements are satisfied if $F_1(p_1,t_{1\to2})\leq F_R$ where F_1 is the risk function for unit U_1 and F_R is an acceptable availability risk level. In other situation the disaster recovery strategy shall cover units U_1 and U_2. That condition may be extended to more complicated system, where the number of parallel units is present. Let the parallel units $U_1,\ldots,U_n$ be the components of reliability network R. The downtime probability $p_{1,\ldots,k}$ is the probability that units $U_1,\ldots,U_k$ fail, while within the switching time $t_{1,\ldots,k\to k+1,\ldots,n}$ the assets $A_{k+1,\ldots,n}$ represented by units $U_{k+1,\ldots,n}$ take over the tasks of the assets $A_{1,\ldots,k}$ represented by units $U_{1,\ldots,k}$. The availability requirements are satisfied if

$$\max_{i=1}^{k}[F_i(p_{1,\ldots k},t_{1,\ldots,k\to k+1,\ldots,n})] \leq F_R,$$

where F_i is the risk function for the unit U_i.

The analysis presented above does not take under consideration the performance of the assets. It is assumed that the taking over the tasks in a case of failure of an asset does not have a negative impact on information processing. Such a situation may appear if there is a backup asset "waiting" for a failure of a basic asset. This is presented on the following picture – in normal circumstances unit U_1 works while unit U_2 is a backup one "waiting" for a failure of U_1.

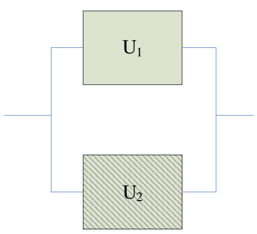

Figure 9. Basic and backup unit configuration

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However, there could be a situation when the asset, in addition to its task, takes over the task of the failed asset. According to (PAS56 2003) such a situation can be described by

- Active/active model – there are some production sites (assets), each of the production site can be a backup for other production site
- Alternate site model – there is a backup site (asset) that periodically functions a primary site

Let the parallel information processing units $U_1,\ldots,U_n$ be the components of reliability network R. Let $t_{1,\ldots,n}$ be the time required to perform given operation having assets represented by units $U_{1,\ldots,n}$, and $-\Delta t_{1,\ldots,k\Rightarrow k+1,\ldots,n}$ describe the negative impact on time required to perform given operation if assets represented by units $U_{k+1},\ldots,U_n$ takes over the tasks of the assets represented by units $U_1,\ldots,U_k$.

Analyzing the time requirements the backlog phenomenon shall be considered (HB221 2003). As the switching time $t_{1,\ldots,k\rightarrow k+1,\ldots,n} > 0$ there are some operations which should be performed within that switching time but have not been performed. These operations shall be performed after switching, which could cause an additional delay $-\Delta t^B_{1,\ldots,k\Rightarrow k+1,\ldots,n}$. If, due to the requirements analysis, given operation shall be performed within the maximal time T the following condition shall be satisfied:

$$T> t_{1,\ldots,n} -\Delta t_{1,\ldots,k\Rightarrow k+1,\ldots,n} -\Delta t^B_{1,\ldots,k\Rightarrow k+1,\ldots,n}- t_{1,\ldots,k\rightarrow k+1,\ldots,n}$$

Case 4. Independent units

The reliability network containing the independent units can be transformed into the reliability networks without the independent units. Such networks can be analyzed according the availability requirements using the cases described above.

The risk function being the basis for availability requirements fulfilment evaluation can be tailored depending on the asset type and risk assessment methodology used. Generally that function shall fulfil two basic requirements:

- The value of function increases while the time being the argument of the function increases. That means that risk of losses caused by the lack of availability increases
- The value of function increases while the probability being the argument of the function increases. That means that the value of risk increases

The time of unavailability is proportional to the loss caused by unavailability; the proportion is typical for the given assets and that shall also be depicted in the risk function. The function can be used while the continuous values for probability and time are used, that is $p\in<0,1>$, $t\in R$, but also if the risk assessment is performed using the failure modes (Dhillon 1999), when the probability and time are discrete, that is $p\in P$, $t\in T$ and P, T are the sets containing the finite number of discrete values. The risk function can, in such a case, be based on models proposed in standards, like (ISO 13335-3 1998) or (AS/NZS 4360 2004). However, the models presented in standards use probability of the loss (or frequency of the loss) and the value of loss, so the relation between the downtime and the value of loss shall be found.

The discussion above covers the analysis of availability requirements – the aim was to find the components of the information systems, which availability is not high enough so they shall be covered by a disaster recovery strategy. The disaster recovery strategy could be depicted using the reliability networks.

Case 1. The reliability network preserves the structure.

This is the situation when the number of assets and the relations between assets are the same as before the disaster recovery strategy was implemented. However, the availability risk for the assets is reduced. It can be reached by decreasing the reparation time or replacing the assets by more reliable ones.

Definition 13. Let $F_1(p,t)$ be the risk function for the asset A_1 and $F_2(p,t)$ be the risk function for the asset A_2. Asset A_1 is more reliable than asset A_2 if $F_1(p,t)<F_2(p,t)$.

Case 2. The reliability network is changed.

This is the situation when either the assets are duplicated or some additional assets (eg. safeguards) are implemented.

Case 3. There is a reliability network in normal situation and another reliability network for the disaster situation.

This is the situation when some processes are performed alternatively in the disaster situation. The basic and alternative reliability networks describe the information system and the change during the disaster.

The preliminary set of disaster recovery strategies includes the reliability networks, which are the candidates for the network describing the final disaster recovery strategy. The networks shall fulfil the following requirements:

- The availability loss risks shall be smaller or equal to acceptable availability loss risk
- The time required for performing the given operation using an information system shall be smaller than maximal acceptable time
- The confidentiality protection shall be sustained
- The integrity protection shall be sustained

The first requirement is to be fulfilled by transforming the network R_1 to network R_2 changing the structure of the network or assets such that the availability risk is decreased to or below the acceptable risk level. The second requirement deals with the performance issue. The problem was already analyzed for the parallel units. The negative impact may

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happen also when the assets are exchanged (more reliable assets are used) or if the safeguards are implemented. Let A_1' be the asset replacing the asset A_1, U_1' be the unit representing the asset A_1' and U_1 be the unit representing the asset A_1. Let U_1' and U_1 be information processing unit. Let T be the maximal time for performing the given operation by assets A_1' or A_1. If t_1' is the time required for performing the given operation by asset A_1' it is obvious that $T>t_1$' It may be also a situation when the asset has an impact on performance of another asset.

Definition 14. Let us take the reliability network R_1 for the given information system I_1 and the reliability network R_2 for the given information system I_2. Let the network R_1 contain unit U_1 being an information-processing unit and do not contain unit U_2. Let the network R_2 contain units U_1 and U_2. Let unit U_1 represent asset A_1 and unit U_2 represent asset A_2. We say that U_2 is an inhibitor for U_1 if the time required for performing the given operation for the asset A_1 in information system I_1 is $t_{1,\text{ in}}$ information system I_2 is t_2 and $t_1<t_2$.

If the reliability network is changed – new units are added or the units are exchanged it shall be analyzed if any new unit U_1 is an inhibitor for any information processing unit U_2 and when it is it shall be assured that $t_2<T$, where T is maximal time acceptable for performing given operation and t_2 is the time required for performing given operation by the asset represented by the unit U_2.

The preliminary disaster recovery strategy selection shall take under consideration also the some issues related to confidentiality and integrity.

Definition 15. Let us take the reliability network R_1 for the given information system I_1 and the reliability network R_1' for the information system I_1'. The information system I_1' emerged as the result of implementation of given disaster recovery strategy into the information system I_1. Let the network R_1 contain unit U_1 and the network R_1' contain units U_1'. Let unit U_1 represent asset A_1 and unit U_1' represent asset A_1'. The asset A_1' emerged as a result of implementing disaster recovery strategy on asset A_1. We say that U_1' is the transformation of U_1 by the given disaster recovery strategy.

Let unit U_1 in the given reliability network R is the confidentiality oriented. R' is the reliability network depicting the information system after the disaster recovery strategy implementation. Unit U_1' being the transformation of U_1 in R' shall be confidentiality oriented as well. That assures that assets in the transformed information systems still protect the confidentiality of information. It may happen the replication approach is used. Unit U_1 is transformed to the number of units $U_1^{(1)}\ldots U_1^{(n)}$. Every unit $U_1^{(i)}$ where $i\in\{1,\ldots,n\}$ shall be the confidentiality oriented unit. The same approach shall be used in the case of integrity protection. The problem how strong the confidentiality and integrity is protected is analyzed more precisely in the second phase of risk assessment.

The next phase of the selection process covers the analysis of the cost requirements. As described in chapter 4 the cost of disaster recovery strategy covers both the implementation as well as further maintenance. The following conditions have to be fulfilled:

$$B > C_A + C_I + C_O$$
$$B_A > C_M + C_{OM}$$

where

- B – budget dedicated for disaster recovery strategy implementation
- C_A – cost of analytical work
- C_I – cost of technical implementation
- C_O – cost of organizational implementation
- B_A – annual budget for the strategy maintenance
- C_M – annual cost for the technical maintenance
- C_O – annual cost for the organizational maintenance

The cost of the disaster recovery strategy is proportional to the assured level of availability. It may appear that the strategies fulfilling the availability requirements are too expensive – that forces the return to the previous analysis phase with the relaxed requirements for the availability. That approach is based on a modified waterfall model (Krutz et al. 2001).

The third phase of the selection process deals with the specific requirements of the information system – the confidentiality and integrity protection.

Let us take the reliability network R representing the given information system I. Let U_I be the information unit in the network R. We define the confidentiality risk function $F_{CI}(R)$ for the given information unit U_I. The function $F_{CI}(R)$ shall possess the following capabilities:

– It shall be considered the threat related to any unit in network R if it has an impact on the confidentiality of information represented by U_I
– It shall be considered the confidentiality safeguard capabilities of any unit in network R if it reduces the probability of exploiting the threat related, directly or indirectly, to unit U_I
– If the unit U_I is replicated it shall be considered the impact of replication on the information confidentiality
– The relation between various threats and relation between various safeguard shall be considered

The first point can be analyzed using recursive approach. The list of threats is created for given unit (initially U_I) and all units being over that unit.

The next point is to analyze the confidentiality protection. In order to find the level of protection only the confidentiality-oriented units are to be taken under consideration. The recursive approach has to

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be used again. However, the units, which are not confidentiality oriented, may be dropped. The following formula for estimating probability of exploiting given threat T having impact on the unit U_I is suggested:

$$E_T(U_I) = \max_{i=1}^{n}[E_T(U_i)]$$

$$E_T(U_i) = \min\{\varepsilon_T(U_i), \max_{j=1}^{m}[E_T(U_j)]\}$$

where:

$E_T(U_I)$ – probability of loosing confidentiality of information asset represented by U_I as a result of occurring threat T

$E_T(U_i)$ – probability, that neither U_i nor any unit being over U_i does not protect against threat T

$\varepsilon_T(U_i)$ – probability, that unit U_i does not protect against threat T

If the information asset U_I is replicated some confidentiality problems related to the synchronization process may appear. Depending on reliability network model they may be addressed in the analysis already described above, but may also require additional attention.

There may be more complicated relations between threats or relations between safeguards. Such relations may be depicted using tools like fault trees analysis (Fullwood et. al 1988*)* or the model presented in OORAM - Object-Oriented Risk Assessment Model (Galach 2002).

The similar approach as presented above may be used for integrity risk assessment. After the confidentiality and integrity risk assessment the value of confidentiality risk function $F_{CI}(R)$ and integrity risk function $F_{II}(R)$ is known. They shall fulfil the following requirements

$F_{CI}(R)<R_{CI}$
$F_{II}(R)<R_{II}$

where R_{CI} is an acceptable confidentiality risk level for the given information, while R_{II} is an acceptable integrity risk level for the given information.

6 SELECTING THE STRATEGY FOR THE SCADA SYSTEM

The SCADA systems play a significant role as a lifeline infrastructure steering component. The availability requirements for such a system are obviously very high. The integrity assurance is required in order to allow the proper work of the system. The confidentiality of the information is still required as well. According to (Stamp et al 2003) the cyber attack is the serious threat for the SCADA system. Beside the implemented safeguards the disaster recovery strategy shall be implemented in order to assure the sustain work of the system. The approach presented in this paper allows finding the disaster recovery strategy for such a system. Some features make selecting of the strategy easier, e.g.:

– Reliability network allows to model the complex relation within the SCADA system as well as the interfaces to the non-IT components
– Defining availability requirements separately for the information assets allows to model different requirements for various information starting from the real time processing up to the archive
– Confidentiality and integrity risk assessment covers only the elements which have the real impact on the information protection – this can be very useful in the case of SCADA being on the border between the IT and automation.

The reliability network schema for the real SCADA system may be very complex, however, the presented approach can improve the disaster recovery strategy selection process.

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On scalable security model for sensor networks protocols

B. Księżopolski
Faculty of Mathematics, Physics and Computer Science, M. Curie-Skłodowska University, Lublin, Poland

Z. Kotulski
Polish Academy of Sciences, Institute of Fundamental Technological Research, Warsaw, Poland &
Warsaw University of Technology, Faculty of Electronics and Information Technology, Warsaw, Poland

ABSTRACT: Distributed sensor networks meet many different barriers that reduce their efficient applicability. One of them is requirement of assurance of the information security when it is transmitted, transformed, and stored in the electronic service. It is possible to provide an appropriate level of security applying the present-day information technology. However, the level of the protection of information applied to the whole network is often much higher than it is necessary to meet potential threats. Since the level of security strongly affects the performance of whole system, the excessive protection decreases the system's reliability and availability and, as a result, the global security of the construction. In this paper we present a model of scalable security for digital information transmission systems for the sensor network. In our model the basic element is the risk management procedure leading to an adequate protection level.

1 INTRODUCTION

Advanced teleinformatic technologies nowadays provide a wide range of possibilities of development of industry or the institutions of public services. The big stress is put on the development of well-available information services called "e-everything", like: e-government, e-money, e-banking, e-construction. These mentioned processes are fulfilled mainly by electronic way, thanks to which one can increase their availability, efficiency, and reliability, decreasing simultaneously the expenses of functioning.

Implementation of the public/firmware services is connected with the proper level of security of information exchanged between the parties of protocols realizing their main functions. Among teleinformatic technologies and cryptographic modules there are ones protecting different information security services, e.g.: confidentiality, integrity, non-repudiation, and anonymity of data (both, anonymity of the origin or destination of the data). The important problem seems to be the establishing the level of information security satisfied by the services in a given protocol. Every use of any network service is connected with information exchange, which in the case of successful attack causes different threats to the whole process. Estimation of the security levels for each phase of the communication or cryptographic protocol could help in solving this problem. However, such an approach seems to be only a partial solution, because thanks to a given service one can send information of different level of threats. A common practice is to use exaggerated tools of information security, which decrease an efficiency, system availability and introduce redundancy. Another effect of exaggeration of the security mechanisms is increasing the system complexity, which later influences implementation of a given project in practice, especially increasing expenses and decreasing efficiency.

The solution of this inconsistency seems to be the introduction of scalable security model, which can change security level depending on particular conditions of a given case. In the paper a mechanism, which can modify the level of information security for each phase of a protocol, is presented. Parameters, which influence modification of the security level, are: the risk of successful attack, probability of successful attack and some measures of independence (leading to completeness) of security elements. The used security elements, which take care of the protection of information, are based mainly on PKI (Public Key Infrastructure) services and cryptographic modules.

As an additional aspect of the scalable security model, especially dedicated to the sensor networks security and reliability, we consider the scalable security through the networks' topology. We introduce a certain core sub-network with higher protection and cross-validation mechanisms to detect incidents wherever in the network. This is especially important in wireless networks with probable natural alternate communication breaks and restorations.

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2 SECURITY SERVICES

In practice, realization of electronic processes is connected with fulfilment of many technological, legal and formal standards. While projecting the systems we can take care of different security services (Lambrinoudakis et al. 2003, NIST 2004). Among them we can specify: confidentiality of data, integrity of data, anonymity (or, more generally, privacy) of parties of the protocol, non-repudiation of senders and recipients, authorization of data and entities, secure data storage, management of privileges, public trust, freshness. Every security service has got its own characteristics (see Table 1).

Table 1: Characteristics of security services.

Group of services	Name of services	Characteristics
Integrity	*Integrity of data*	Guarding against improper information modification or destruction
Non-repudiation	*Non-repudiation of action*	Non-repudiation of sending the message
	Non-repudiation of sender	Non-repudiation of sender's identity
	Non-repudiation of receiver	Non-repudiation of recipient's identity
Confidentiality	*Confidentiality of data*	Preserving authorized restriction on information access and disclosure
Authorization	*Authorization of parties of the protocol*	Correct authorization of parties of protocol is required to participate at the protocol
Privileges	*Management of privileges*	A function in protocol depends on the permission level
Anonymity	*Network anonymity*	Anonymity of message sender (with network anonymity)
	Anonymity of data	Anonymity of message sender (without network anonymity)
Availability	*Availability of services*	Ensuring timely and reliable access to and use of information
Public trust	*Trust between parties of the protocol*	Possibility of public verification of action in a protocol between parties of the protocol
	TTP trust (Trusted Third Party)	Possibility of public verification of action in a protocol with TTP usage
Secure storage	*Secure storage of data*	Confidential and permanent storage of information
Freshness	*Data freshness*	Data freshness implies that data is recent, no old massages are replicated
	Key freshness	Each shared cryptographic key is fresh

The system conditions, which are described by the security services, can be provided by many different security elements. To obtain appropriate security level we can use different security mechanisms. Some specific mechanisms as well as systematic reviews of the security tools can be found at the literature (Menezes et al. 1997, Anderson 2001, Groves 2001, Pietro et al. 2002, Patel et al. 2002, Chlamtac et al. 2003, Kulesza & Kotulski 2003, Hu & Sharma 2005). In this paper we concentrate on describing conditions for appropriate selection of the countermeasures adequate for a certain level of threats.

3 SYSTEM ASSUMPTION

Before we outline the model of scalable security, it is worth describing the system architecture and potential security assumption.

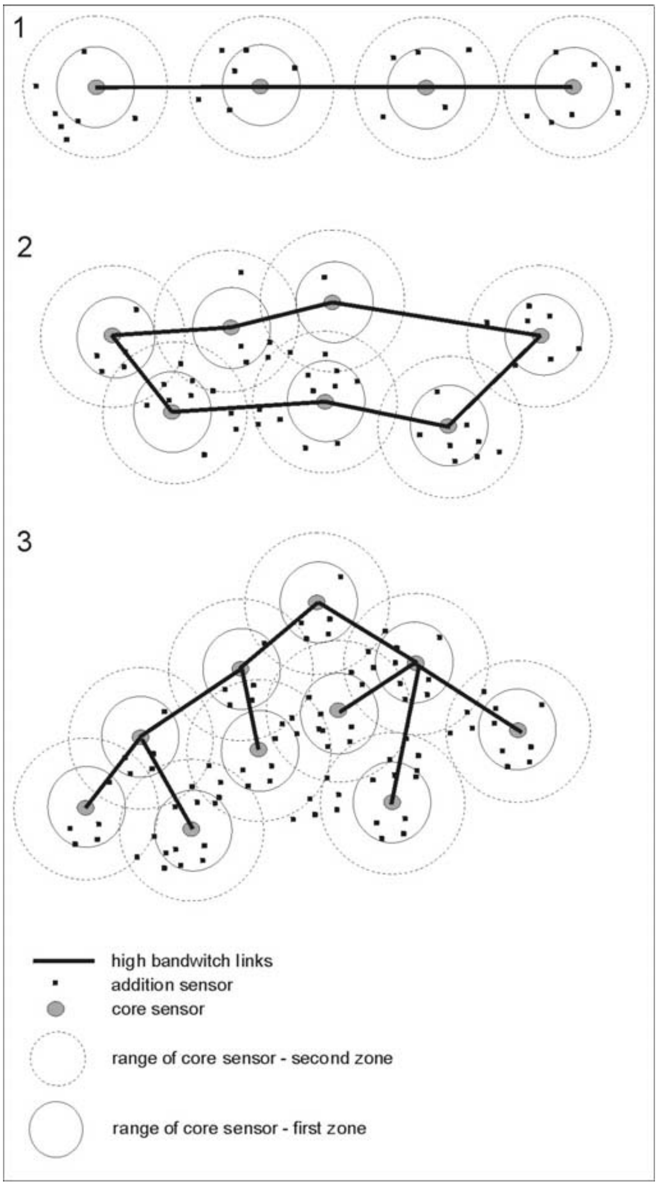

Figure 1: System communication architecture.

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3.1 *System architecture*

In this paper we consider a sensor network, which is built of two kinds of sensors: core sensors and additional sensors. The core sensors are constructed of some highly efficient devices, so they can realize all security requirements by using advanced mechanisms of information protection. The devices are linked to each other with high bandwidth network connections by means of which the data can be very fast transported between the core sensors. The core sensors are crucial in our scalable security model of security because they are responsible for the additional sensors' management.

The additional sensors sub-network is based on small devices that have limited communication and calculations possibilities. Especially, they have limited energy storage. An example of such a device that could play a role of the additional sensor is the sensor used in SmartDust (Perrig et al. 2001) program; its basic characteristics are presented in Table 2.

The communication between the additional sensor and the core sensor is performed by means of wireless network, using earlier defined communication (secure) protocols (Feeney 1999, Perrig et al. 2001, 2003).

Table 2: Characteristics of prototype SmartDust nodes

CPU	8-bit, 4 MHz
Storage	8 KB instruction flash
	512 bytes RAM
	512 bytes EEPROM
Communication	916 MHz radio
Bandwidth	10 Kilobits per second
Operating System	TunyOS
OS code space	3500 bytes
Available code space	4500 bytes

In such a network, the system communication architecture can be freely modified, see Figure 1, but firstly, the technical requirements of using communication protocol must be taken into consideration. However, they are out of scope of this paper; we implicitly assume that they give no additional constraints on the security services within cryptographic protocols.

3.2 *Security Assumptions*

In this section we specify the possible security services, which can be used at the sensor network. As mentioned above, in our security model one can distinguish two groups of sensors: the core sensors and the additional sensors. The core sensor are considered as highly efficient devices and can run any security services, which can be realized by the whole variety of information protection mechanisms (Menezes et al. 1997, Groves 2001, Patel et al. 2002, Pietro et al. 2002, Kulesza & Kotulski 2003). For the core sensors one can realize any assumptions of information protection defined in a given system.

In the case of very low efficiency of the additional sensors, the limitations on possible security services are very significant. However, using security protocols appropriate for low efficiency sensor networks, see e.g. (Perrig 2001), one can provide such security services as: system availability, authorization of sensors, confidentiality of transmitted information, and freshness and integrity of the measured data.

4 MODEL OF SCALABLE SECURITY

A successful realization of an electronic process strongly depends of the proper level of security. During the project phase of the process among others, the security mechanisms are also established. For the sake of security, they are usually overestimated in comparison to real risk. One can notice that even in the same electronic process there are differences in the pieces of information sent, their priorities and values. Thus, they are subjects of different threats, which in the case of successful attack will affect some certain parts of the security protocol. In the case of small threat there is a chance of decreasing some redundant tools of information security, what in effect can improve the system efficiency, data availability and, as a consequence, can increase the system overall security and reduce its costs of operating.

In this paper we present for the sensor network the model of two-stage scalability, containing the scalability of core and additional sensors.

4.1 *Core sensors*

Under our assumption of the practically unlimited resources of the core sensors sub-network, its scalability can be fully realized. To describe the level of security of electronic process in such a network we propose the semi-empirical formula, where the security depends on several intuitively interpreted factors. Thus, the security level can be modified by means of the proper choice of the parameters. In the presented conception of scalable security, the protection of information is a scalar quantity, which is a function of three multiplicative components, that is:

$$F_S = \sum_{i}^{a} \sum_{j}^{b} \sum_{x}^{c} (L_{ij}^{x})[\omega_{ij}^{x}(1 - P_{ij}^{x})](\frac{\omega_{ij}^{x} L_{ij}^{x}}{\omega_{ij}^{x}})^{Z} , \qquad (1)$$

where s is the security level, which is realized by a given version of protocol; i is the number of subprotocols in a given protocol; j is the number of steps of parameters in a given subprotocol; x is a concrete security service; ω_{ij}^{x} is the weight describing an av-

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erage cost of loses after a successful attack for a given service, $\omega_{ij}^{x} \in (0,1)$; L_{ij}^{x} is the value of security elements for a given service, $L_{ij}^{x} \in (0,1)$; P_{ij}^{x} is the probability of an attack on a given service, $P_{ij}^{x} \in (0,1)$; Z is a degree of convergence of security elements, $Z \in (0,25)$.

The three multiplicative factors of the Equation 1 can be interpreted as the essential security elements, namely:

The protection level: L_{ij}^{x};

The risk of attack on a given service: $[\omega_{ij}^{x}(1-P_{ij}^{x})]$;

The dependence of security elements: $(\frac{\omega_{ij}^{x} L_{ij}^{x}}{\omega_{ij}^{x}})^{Z}$.

As it is seen, in the Equation 1 every parameter from the above list is calculated for all subprotocols constituting the main protocol and for all steps included in the cryptographic subprotocols.

All these three parameters have a good interpretation based on real functioning of the electronic information system. Their values can be either estimated from behaviour of the operating system and its environment, or calculated under some hypotheses concerning threats and countermeasures.

The first parameter in the Equation 1 is a definition of the protection level for a given cryptographic service in a certain step of the subprotocol. Thus, one can create dependency of possible security elements and define for each of the others the value of the parameter *L*. For every step of the process one can select any security mechanisms. The impact of the mechanism on the security services is defined just by the parameter *L*. The total value of the parameter *L* is a sum such parameters calculated for all chosen security elements, which guarantee sufficient security level of a given service. As we assumed, for the core sensors sub-network all possible security mechanisms can be used for creating the overall security system (Księżopolski &. Kotulski 2005); it is possible due to high efficiency of the core sensors.

The second parameter shows a risk of attack on a given security service. This is a product of average losses caused by a successful attack and a probability of attack on a given security service. The parameter, which is set up for every step of the subprotocols, is the weight for particular services ω_{ij}^{x}. The weight can be changed in particular processes, because the losses due to a successful attack can be different for certain, transported information. The probability of an incident occurrence *P* is defined for all steps described by a given protocol.

The third parameter from the list describes independence of security elements used to gain a proper protection level. The security elements are somehow tied; neglecting some information protection mechanisms in the initial subprotocols strongly influences other subprotocols. The degree of convergence can also be changeable; it depends on e.g. a number of subprotocols, security level.

The security level of electronic processes mainly depends on the used elements of protection of information required by security services.

4.2 *Additional sensors*

In the considered sensor network the essential role play the additional sensors. They make possible making measurements in a huge number of spatial points, due to low cost of the sensor devices and easy sensor location. However, application of the scalable security procedure for the additional sensors is strongly constrained by technical conditions. Therefore we propose the new procedure of the security level switching in the scheme, based on the methodology, which uses the cross-validation of the results of measurements obtained, by the core sensors and the additional sensors. We assume that the results obtained from the core sensors are reliable (due to their cryptographic protection sufficient at actual environmental conditions). The measurements obtained from the additional sensors should agree (in a certain sense) with the measurements of corresponding core sensors. To verify this agreement we apply the cross-validation procedure, which should prepared in a way adequate for the concrete structure where the sensors are located. Generally, such a procedure can be planned for an individual core sensor and its surrounding, several core sensors or the whole sensors network.

To describe the scalable security model for the additional sensors sub-network assume that it works with an adequate security level, collecting the measurements. We consider if the level should be changed. The procedure of changing the security level is based on calculation of the difference (the total sum of differences) between the results measured by a core sensor and the analogous result estimated from the measurements of the surrounding additional sensors. This difference can be calculated, at any time *t*, by means of following formula:

$$\Delta(m,t) = \sum_{j=1}^{n} \left| g\left(m_j^c(t)\right) - f\left(m_i^{ad}(t), \gamma_{ji}; i=1,\dots,k\right) \right|, \quad (2)$$

where *t* is the moment of time when the measurement is taken; *j* is the number of core sensor; *i* is the number of additional sensor; $m_j^c(t), j=1,\dots,n$ are the values measured by core sensors; $m_i^{ad}(t), i=1,\dots,k$ are the values of parameters measured by additional sensors (all at a certain moment t); $g_j, j=1,\dots,n$ are some scaling functions; f is a certain model function that relates results of measurements by additional sensors to the result of measurements by the

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core sensor $\gamma_{ji} \in [0,1], j = 1,...,n, i = 1,...,k$ are the weights that define an impact of i-th additional sensor on the j-th core sensor. In the particular model presented in Figure 1, the value of γ_{ji} is equal 1 if the i-th additional sensor is the first zone of the j-th core sensor, 0.5 if in the second zone, and 0 otherwise (we could also assume some continuous scaling of the ranges of additional sensors).

Equation 2 is a counterpart of the formula, which in statistics makes possible the cross-validation of experimental data (Hildebrand et al. 1977, Stone 1978). In this method some selected data point (a result of measurement) is verified on the basis of the values of other measurements due to application of some regression dependencies. For the cross-verification of the measurements in the sensor networks we can use not only the statistical regression, but also some physical dependencies (formulae) resulting from the known model of the measured engineering structure.

The reasoning in the method is the following. If we observe the agreement of the results, that is the difference is below a certain earlier determined level, we leave the security level unchanged. If the difference excides this level, we increase the required security level for additional sensors and switch on certain security services for the additional sensors network (suspecting an attack on the additional sensors). Then we continue an action according to some alert procedure, deciding whether we observed the attack or some abnormal behaviour of the structure.

Extending the model, we can assume that the level of system standby depends on deviations between estimated and measured values. Along with growing deviation, the system of appropriate additional sensor is set up on a higher threat level. That level controls the security mechanisms used in the network of additional sensor. The defined alarm levels are connected with specified security mechanisms, which fulfil a given process assumptions.

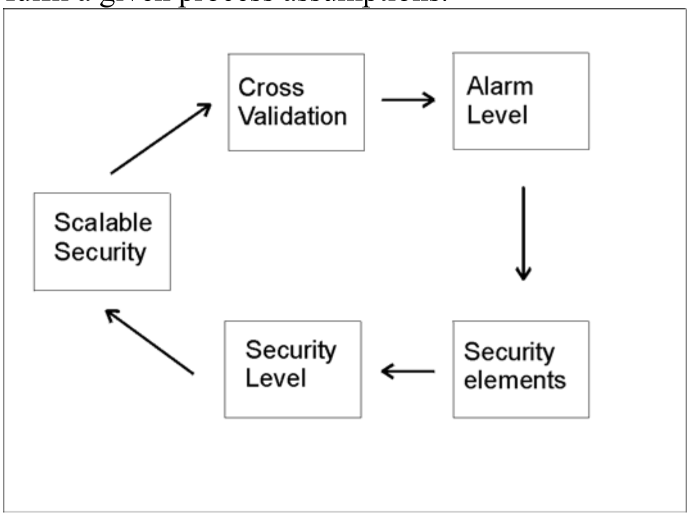

Figure 2: The scalable security cycle for additional sensor

When the additional sensors sub-network increases the protection level, the specified security mechanisms are established. These selected mechanisms will be used to calculate the protection level for the defined group of sensor. Calculation of the additional sensors sub-network protection level is similar to the analogous calculation for the core sensors, to this end it is used in Equation 1. For the additional sensors sub-network it should be created special combination of security mechanisms, which will be adequate to abilities of the used devices. Thus, this combination should be preceded by a detailed analysis.

The mentioned procedures are realized by a cyclical process. Therefore, after defining the protection level, the security level of the core sensors is defined. The described cycle is presented in Figure 2.

To complete the model we assume that in a case of expected threats (some general alert), the security level of the additional sensors sub-network can be increased manually by the operator.

5 RISK ANALYSIS

The scalable security for the additional sensors sub-network can be realized as a risk analysis cyclic process (see Figure 3). As mentioned above, the components needed in the risk management process are complex, based on many information protection items (ISO/IEC FDIS 13335-1). The steps in the cyclic process in Figure 3, extended with the scalability mechanism, are the following.

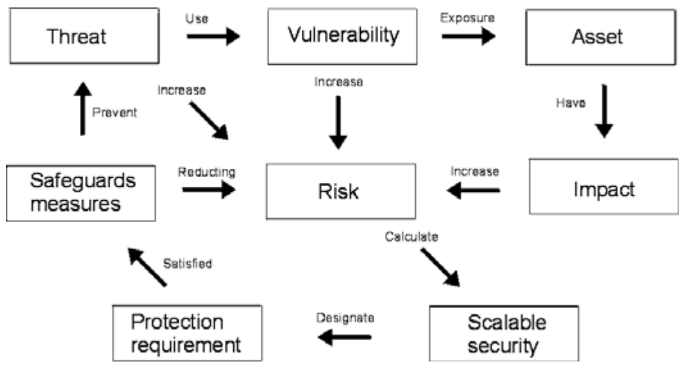

Figure 3: The cycle and relationship of security elements for risk management

5.1 *Assets*

The basic step in setting up security process is analysing the organization assets. One has to establish the level of vulnerabilities of assets and on this base one will set up proper security elements.

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5.2 *Threats*

Potential threats can cause harm on gathered assets by a given organization. The harms can be caused by attack on information taking part in process or on the system. The threats must use vulnerabilities in assets and then can cause some harm. Threats can be divided into human and environmental, and next into deliberate and accidental. For setting up the threats one should define the level of such a threat and calculate the probability of such an incident occurrence.

5.3 *Vulnerabilities*

A weakness of an asset that can be exploited by one or more threats is known as Vulnerability. Vulnerabilities associated with assets include weaknesses in the physical layout, organization, procedures, management, hardware, software, information etc. Vulnerability itself does not cause harm but only in the case of an attack.

5.4 *Impact*

Impact is the result of some information security incident, caused by a threat, which affects assets. The impact could be a destruction of certain assets, damage security system and compromise of confidentiality, integrity, availability, non-repudiation, authenticity, reliability etc. Possible indirect impact includes financial losses, company image, etc.

5.5 *Safeguards*

Safeguards are practices, procedures or mechanisms that may protect against a threat, reduce vulnerability, and reduce the impact of an information security incident.

5.6 *Risk*

The risk is characterized by a combination of two factors, the probability of the incident occurring and its impact. Any change to assets, threats, vulnerabilities and safeguards may have significant effects on risk.

5.7 *Scalable Security*

Additional item in the risk management process one can attach scalable security (Księżopolski & Kotulski 2005). Every analysis of information protection often shows new vulnerable structures in the system, which causes additional security elements. These protections are often overestimated, what in a general case lowers efficiency, availability of system, and excess redundancy. Thanks to scalable security one can change security level depending on given requirements of the electronic process.

All of the mentioned elements are closely connected and their relationship is precisely presented by standards (NIST 2004, FIPS 140-2, ISO/IEC FDIS 13335-1 ISO/IEC 19790) and analysed in research papers (Patel et al. 2002, Lambrinoudakis et al. 2003, Księżopolski & Kotulski 2005). Consideration on security of systems is a never-ending process. The risk analysis cannot be stopped, because the threats can never be completely eliminated.

6 THE MODEL USAGE

The model of scalable security proposed in this paper can be used only if within the sensor network the core sensors sub-network could be created. The core sensors must be linked to each other by high bandwidth connection. As an example of possible application of our model of security in real structure we could consider a bridge along which we can distribute the sensors to measure displacements of the structure as well as other parameters of its functioning. It is obvious that we can find some safe places where the core sensors could be located (and linked to the communication wired or optical fibre system). However, to have more detailed measurements we should also locate sensors in some exposed places (lines, guy ropes, moving elements, etc.). Thus, the additional sensors in our model, which measure densely distributed and very local values of parameters, could be placed in any positions, in particular in the locations where the solid physical connections to the core sensors are difficult or impossible to realize. The number of used additional sensors could reach up even to a couple of thousands (Chlamtac et al. 2003, Hu & Sharma 2005). The reliability of the measurements obtained from the additional sensors verified by the cross-validation procedure with the core sensors according to the methodology described in the above.

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Agent-enabled model integration in a knowledge-based planning environment

U. Rüppel, M. Theiß & M. Lange
Institute for Numerical Methods and Informatics in Civil Engineering, Technical University of Darmstadt, Darmstadt, Germany

ABSTRACT: The field of fire protection engineering is characterized by the cooperation of experts and by the distribution of knowledge resources. The availability of relevant knowledge in all states of the planning process is the basis for a high product quality and for optimal conditions for the rescue of persons. Hence, this project aims to create a knowledge based planning environment that offers multiple services for decision support in fire protection engineering. Therefore, structured information resources (such as model and product databases) and unstructured information (such as legal guidelines and other document-based information) have to be identified and integrated. This paper focuses on the integration of distributed partial building models in a network-based planning environment. The implementation of this integration as an agent-based component and its role in the knowledge-based planning environment are presented. Different distributed design models are integrated on the basis of mobile agents. The concept of an agent-based integration of information resources is demonstrated via the implementation of a knowledge based service that checks the distributed models for compliance with fire protection requirements.

1 INTRODUCTION

This contribution is based on the research activities within the program "Network-based Cooperative Planning Processes in Structural Engineering" (DFG 2000) supported by the German National Research Foundation. This research program supports various projects within the context of the network-based cooperation and bundles different activities in informatics in civil engineering in Germany.

This work provides an approach to support the distributed and knowledge intensive planning processes of fire protection engineering. Fire protection engineering is a task that involves planners from many fields. Furthermore, not all planners dealing with fire protection problems have profound knowledge in this area. Therefore, knowledge has to be offered to the distributed planners. In this contribution knowledge is provided as services in a knowledge based planning environment using software agents.

2 FIRE PROTECTION PLANNING

Huge fire disasters have caused fire protection to become one of the central aspects for administrative authorities in the process of licensing the building design. In Germany, fire protection is divided into two domains: the preventive and the defensive fire protection. The preventive fire protection contains all structural, technical and organizational fire protection aspects. The fire fighting and rescue are aspects of the defensive fire protection. Within the preliminary planning, the elementary requirements for effective rescue and optimal fire-fighting are created by the preventive fire protection (Schneider 2000). For that purpose, the building geometry and the adjustment of escape routes are important. Furthermore, the building components' requirements are determined with regard to fire resistance. All measures to guarantee the fire protection in a building contribute to the planning objectives, which improve the safety level of a building (Klingsohr 2002). The realization of the defined protection objectives and the specification of fire protection elements in the detailed planning are an integral component of a holistic fire protection concept (Loebbert 2000). According to the type and size of a project, planners from different fields (e.g. statics, construction, heating, ventilation, electric, and geotechnics) are involved. Methods to validate the planning results with regard to completeness and effectiveness regarding the fire protection objectives must be provided. Therefore, a large number of codes and regulations concerning fire protection of buildings have to be evaluated.

The presented approach focuses on the preventive fire protection engineering. This part has to be rec-

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ognized during the whole planning and construction phase and is the basis for the defensive fire protection.

3 KNOWLEDGE BASED PLANNING ENVIRONMENT FOR FIRE PROTECTION ENGINEERING

As described above, fire protection engineering is a task that includes planners from many fields. The fire protection engineer defines objectives and measures in a fire protection concept. All other planners have to consider the input of the fire protection engineer in their detailed planning. That means checking their work for fire protection deficiencies. The aim of this work is to provide a knowledge based planning environment to integrate all parties of the planning process and to provide knowledge based services to support the planners in their detailed planning regarding fire protection.

Different categories of knowledge have to be considered in this process. These are domain knowledge, corporate knowledge and project knowledge (Zarli 2001). These kinds of knowledge have to be incorporated into the building model in the course of the planning process. In this project, it is assumed that distributed planners are working on partial building models.

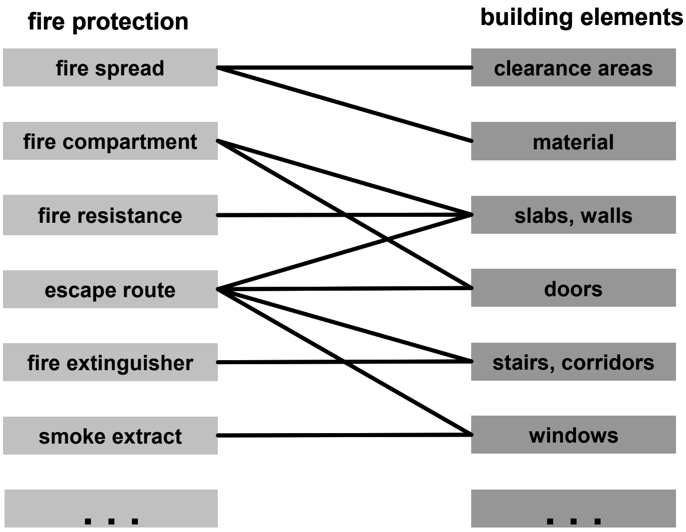

Figure 1. Interrelated partial models

The fire protection partial model is highly interrelated with other partial models. As shown in figure 1 this is due to most fire protection elements being associated with building elements. A floor in the building model, for example, can be identified explicitly as an escape route. The definition of an escape route defines special requirements on the linked building components. These requirements must be permanently checked up during the planning process. (Rüppel 2002a).

One of the planning process' main goals is to build up these partial models while preserving consistency with each other. The integration of the distributed partial models is a main precondition for the incorporation of the different knowledge sources. On the basis of the integrated partial models knowledge based services to support the planner can be implemented. The architecture of the planning environment offering different knowledge based services on the basis of the agent based model integration is shown in figure 2.

One of the knowledge based services based on the coupled partial models is the fire protection agent. This agent checks the current planning state represented by the coupled models for compliance with the fire protection requirements. To do this, the fire protection agent has to process parts of the models with the requirements from the design codes. This agent is described in section 7 of this paper.

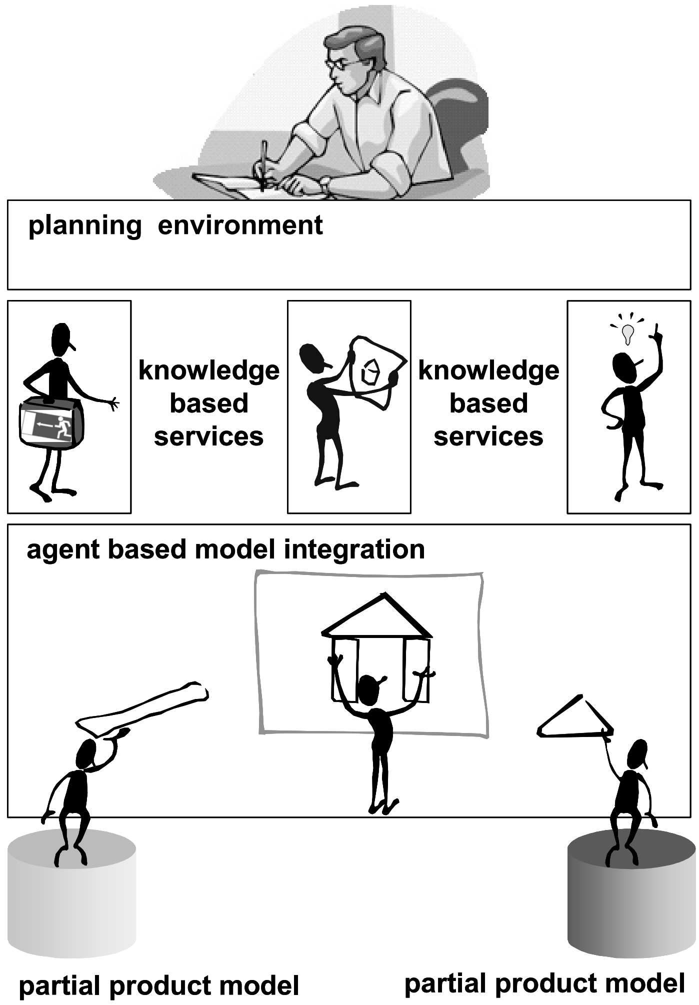

Figure 2. Agent-enabled model integration in a knowledge-based planning environment

Another knowledge based service supports the planner in the usage of project experience. It helps the planners in the process of finding solutions for new planning tasks by searching an organizational memory for similar problems. There, completed and already approved building models are stored. An ap-

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proach for searching for similarity in planning tasks is described in (Lange 2004).

Further knowledge based services can be developed on the basis of the architecture described in this paper.

To evaluate this approach, a prototypical web based user interface has been implemented. This interface allows the planner to access the distributed partial models and different knowledge based services. The web interfaces provides the planner with different views of the fire protection elements of a building. Furthermore, the described knowledge based services, for example the fire protection agent, are accessible through a task bar in this user interface.

This paper focuses the integration of the partial models on the basis of a multi-agent system. The presented multi-agent system is based on the agent development framework JADE (JADE 2005) and is able to fulfill the high demands of a distributed planning process in building design on a software system concerning distribution, communication, robustness and flexibility.

4 AGENT BASED MODEL INTEGRATION

As mentioned above, the integration of partial models stored in databases is an essential task. In the developed agent system every partial model has a proxy in the form of a stationary wrapper agent on its platform. This agent answers questions regarding the underlying model representing the planning details. The transportation of the model information is supported by mobile agents (figure 3). This architecture supports a flexible integration of the partial models.

The database wrapper agents are used to integrate the relevant design information into the multi-agent system. They provide the relevant product model data to other agents in the multi-agent system, independent on their physical location. Thus, database wrapper agents act as an interface between the multi-agent system and heterogeneous database systems (Bilek 2003). The communication between the database wrapper agents and other requesting agents implies a common vocabulary, a specific database ontology mapping database related message contents to database objects. Hereby, the software-wrapping technology enables the various design experts to plug existing database systems and data resources into a specific multi-agent system. As a consequence, dynamic changes in the design information of large collaborative engineering projects are adequately supported (Hartmann 2004).

On this basis it is possible to support the planners with knowledge based services. One of these services is the fire protection agent. This agent can be addressed by every planner to check his planning for consistency with the fire protection guidelines.

The integration of the partial models on the basis of wrapper agents, information agents and ontologies is described in detail in the following sections.

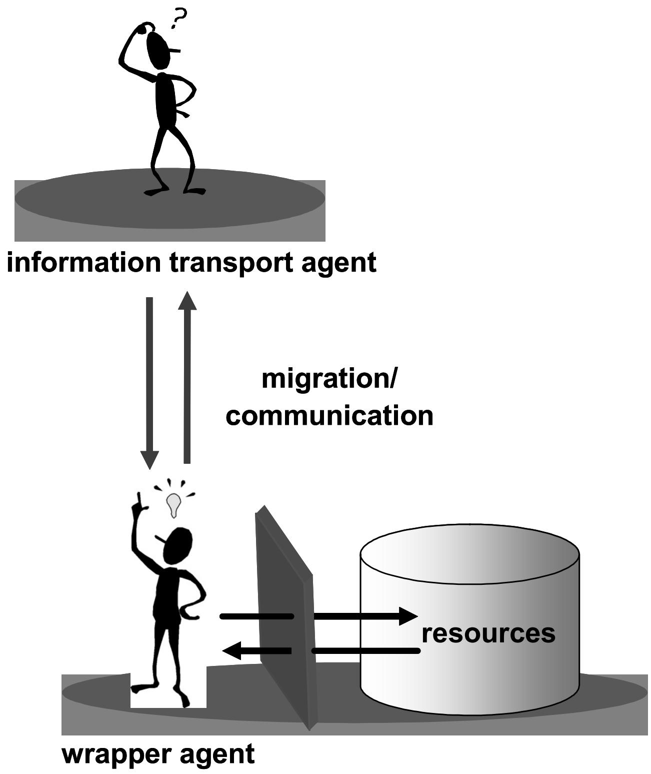

Figure 3. Agent-based model integration

5 THE WRAPPER AGENT

The Foundation for Intelligent Physical Agents (FIPA) has incorporated the concept of wrapper agents in its specifications for the design of multi-agent systems (FIPA 2005). The FIPA software integration specification makes use of so-called wrapper agents that “agentify” external resources. These wrapper agents provide a public interface to specific external resources although these resources usually cannot be accessed from other software agents in the multi-agent system directly. Wrapper agents are usually implemented in terms of stationary agents. They act on the host where the applied resource is located. Wrapper agents provide an easy to use interface to the services provided by the integrated resources. Thus, they hide the internal database structure required for accessing the encapsulated data resources. The architecture of the database wrapper agent is introduced in (Theiß 2003). The main focus in the development of the wrapper agent lies on the communication component. Two important problems have to be considered when modelling the communication between agents. Firstly, the structure of the communication process and secondly, the syntax and semantic of the message content.

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To support agent communication, the FIPA has defined so-called agent interaction protocols (IP) and communication acts (CA) (FIPA 2005). An interaction protocol describes a complete communication dialogue between two interacting agents. Figure 4 shows the information-request-interaction-protocol described in AUML (AUML) (Odell 2000) that is implemented in the agent system.

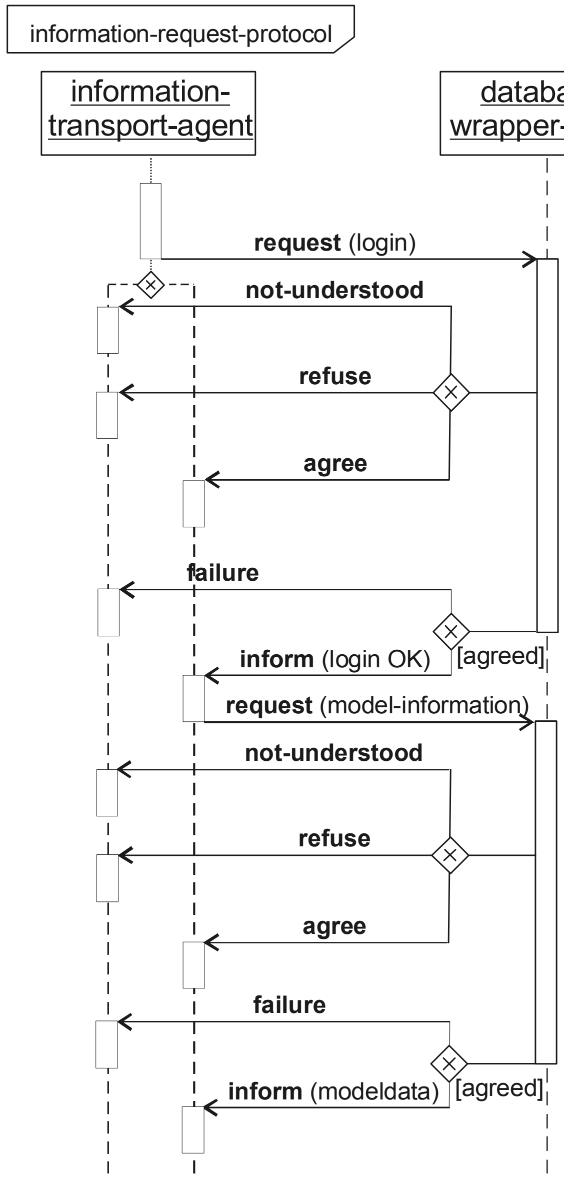

Figure 4. Information-request-interaction-protocol

The shown interaction-protocol models the interaction between the information and the wrapper agent. After receiving the CA *"request"*, the wrapper agent informs the information agent whether it *"refuses"* or *"agrees"* by accepting the received query. After a successful login, a query is passed to the wrapper agent. In case of understanding the query the wrapper agent processes the query and responds using the CA *"inform"*.

The wrapper agents as well as the querying agents need to implement the CA introduced above in terms of JADE-behaviours (JADE 2005) on a technical level.

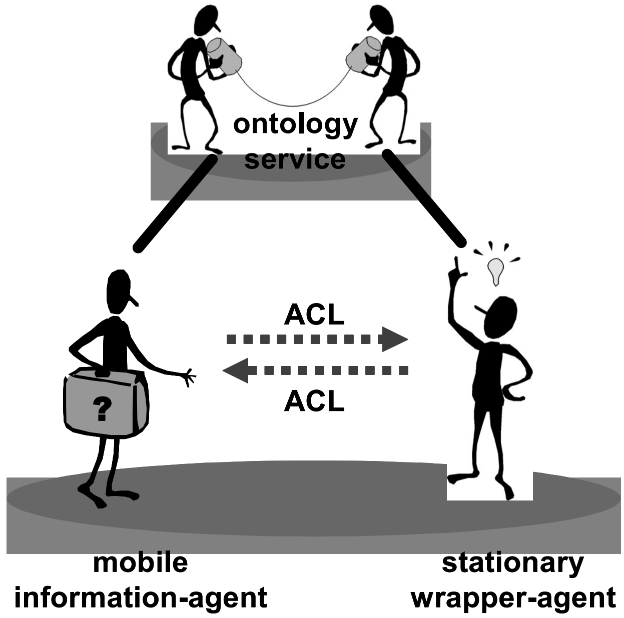

Figure 5. Agent-based ontology service

In addition to the communication acts and realized interaction protocols, ontologies have been developed which define the homogeneous vocabulary used in the message contents. A request ontology determines the query model defining the three action tags *"select"*, *"insert"* and *"update"*. The request ontology is fundamental for each database wrapper agent implementation because it matches the agent's core functionality. Depending on the project related tasks and knowledge, further ontologies are necessary to describe the specific technical contents and product models. In this project, an ontology defining the structure of a building is being implemented (Hartmann 2004). The ontology is provided to the agents by an ontology service that acts as a translator in the agent based planning environment (figure 5).

6 INFORMATION TRANSPORT IN AN AGENT BASED PLANNING ENVIRONMENT

As shown above the different partial product models have to be retrieved by an agent for processing purposes. The information transport agent outlined in this section offers the service of information transport in the network based planning environment. The information transport is divided into two steps. The first step is the transport of the query to the database wrapper agent; the second step is the transport of the response from the database to the initiator of the query. Thus, the information transport agent features two main characteristics: mobility and communication.

The multi-agent system consists of several agent-platforms. One platform can comprise several computers, whereas an agent can migrate within this

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platform. For the inter-platform migration of agents a new service has to be developed. Every platform with inter-platform agent migration support has to instantiate this service. The service offers sending and receiving of agents. The process of agent migration contains several steps: after starting the migration process, the agent class and all inner classes are packed. To restart the agent, all starting parameters have to be saved and packed as well. Before sending, all data collected on the platform has to be packed. Then the result is transformed into the content of an Agent-Communication-Language(ACL) message. The content is hashed by a MD5 hash key for security reasons. Finally, the message is sent to the agent migration service of the destination platform. The process of reactivating the agent after migration corresponds to the sending process in reverse order. Thus, a multi-agent system with inter-platform-mobility could be realized.

For communication the information transport agent uses the same ontology and interaction protocols as the database wrapper agent described in this article. In (Hartmann 2004) the communication is shown in detail. By the use of the described communication interface, and the shown migration service, an information transport agent is enabled to query and to receive model data. The transport agent analyzes the address of the building planner and migrates to his platform. On this platform, the agent starts to communicate with the local database wrapper agent and hands out the query for the model data. This query will be mapped to the local database schema by the database wrapper agent. The database response will be mapped to a public building model ontology and passed on to the waiting information transport agent. This agent migrates back to the initiator with the result. An application for this agent based model integration is given in the next section.

7 A KNOWLEDGE BASED SERVICE: THE FIRE PROTECTION AGENT

On the basis of the described agent based model integration, knowledge based services are implemented and provided to the planner in a planning environment. In this section the “fire protection agent” is presented as one of these services.

In Germany, fire protection as well as building design supervision is the sovereign right of the federal states. Their codes differ in details in every state. In result, there is a great number of design codes and special building regulations (for multistorey buildings, hospitals, etc.) (Rüppel 2002b). To comply with these complex standards completely and without errors during the design process is a challenge in collaborative fire protection engineering (Meißner 2004).

To enable the validation of fire protection requirements, the fire protection agent has been integrated into the knowledge based planning system. The agent has to be able to process the facts of the building’s fire protection model in accordance with the requirements from the design codes. The rules in fire protection are declaratively styled. Rule-based expert systems are well known in processing declarative rules. The Java Expert System Shell (Friedmann-Hill 2003) is one of the most used rule-based expert systems and is the reference implementation for the Java Rules Engine API. JESS is Java-based. The Jess API can be integrated directly in an agent of the Jade system. Rule-based systems work with rules and facts. An example for a fact is the width of an escape route; the corresponding rule is that every escape route must have a minimum width of 1.25 meters.

The fire protection agent has to process information from all involved models (Meißner 2003). At first, the relevant fire protection element has to be identified in the fire protection model. Thereafter, all relevant fire protection rules have to be retrieved from the fire protection rule model by the information transport agent and the corresponding database wrapper agent. In addition, the corresponding planning model elements have to be retrieved from the building model databases in the same way. After retrieving all information, the fire protection agent checks whether it has all facts to process the rules. This is an iterative process. So, step by step, all rules and facts needed for the fire protection requirement check are transported to the fire protection agent. As a result, the fire protection elements can be checked for accordance with the valid fire protection regulations. This approach enables the planner to check his design for consistency with the fire protection objectives.

8 CONCLUSION

This paper presents the idea of a knowledge based planning environment to support planners in fire protection engineering tasks. The integration of the partial models of the different planners has been identified as a basic precondition for providing knowledge based services. This integration has been implemented by use of a multi-agent system which fulfills the requirements of the distributed planning process concerning distribution, communication, robustness and flexibility. Thereby, the integration of information resources by means of wrapper agents and the information transport in the distributed planning environment by means of information agents have been implemented. As an example for a knowledge based service working on the integrated models the fire protection agent has been introduced. This agent supports the planners by checking the current

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planning state, represented by the coupled models, for compliance with the fire protection requirements.

The presented agent-enabled model integration is the basis for the development of further knowledge based services working on the coupled models and consequently for the extension of the described knowledge-based planning environment.

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Integrated Multiagent and Peer-to-Peer based Workflow-Control of Dynamic Networked Co-operations in Structural Design

S. Alda & A. B. Cremers
University of Bonn, Germany

J. Bilek & D. Hartmann
University of Bochum, Germany

ABSTRACT: Modern engineering projects in the application domain of structural design are organized in networked co-operations due to permanently enlarged competition pressure and a high degree of complexity while performing concurrent design activities. One of the major challenges of these networked co-operations constitutes the coordination of the activities of all involved participants. In the course of our common research activities, we have developed two different directions for coordinating these projects: i) a workflow-based concept regulating the activities explicitly by a global workflow model (University of Bochum) and ii) an awareness model that allows to perceive activities of other protagonists and to derive new activities mentally. This paper describes a novel integration approach of these two models: according to the global workflow model, users can be connected through awareness channels that enable them to detect potential inconsistencies during their concurrent modeling activities. Inconsistencies that would otherwise remain in the project progress can thus be discovered at a very early stage.

1 INTRODUCTION

Large engineering projects in construction engineering necessitate the involvement and the close collaboration of different engineers and other specialists residing in different geographic locations. We indicate such virtual project constellations as so-called *networked co-operations*. Networked co-operations in construction engineering exhibit major benefits in particular for organizing complex planning processes. Engineers can be involved in many projects concurrently, while residing in their local offices and, thus, reducing the costs for time-consuming business travels. Modern software systems allow these participating individuals to share project documents (e.g. IFC-based CAD documents), to receive an accumulated view of the overall project progress, and even to execute verification algorithms to partial building models for establishing the consistency to other models.

In the course of our common research activities carried out at the Universities of Bonn and Bochum, we have proposed and developed an integrated multi-agent and peer-to-peer software architecture *(MAS-P2P)* for supporting collaborative structural design processes within networked co-operations. Our software architecture covers fundamental aspects of a component-based peer-to-peer model for the flexible integration of heterogeneous software in a co-operation (project *CoBE*, Bonn) as well as a generalized agent model utilizing collaborative structural design based on an agent-based product and workflow model (project *ACOS*, Bochum).

In the current version of our approach we have implemented two different approaches for *coordinating the activities* of all project members belonging to a networked co-operation. First, an agent-based process support model is available to control and distribute the overall workflow of the project to the appropriate engineers. A workflow agent has been implemented to take over this task. The capabilities provided by the workflow agent are based on the Petri net theory. Based on Petri nets, the workflow agent links design processes to project resources (product models, software, and human experts). Besides, the CoBE awareness model enables human users (e.g. structural engineers/designers) and ACOS software agents to directly perceive planning activities that result from the modification of local (partial) product models. We already indicated that the adoption of software agents into the CoBE awareness model (both systems are technically concatenated by the *consistency agent*) is an important improvement, especially to guarantee the consistency of the distributed partial product models throughout the entire design life cycle.

However, our firstly proposed MAS-P2P architecture makes a couple of rather weak assumptions for the sake of simplification: At first, it premises an existent, already initialized static co-operation net-

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work, in which all pertaining users and agents are connected initially. At a given point in time within a project, no assumptions can be made, which of the enrolled users should or *must* actually be connected through CoBE's awareness channels. Also, neither the exact rationale nor the duration of their connection with respect to a global (process) model can be defined for a connection among different people.

In this paper, we propose a further integration of our two coordination models, that is, the awareness model and the agent-based workflow model within the existing MAS-P2P approach. Given a global workflow model being controlled by a workflow agent, project members are connected *dynamically* through an awareness channel by this agent, i) if their activities *are about to be executed* concurrently within the workflow and ii) if their activities refer to the *same dataset*. So, potential inconsistencies that could occur during parallel modeling activities can be detected early enough in this stage of the workflow through the awareness of the single activities.

The rest of this paper is structured as follows: section 2 provides background information about both involved projects including a brief introduction about the inherent coordination models for concurrent design activities. Section 3 presents the MAS-P2P architecture including an extensive description of the integrated coordination model. Section 4 finally concludes this paper.

2 BACKGROUND: ARCHITECTURAL SUPPORT FOR STRUCTURAL DESIGN PROCESSES

In the course of the priority program 1103 "*Networked-based co-operative planning processes in structural engineering*" funded by the German Research Foundation, we have scrutinized possible software architecture models for enhancing networked co-operations within collaborative structural design work. In this context, two major models evidenced as feasible: 1) the *peer-to-peer* architecture model that was evaluated by the University of Bonn and 2) the *multiagent* architecture evaluated by the University of Bochum, respectively. In the subsequent sections, we will first outline fundamental concepts of both models. Hereby, we primarily focus on the coordination between design activities that are carried out by the various structural design experts concurrently. The first, peer-to-peer based research project supports synchronous and asynchronous design activities by implanting the *awareness framework*. In contrast, the second, agent-based research project utilizes *workflow techniques* based on the theory of *coloured Petri nets* for the coordination of the concurrent design activities. Both coordination approaches reveal particular pros and cons that are pointed out at the end of this chapter.

2.1 Multiagent Architecture

Multiagent systems (MAS) are a rapidly developing area of research that emerged from the distributed artificial intelligence (DAI). Within the Bochumer project a *software agent* is defined as an *encapsulated software unit that is situated in a dynamic, heterogeneous environment, capable of solving well defined tasks autonomously and pro-actively in co-operation with other agents by order of personal (human) or non-personal principals.* In practice, software agents primarily assist their assigned design experts in their activities aside the support of other software agents in the environment. Several interacting agents, thence, are understood as a multiagent system. The adaptation of agent technologies to the specific needs and requirements of collaborative structural engineering implicitly requires the *decomposition* of the *entire structural design process* into adequate, domain-specific interacting agents (Bilek & Hartmann 2003).

In our research work we identified the following four substantial domains that were incorporated into the overall *agent model for collaborative structural design:* i) the participating specialized design experts and their associated characteristic, dynamic organizational structures (agent-based co-operation model), ii) the specific structural design processes (agent-based process support model), iii) the associated (partial) product models (agent-based product model), and iv) the applied, engineering standard software (agent-based software integration model).

Within the *agent-based co-operation model* (i) human experts and their assigned, design-specific organizations (like specialized engineering offices, other building companies, and authorities) are represented by *co-operation agents*. It is vital to differentiate between two fundamental co-operation agent types, the *personal* and the *non-personal co-operation agents.*

Personal co-operation agents directly assist their assigned individuals in their design activities. For that reason they provide a graphical user interface that enables the human experts to interact with other project associates and the multiagent system.

Non-personal co-operation agents can be seen as virtual representatives for the participating organizational entities, primarily the building companies. They hold specific information about their associated organization like enlisted project co-workers, time schedules and design tasks that have to be conducted. A very special non-personal co-operation agent is the *project agent*. It represents and supports the common, intrinsic project work by supervising and controlling the project handling, administrating the project members, responsibilities and delegating design tasks.

The next fundamental agent-based submodel, the *agent-based process support model* (2), is to control

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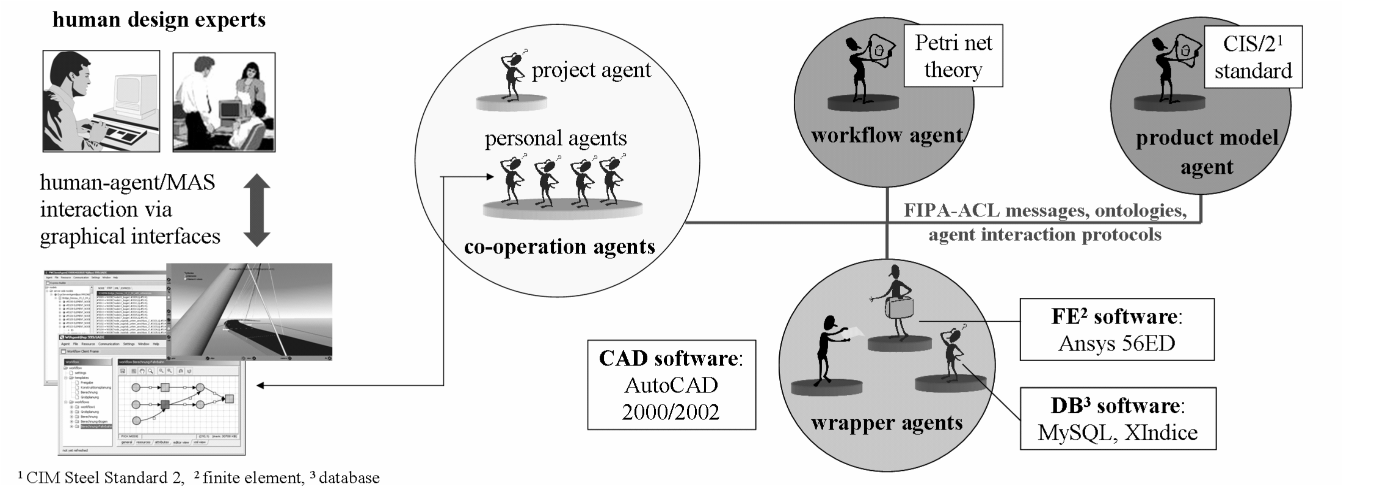

Figure 1: Agent model for collaborative structural design and prototypical implemented agents within ACOS

and allocate the complex design processes to convenient participating designers. For that, a *workflow agent* has been modelled as a delegate to the project agent. Based on the Petri net theory, the workflow agent links design processes to project resources (product models, software, human experts). For a more detailed depiction of the incorporated Petri net based workflow concepts see section 2.3.

The third basic submodel, the *agent-based product model* (3), rests on the decomposition of the entire structural system into smaller structural subsystems. Each structural subsystem thereby is accessible via an assigned product model agent that owns and stores knowledge about several structural elements created by the participating structural designers during the design process. The product model agents adjust their knowledge and, thus, check structural dependencies and retain product model consistency. The product model specification used conforms to the CIS/2 (CIM steel integration standard) standard. CIS/2 is a set of formal computing specifications that are based on ISO 10303 (STEP – STandard for the Exchange of Product model data) and allow the modeling of steel structures. CIS/2 covers the three major planning phases structural analysis, structural design and fabrication aside data management issues (Reed 2002).

The integration of heterogeneous engineering standard software (such as CAD-, FE-programs, databases) is achieved through the implementation of wrapper agents as specified in the *agent-based software integration model* (4). Wrapper agents operate as interfaces between the MAS and locally installed software such that the software applications can be used by all other agents and/or human design experts in the agent network.

In the course of the prototypical implementation ACOS (**A**gent-based **CO**llaborative **S**tructural Design) the delineated four submodels have been simplified such that only basic and necessary conceptual elements must be implemented into a set of design-specific software agents (Fig. 1). These agents interact with each other by exchanging several speech-act based messages that conform to the FIPA (Foundation for Intelligent Physical Agents) agent communication language (FIPA-ACL) specifications (FIPA 2000). The realisation of complex dialog structures is provided by task specific interaction protocols (IP). In addition, several domain specific ontologies have been developed (product model ontology, workflow ontology, etc.) and concatenated with agent specific capabilities. It has proved that the sum of several lously-coupled, design specific software agents in a dynamic environment is a convenient, flexible and applicable way to support collaborative structural design activities.

2.2 Component-based Peer-to-Peer Architecture

The peer-to-peer architecture concept is a novel abstraction for developing software aimed to support virtual organizations. Following this style, a peer-to-peer architecture constitutes a distributed architecture that consists of uniform clients or so-called peers. Peers are capable not only of consuming, but also of providing computer resources like data, legacy applications, proprietary software solutions, simple routines, or even hardware resources. These resources are encapsulated by *peer services*. In contrast to other service-oriented architectures, peer-to-peer architectures assume an unstable and dynamic topology as an important constraint. That is because peers are solely responsible to affiliate to a network. Beyond the possibility of direct resource sharing, peer-to-peer architectures enable single peers to organize into so-called peer groups. These self-governed communities can share, collaborate, and communicate in their own private web. The purpose is to subdivide peers into groups according to common interests or knowledge independent from any given organizational or network boundaries.

Peer-to-peer architectures have mainly been used to implement file sharing systems such as Gnutella or Napster. The exchange of files, thus, constitutes

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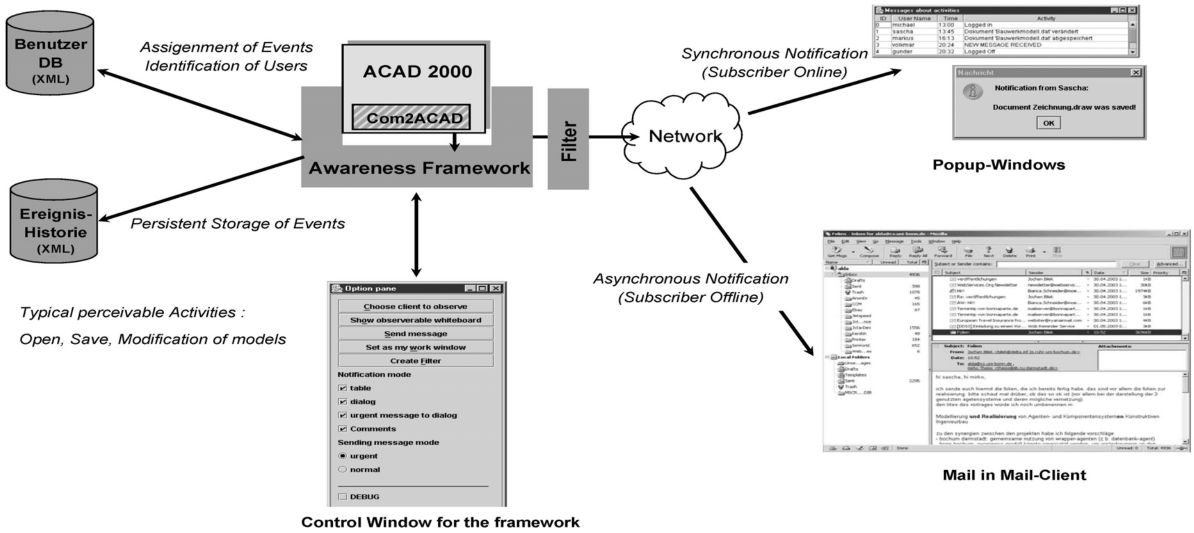

Figure 2: The CoBE awareness model.

the only service that is shared among all participating peers. Other systems such as Seti@Home integrated unused computing cycles towards a virtual super computer that allows the concurrent computation of a massive amount of data. Here, the access to a local processor corresponds to the only shared service. The brief illustration of the above mentioned systems reveals that peer-to-peer architectures principally support the *vertical integration* of services, that is, only a small number of service types are integrated. The de facto standard peer-to-peer framework JXTA leverages the original notion of peer-to-peer towards a rather service-oriented architecture, where a wide range of services can be published and discovered by a single peer. However, the JXTA approach exhibits two apparent drawbacks: first, no notation is provided to describe compositions of services towards higher level application. Secondly, no mechanisms are implemented to react on the unavailability of peer and peer services.

In the course of the research project CoBE, we have developed DeEvolve (Alda and Cremers. 2004), a self-adaptable peer-to-peer architecture based on top of the JXTA standard peer-to-peer framework (Sun 2004). DeEvolve incorporates the component technology as another fundamental technology. According to the component technology, peer services are made up by the composition of single software components. A component model called FlexiBean does prescribe the valid interaction primitives for both the local interaction within a service and the remote interaction among distributed services. Peer services can be made available (published) to other peers by means of advertisements. Each service can be assigned to at least one or more group affiliations, in order to restrict the access to a service for authorized group users. Users of other remote peers are able to discover and use these services. Additionally, we provide a composition language called PeerCAT (Alda and Cremers 2004), which enables users to declare the composition of different peer services towards individual, higher-level applications. As a self-adaptable architecture, DeEvolve is capable of detecting and resolving unanticipated exceptions such as the failure or unavailability of peers. The handling of exceptions is done in strong interaction with users: a user, for instance, is able to decide which routine is to be executed for resolving an occurred exception. DeEvolve is accompanied by a couple of auxiliary tools not only for the discovery, advertisement, and composition of services, but also exception handling, as well as for the management of groups.

2.3 *Coordination of concurrent Design Activities*

In both research projects different process support models are favored: the agent-based project makes use of high-level *Petri net based workflow management concepts* (van der Aalst 1998) whereas the peer-to-peer based research project avails *awareness based approach*.

The theory of awareness for regulating distributed activities has become a popular research topic in the area of groupware systems. These systems are usually deployed in an environment consisting of a group of people, which perform the general role of supporting the co-operation within this group. According to the author Dourish, awareness is an understanding of the activities of others, which provides a context for your own activity (Dourish 1992). With the introduction of awareness in groupware systems, each user is equipped with mechanisms, with which he can be aware about activities of other users belonging to a common activity or a common data set. For example, if a user is modifying a shared document, a predefined number of users will be informed about all subsequent changes. For

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receiving notification events about status changes, a user first has to subscribe to a notification list. This kind of awareness is also called task-oriented awareness. Awareness can be regarded as a foundation for conflict recognition and resolution. In the field of networked co-operations, where one has a high potential of conflicts and problems among the members, it appears reasonable to have such conflict prevention techniques.

For the CoBE project we have developed the CoBE Awareness Framework (Alda et al., 2004), which realizes a decentral awareness model to coordinate the working activities within a networked co-operation. In contrast to other existing implementations of the awareness model, our system does not rely on a global server that takes over the notification of users with awareness events. Here, the peer-to-peer ideology has also been adopted for our awareness framework: each peer is not only capable of acting as a publisher of awareness events, but also as subscriber who receives events from other peers through single (peer-to-peer) *awareness channels*.

The current version of the CoBE awareness framework can be used by any component-based application that is deployed in the DeEvolve environment (figure 2). The purpose of this framework is actually to make the local interactions between components explicit for other remote users. Users obtaining information about occurred interactions are thus accomplished to derive further actions based on the sole awareness of precedent activities stemming from other users who, for instance, belong to the same co-operation. Users can either be notified directly on the screen or, given that they are unavailable, asynchronously via email. In order to avoid any violation of privacy issues of individual co-operation members, each member is capable of defining so-called *filter agents*. The purpose of these agents is to pre-select events of activities that should not be made explicit for other users. Also, agents allow the selection of non-relevant events stemming from other members.

Apart of the strengths of the awareness model for coordinating planning activities in networked co-operations, a couple of drawbacks have to be faced. First, an awareness model does not assume a global coordination or process model that clearly prescribes when planning activities should be started or finished. Also, no global statements can be made, which of the participating co-operation members should actually be connected through the awareness framework. We simply assume that each participant is responsible on his own to identify and, in turn, to connect to depending members, who work on common data sets or on common activities. As we explain later, these weaknesses can be eliminated in combination with the concepts incorporated in the Bochumer project.

In the Bochumer project the coordination of collaborative design processes is handled by the *workflow agent*. In principle the delegation and coordination of design tasks is accomplished as follows: The workflow agent receives a process template for a given sequence of activities either from the project agent or the project manager. Afterwards, the process template is instantiated with given boundary values. Then, the workflow agent delegates "fireable" design activities (work items) to subscribed design experts subject to the current state of the workflow until the complete workflow is finished.

The applied process support model, thereby, has to fulfill several major requirements that derive from the specific characteristics of collaborative structural design. On the one hand the process model has to support concurrency; on the other hand it has to facilitate time dependent activities e.g. a given task has to be completed at a given point in time. Moreover, the process model has to provide an opportunity to integrate any kind of resource (like product model data, engineering software e.g. for the (semi-)automatic execution of processes, designers, etc.).

We analyzed different Petri net (PN) types with respect to the proposed requirements. As a result high-level, colored, time dependent Petri nets turned out to fulfill our pre-conditions in a convenient way. In particular PN are well suited for systems in which communication, synchronisation and resource sharing are of great importance like in the structural design domain. Another advantage of colored, timed Petri nets is that they can be described with the standardized Petri net markup language (PNML) and provide means for an intuitive graphic representation. Furthermore, it is possible to concatenate several process chains by using the more complex hierarchical colored Petri nets.

Basically, a Petri net is a graphical and mathematical modeling tool for discrete, distributed systems. The structure of a PN consists of places (the passive part of a PN, representing system states), transitions (the active part of a PN, representing events, activities, etc.), and directed arcs. Arcs connect a place to a transition and vice versa. Mathematically, the structure of a low-level PN is represented by a quadruple $PN = (P, T, A, M_0)$ where $P = \{p1,...,p_n\}$ is a finite set of places, $T = \{t1,...,t_m\}$ is a finite set of transitions, A is a finite set of arcs and M_0 is a finite set of initial markings $M_0 = \{m_0^1,...,m_0^n\}$. *Markings* (or sometimes called *tokens*) are attached to places. Tokens are responsible for the execution and, thus, dynamics of the system. The current state of the modeled system (the marking) is given by the number of tokens in each place. If the system state changes at least one transitions "fires". Transitions are only allowed to fire if they are enabled, which means that all the preconditions for the activity must be fulfilled (enough tokens must be

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available in the input places). When a transition fires, it removes tokens from its input places and adds some at all of its output places.

The major enhancement of colored Petri nets compared to low-level Petri nets is that they are characterized by distinguishable, high-level tokens of different data types, i.e. places are marked by structured tokens where information is attached to them. More complex high-level Petri nets add individuals, their changing properties and relations to the ordinary (low-level) Petri nets. In other words, tokens have an identity and arcs are labeled with variables, and the transitions may be annotated with a formula. The formula limits the conditions when the transition can fire.

The implemented process support model incorporated in the workflow agent consists of basic high-level Petri net features. For example, it currently supports three types of resources that can be attached to workflow transitions within the *resource manager*: i) subscribed individuals and groups/ organizations, ii) timed resources and iii) an interface for arbitrary application based resources e.g. for the automatic shipping of emails. Besides, arcs can be labeled with formulas that make use of global system variables designed and controlled within the *attribute manager*. The activity manager provides the possibility to link any transition to an implemented, application dependent activity with customized, advanced features. For this purpose, each fireable transition can be mapped to any customized activity class that implements the *activity interface.*

Many design activities in structural design require the preparation of (at least partial) product model data that in many cases cannot be integrated into the Petri net based process model directly. For example, in an instantiated workflow different design activities (fireable transitions/ work items) are attached to the common product model objects that are controlled by the product model agent. Let's assume three of these transitions fire simultaneously and their attached work items are delegated to three different design experts (designer A, B, C) subsequently. Then, in the near future the designers A, B and C have to operate on the same product model objects concurrently without knowing from each other's similar work items. One of the designers (designer A) may start to manipulate some product model objects in co-operation with the product model agent. Let's suppose he finishes its activities before the other designers (designer B and C) start their intended operations. In this case the already permitted operations of individual A can totally differ from the intended operations that designer B and/or C are willing to perform (Fig. 2). This use case may result in severe planning conflicts and inconsistencies.

The above illustrated scenario can easily be im-

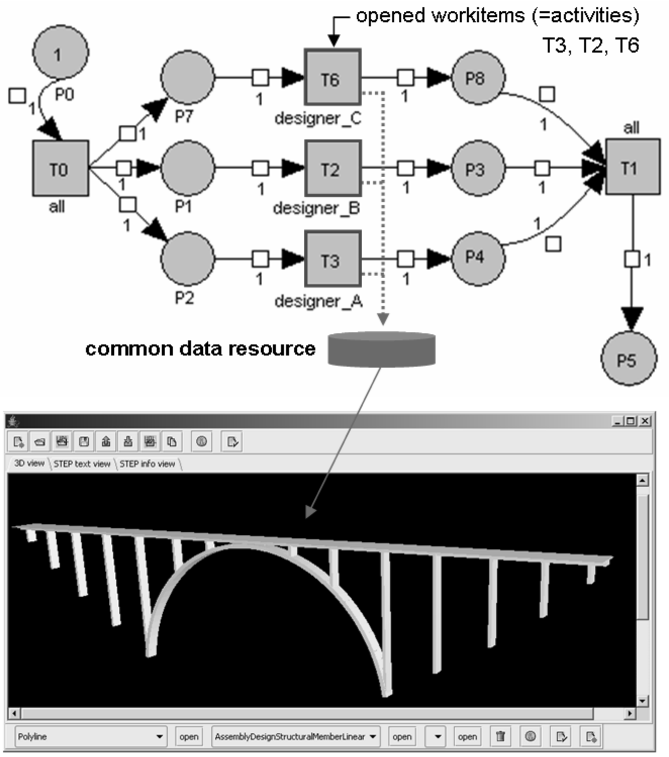

Figure 3: Conflicting use case: designer A, B and C have to operate on the same bridge model objects concurrently.

proved by deploying a simple notification and awareness mechanism. Every time the designers A, B or C operate on their assigned product model objects the other two designers have to be informed about fundamental manipulations immediately. Such a mechanism can solve or at least reduce planning conflicts and prevent design deficiencies effectively. The above depicted CoBE awareness framework provides exactly such a pluggable mechanism. However, with CoBE subscribed users can perceive all event notifications within a group, but it still depends on them, how to interpret them. In chapter 3 we illustrate how the CoBE awareness framework is integrated into the workflow model and how both approaches are conceptually and technically combined with each other in a favorable and profitable way.

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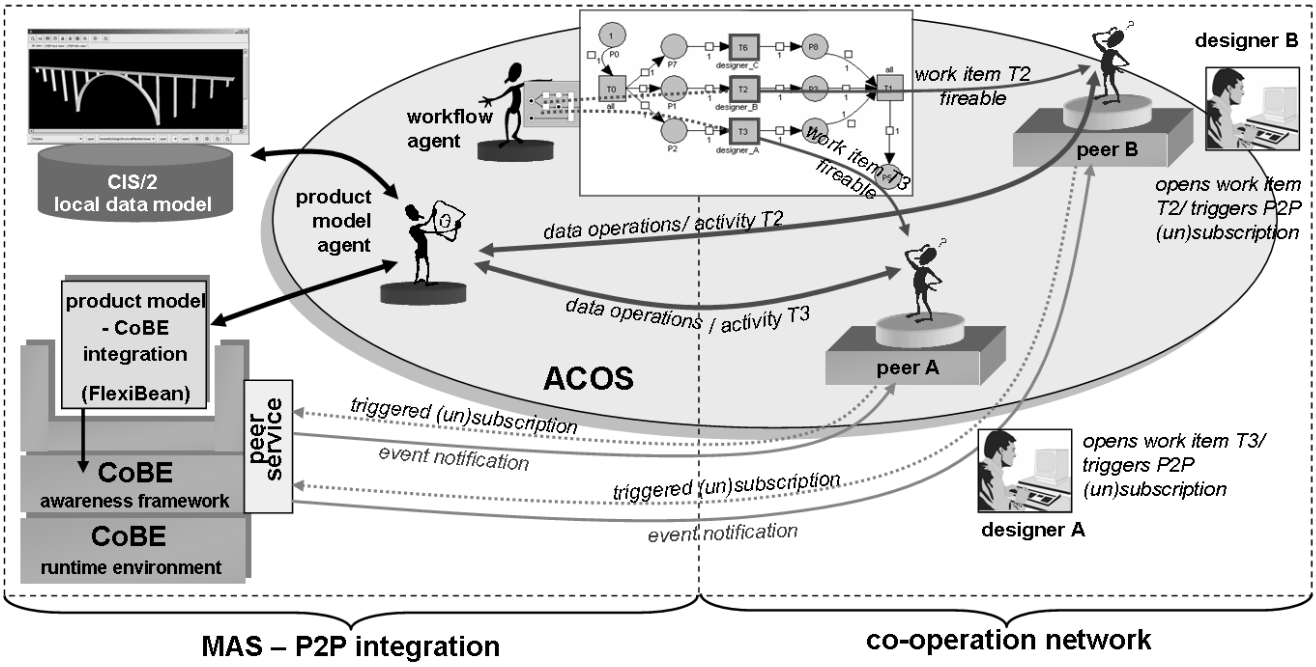

Figure 4. Overall design of the integrated MAS and P2P architecture incorporating enhanced coordination mechanisms.

3 MULTIAGENT AND PEER-TO-PEER BASED WORKFLOW-CONTROL

3.1 *Preliminary Work*

In the course of our common research activities, we have already proposed and developed an integrated Multiagent and peer-to-peer software architecture *(MAS-P2P)* for supporting collaborative structural design processes within networked co-operations. According to this integrated platform, not only human experts, but also software agents are capable of perceiving awareness events that result from past planning activities. This approach decreases the likelihood that inconsistencies in partial models remain undetected by human actors. Undetected inconsistencies are typically caused by two reasons: (1) human actors are swamped to tackle with too much information and (2) human actors still possess the freedom how and when to react on events. The advantage of agents being able to receive awareness events is motivated by their semi-autonomous characteristic: agents are able to react *immediately* and *autonomously* on events and, accordingly, to react directly on occurred inconsistencies in partial models. More information about the basic assumptions of this platform can be found in (Alda et al, 2004).

3.2 *Design Issues*

Figure 3 depicts the overall design of the integrated architecture (MAS-P2P) featuring fundamental aspects of both the peer-to-peer and the agent architecture model, respectively. Beyond, the figure points out the incorporated enhanced Petri net based workflow control mechanism and the CoBE awareness model. What one can figure out from the first view is that each participating engineer (e.g. designer A and B) is equipped with an integrated MAS-P2P environment comprising an ACOS personal software agent and a CoBE peer-to-peer runtime environment.

Within ACOS personal agents constitute a kind of gateway to other agents and services like the workflow agent. The workflow agent controls initialized workflows and notifies workflow subscribers about changes in the current workflow state e.g. if an activity was completed and tokens are moved. In the structural design domain a subscriber is primarily an individual personal agent attached to a participating engineer. With that, the workflow agent is able to allocate fireable work items to authorized individual personal agents. The individual structural designers then may decide whether to *open* the received work item or not. Once one of the authorized designers has opened the eyed work item it is no longer fireable. An already opened work item we call *activity*. An activity may be cancelled or closed by its associated design expert. If closed the workflow switches to the next state, if cancelled the work item's state is reset to fireable again.

In structural engineering many activities deal with product model operations. For that reason we implemented the *PMConnectActivity* class, a customized activity that automatically connects a personal agent to the responsible product model agent once a product model based work item is opened. As already indicated it may arise that two or more designers get connected to the same product model agent simultaneously and subsequently are operating on the same common local data model concurrently. In this case it is vital that each designer gets immediately notified when product model objects relevant to its design task have been manipulated by other participating design experts. Additionally, a designer

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may only be interested in particular notifications e.g. modifications of particular product model objects or parts of the overall product model. In this case a sophisticated, adjustable filter mechanism is required that accepts only relevant notification events.

For that reason each personal agent is equipped with an individual peer-to-peer runtime environment that easily allows perceiving modeling activities on a common, local model by means of the CoBE awareness framework. Local data manipulation activities, thus, can be made explicit to all (subscribed) members within the P2P co-operation network. For that purpose, all data operations have to be published by peer services. In our MAS-P2P environment the product model agent has to publish all incoming data manipulating actions as a peer service to which other peers – the participating personal agents – may subscribe or unsubscribe.

Technically, the product model agent delegates information about the performed product model operations to a customized *FlexiBean component* (product model – CoBE integration FlexiBean), that is plugged into the CoBE awareness framework. The FlexiBean then is able to trigger appropriate actions like the immediate notification of subscribed cooperation network members every time a data manipulation has been noticed. The following events can be perceived: adding, deleting or modifying of product model objects and state changes of product model object like *locked, unlocked* or finally *released* as well as events indicating that a member has become online or offline. Accessorily, the CoBE awareness framework provides means to filter received information. For instance, a design expert may only be interested in operations on the product model objects with ID #1220 to #1250. Then, the awareness framework automatically filters out events associated to the denoted objects.

However, before the participating designers can receive triggered events they first have to apply for membership to the product model agent's published peer. Obviously, the individual engineers cannot exactly know when to subscribe or unsubscribe to the product model agent's peer in the course of the executing workflow. Instead we enhanced the *PMConnectActivity* with an automatic subscription/ unsubscription mechanism. Every time a participating designer opens a PMConnectActivity work item not only a FIPA-ACL based connection to the relevant product model agent is established automatically but also the inherent designer's peer is triggered to subscribe to the to the product model agent's peer. On the other hand if the considered designer cancels or closes its PMConnectActivity the designer's peer is triggered to unsubscribe from the P2P network.

Let's assume only peer A is subscribed to the P2P network. Then designer A may only be notified about its own product model operations, respectively. Of course, this makes no sense such that these events are suppressed. But assuming designer A and B are both preparing a PMConnectActivity concurrently then designer A gets informed about all the data manipulation actions performed by designer B and vice versa. As we can see the P2P based cooperation network consisting of subscribed peer members dynamically changes due to the current state of the Petri net based workflow. Furthermore, the co-operation network is interconnected automatically without explicit user interactions. It has proved that this mechanism significantly helps to avoid or at least reduce intricatenesses evoked by concurrent, product model based design activities. Thereby, the MAS-P2P environment can only identify potential planning conflicts that finally have to be handled by the affected design experts.

4 CONCLUSIONS

In this paper, we have presented our approach of an integrated architecture model for the effective and efficient support of concurrent activities in the structural design domain. Our integrated MAS-P2P based environment covers the benefits of two major models for coordinating distributed planning activities, that is, an agent-based workflow model and an awareness model.

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Human oriented mobile system for on-site problem solving

A. Magdic & D. Rebolj
Faculty of Civil Engineering, University of Maribor, Slovenia

ABSTRACT: Uncertainties and the dynamic nature of on-site activities require complex coordination of information, resources and tasks. Problems caused by unanticipated events must be solved concurrently and should avoid project delays and costs increasing. For effective solving of such problems, the immediate availability of information and a prompt response of project participants on various levels of project organization are crucial. A combination of both conditions facilitate the optimum decision-making in cases of unanticipated events. Based on experiences from a series of experimental projects called E-site, it is our strong belief that a large amount of potentials for on-site problem solving lies in the knowledge, experience and capability of the site staff themself. Therefore, there is also a need to effectively link together the rich knowledge and experience of site staff and include site staff into problem solving processes. This paper describes a human oriented on-site problem solving system supported with context-aware communication to help dealing with unanticipated events on construction sites.

1 INTRODUCTION

Each day on a construction site brings new problems. The solution of daily problems in the construction process significantly affects the building and general project process, due to unanticipated events. Although unanticipated events can not be prevented, they can be managed effectively. It is our strong belief that a large amount of potentials for on-site problem solving lies in the knowledge, experience and skills of the site staff themself. A proper mobile interpersonal communication network can link together the rich knowledge and experience of site staff and facilitate information exchange when solving problems.

Mobile computing, including mobile and ubiquitous applications as well as wireless technologies provide interesting approaches to supporting people to interact with other persons (Johanson et al. 2004, Beyh and Kagioglou, 2004), to find out about people's availability through location detection (Burrell et al. 2002), and to reach and manage information items even though not being present in the office (Fleck et al. 2002). In case of building ad-hoc mobile teams for joint problem solving a combination of mobile computing approaches is needed with emphasis on interpersonal communication. Therefore, this paper focuses on presenting interpersonal communication by on-site problem solving process supported with context-aware communication.

2 KNOWLEDGE SHARING IN ON-SITE PROBLEM SOLVING PROCESS

2.1 *The E-Site Experience*

Observing on-site interpersonal communication characteristics in a series of experimental projects called E-Site we identified importance of informal communication by on-site problem solving process (Magdic et al., 2004). When dealing with a specific on-site problem quick solution is needed, immediate availability of information and a prompt response of project participants on various levels of project organization are crucial. Often, just open and direct project-wide communication is what contributes to the successful problem solving, enabling all participants to be permanently, actively involved.

In case of solving specific problem it was evident that all involved persons were experienced workers. Instead of formal, specified communication, they used spontaneous, informal communication which enables them to rapidly and continually exchange information, monitor progress, and learn about what others are doing.

2.2 *Important aspects*

Four aspects can be identified as important for the purpose of supporting on-site knowledge exchange: interpersonal communication, presence awareness,

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common information space and project organization hierarhy.

Interpersonal Commmunication

Not only knowing who knows is important when finding things out in order to solve a problem, but also to be able to communicate with others. This can be accomplished through either short notifications, longer chats, e-mail, sms, telephone calls, or face-to-face communications. Which communication channel is used depends on, among others, the persons involved, on the distance at the moment, on the availability of systems and on the character of the problem.

Each communication channel has a separate user interface, which each have access to the contacts database. Thus when initiating communication first the channel and then the recipient is selected. This is a channel-oriented approach to person-to-person communication.

People often start communication in resolving a problem not by choosing the communication channel, but with choosing the person with whom they want to communicate. Therefore there seems to be a need for complementing the channel oriented approach with a person oriented approach e.g. integrate the communication channels into the contacts database instead.

Presence Awareness

Our observations showed that how people conduct their search for knowledge and skills in order to solve a problem depends on the situation, on who is around and available at the moment, and on the nature of the problem itself.

How awareness information is presented may also be an important consideration. If an awareness system uses i.e. sensors or electronic calendars, to capture information about people's activities and availability, the information can be presented as it is, leaving it for the user to interpret where the person is and when will be available again. Another possibility, based on usage statistic, would be to compute a presentation that would be the most likely interpretation.

Increased availability may lead to an increased amount of annoying interruptions, therefore privacy aspects can be dealt with by letting people decide for themselves who should see their information and who should not.

Common Information Space

When solving problem on site Common Information Space sholud provide the user with one point where all already existing information (documentation, internal company's information) can be searched for knowing who does what, who knows what, and where and how people can be reached. Certainly this could reduce the number of persons asked when solving a problem.

The structuring of the information could be created using ontologies or even better indexing (Google) without providing any structure of the information.

Organisational Barrier

Informal communication means a direct and open communication, which shows additional benefits in cases where problems must be solved instantaneously.

In the existing project organizational structures the chain of command or information gathering is inherently hierarchical. The hierarchical status determines the roll and authority of the individual subject, which is the main reason for the lack of effectiveness continuous on-site problem solving in the construction process and on the higher project level.

Lack of efficiency shows the need for transformation of the multilevel organizational structure on a single (flattened) networked structure. In this way, decisions are also made on lower hierarchical levels or on levels in the organisational structure where they are necessary (Figure 1).

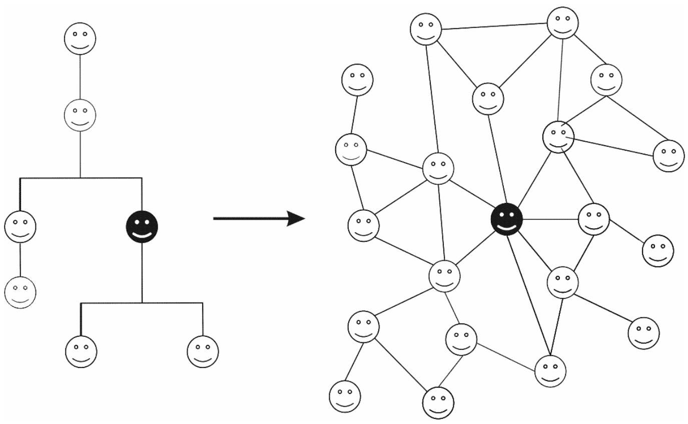

Figure 1. Novel decision and organizational structure

Our further activities within E-Site project are also related to optimize decision processes, and through the change of the decision model to develop an essentially optimised generic organisational model. In the frame of the created model, we will also define the responsibilities, authorities, and competencies of individual participants.

3 SUPPORTING ON-SITE AD-HOC COMMUNICATION

Informal ad-hoc communication between remote team members can be supported via tools for lightweight interaction (Whittaker et al, 1997) such as

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phones, e-mail, instant messaging, shared workspaces, and awareness technologies.

Focusing on supporting on-site personnel in knowing about others' availability when initiating communication in problem solving process we suggest a pragmatic human oriented solution.

Our solution suppose when initating informal communication people already know who to contact, which is also the case in on-site practice. Since by problem solving quick solution is needed it is important to know if our contact for solution is available or at least when he will be available. One cuold easiliy use mobile phone and call his contact hoping to get a response first and if there is no response the procedure is repeated with another contact again not knowing if it's available.

Therefore, system should provide the user with context information about potential contacts. We propose a sort of electronic secretary that combines context information from company's instant messaging system and electronic calendars and on request transfers this combined information via different clients (Figure 2).

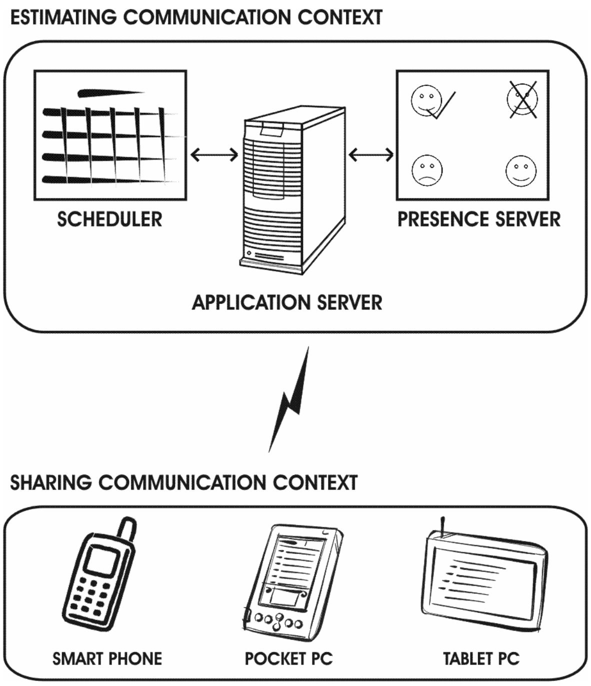

Figure 2. Simplified system configuration

Knowing information about current status and appointment's of the potential contact enables system users to select the timing and media of communication.

To assure up-to-date availability informations it is necessary for system users to maintain their own availability data either thru manual updating other thru system's automatic location detection.

4 DISCUSION AND CONCLUSION

This paper has highlighted the importance of the informal personal communication by on-site problem solving process. Presented are important aspects which need to be considered when designing support for mobile knowledge sharing on contruction site.

As a part of ongoing research within experimental project E-Site a pragmatic human-oriented approach for initiating communication in on-site problem solving process is presented. Our further challenge is to actualize the discussed approach and apply it to a present on-site process with our partners from the construction industry. Implementation of a prototype will then serve for improving existing project organizational structures.

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Implantation strategy of mobile technologies in construction

K. Eisenblätter & K. Menzel
Institute for Construction Informatics, TU Dresden, Dresden, Germany

ABSTRACT: Small and medium sized enterprises in the AEC sector most often are lacking human and financial resources to implement and test mobile technologies within their businesses. Consequently, SME do not benefit from the various advantages of integrating field personnel into the company's IT-infrastructure. To foster the adoption of mobile technologies by SME in the AEC sector we have developed an implantation strategy as part of the research project called *IuK-System Bau*. The strategy provides a structured and user-oriented guideline concerning the introduction of mobile devices, wireless networks and mobile services into the individual company's specializations. This paper describes the various steps we have taken to develop the implantation strategy. One special focus of the paper concentrates on the presentation and analysis of the field tests conducted within our research project to evaluate the prototypes developed, namely the *Extended Construction Diary* and the *Mobile Errors and Omissions Management* application. The outcome of the field test has significantly determined the development of our implantation strategy.

1 INTRODUCTION

Recent papers have stated that the availability of mobile technologies such as mobile devices and wireless networks contributes to improved integration of field personnel into the electronic information flow of field personnel (Reinhardt et. al. 2002, Menzel et. al. (2003). However, the slow adoption of these technologies by SME shows that the availability of these modern technologies alone is not sufficient to close the gap in the information flow. Much more is needed to guide potential end-users of mobile technologies such as construction companies through the implantation process. Therefore, the authors have developed an all-embracing implantation strategy supporting end-users in their decisions concerning the implantation of mobile technologies into their businesses based on a detailed understanding of the related processes.

Currently, SME do not have adequate human and financial resources to test and implement mobile technologies within their organizations. However, SME are of big economical and societal importance in Europe. Therefore, the implantation strategy developed specifically focuses on the needs of SME in Architecture, Engineering, and Construction (AEC) and addresses the various aspects of the mobile computing paradigm in a holistic way. According to Rebolj (2001) the Mobile Computing paradigm is defined by three overlapping tiers: (1) mobile devices, (2) wireless networks and (3) mobile services.

Funded by the German Ministry of Research, Technology and Higher Education the authors have developed an implantation strategy of mobile technologies for SME in the AEC sector. The strategy efficiently and systematically enables SME to implant mobile technologies into their businesses by analyzing and re-engineering their business cases.

In this way, SME can compensate the disadvantages such as: (1) lack of up-to-date information, (2) delayed integration and validation of collected data, and (3) additional effort to collect and manage data. In the long run this enables SME to improve their organizational and working patterns, strengthen their market competitiveness and increase the qualification profile of their employees.

The implantation strategy was developed as part of the *IuK-System Bau* research project. The strategy is based on the two reference processes activity documentation (construction diary) and management of errors and omissions.

The paper is structured into five sections. Section 2 defines the requirements for the development of the implantation strategy by analysing the characteristics and needs of SME. Section 3 describes the project background emphasising the results of process analysis and system design. Section 4 describes the field tests conducted. Finally, section 5 integrates the findings into the envisaged implantation strategy.

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2 REQUIREMENTS FOR SME

Small and medium-sized enterprises account for the majority of companies in the European AEC sector. About 97 % of all companies in that sector have less than 20 employees and 93 % less than 10 employees, in FIEC (2005). They employ the highest percentage of people, and they generate about 82 % of the turnover in that sector, in Günterberg (2004).

However, SME are much slower in taking up new information technologies, respectively mobile technologies. But in today's time of e-Business, e-Commerce and e-Government the lack of appropriate IT-systems is a serious drawback for these companies, e. g. because contract participation requires electronic procurement and online submission, standardized data exchange, project communication and project information spaces.

The slow adoption of new technologies is due to the tight human and financial resources that do not have the capability to test and implement mobile technologies, in Günterberg (2004). In addition, SME are under-represented within the national and European research funding.

According to the European research rules and guidelines SME are defined as enterprises with fewer than 250 persons and an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million, in EU (2003).

However, SME are very diverse. Therefore, the authors have conducted several end-user workshops during the IuK-project with construction companies, service and technology providers to discuss the potentials of mobile technologies in the AEC sector. During the workshops end-user requirements for mobile technologies were defined, and a realistic picture of the situation of today's SME was obtained.

The authors identified the following main characteristics:

- different level of adoption of information technology,
- heterogeneous proprietary software systems, lacking open data exchange standards or only equipped with a minimal standardized interface,
- limited electronic standardized data exchange,
- different roles (as general or sub contractor),
- flat organizational hierarchies (typically one employee holds multiple roles),
- concentration on day-to-day business with a limited budget for research and IT.

The proposed mobile solution (including the implantation strategy) should be flexible and easy to configurate to meet the particular requirements of a certain company. The following major system features were identified:

- platform independence and integration need into available IT-infrastructure,
- integrated system for all project contractors and mobile remote access to the system (on-/offline),
- use of commercially available mobile devices and network types,
- standardized interfaces to proprietary systems,
- modularity and context adaptation.

3 PROJECT BACKGROUND

The proposed implementation methodology was developed in fulfillment of the *IuK-System Bau* project, which has been funded by the German Ministry of Research, Technology and Higher Education since June 2002. The funding aimed at the investigation and development of mobile solutions for controlling and documentation of construction site processes in SME. Two research institutes and two construction companies were involved in the project. The industry partners provided the system requirements as well as the test cases and test beds. The project work was divided into four phases:

1. specification and analysis of basic technologies,
2. process and requirement analysis,
3. system design and implementation, and
4. field testing, evaluation and set-up of implementation methodology.

Chapter 3 summarizes the results of the process analysis and system design, which were discussed in detail in Menzel et. al (2003) and Menzel et. al. (2004).

3.1 *Process analysis and potentials*

A profound understanding of relevant activities and their inter-relationships is needed to efficiently use and apply mobile technologies and solutions in practice. Furthermore, current management and process models need to be analyzed and re-engineered in order to fully exploit the potentials of mobile technologies.

Within the *IuK-System Bau* project two reference processes were analyzed, namely:

- the documentation process of construction activities resulting in the *Extended Construction Diary* application and
- the errors and omissions management processes resulting in the *Mobile E&O* application.

In the first step, the "as is" status of both processes was modeled - using the ARIS-methodology - and analyzed. Based on these models and in close co-operation with the construction companies (end-users) the processes were re-engineered and an optimized, general "as should be" model was developed. Different knowledge elicitation techniques were applied: interviews with employees of con-

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struction companies, intensive literature review (including technical guidelines, regulations, and recommendations).

Different types of process and data models (e.g. ARIS (with eEPK), UML, and ER-Models) were developed to illustrate and sustainably document the potentials of Mobile Computing applications. Potentials of mobile applications in construction may range from simply streamlining processes to the definition of complete new ways of working, including new organizational patterns, roles, and responsibilities, in Rebolj (2004).

3.1.1 *Extended construction diary*

Construction companies typically document their activities by using a construction diary which provides a summarized view of ongoing activities, occurrences, problems and circumstances at the construction site. It integrates information from other documents such as a list of drawings, a list of attendance or test records in compressed form. It is an important document of the companies' external reporting to the client or main contractor.

Currently, construction diary data is collected paper-based by construction managers or foremen on site. Additionally, it is necessary to collect data for other functional units using their specific forms (e. g. attendance list or material delivery list). So far, data collection is performed redundantly and parallel, but in different granularity and scope, leading to misunderstandings, failures and inefficient process patterns.

Therefore, the *Extended Construction Diary* application was developed to integrate different activities into one single process of data collection and documentation. In this way, the construction manager collects rhe data only once. By using mobile devices, data is immediately stored within an integrated information system. Nevertheless, each functional unit can access and analyze needed data and generate task-specific reports. The advantages of the new process and the mobile application are that data is collected only once but can be used multiple times according to the individual context.

During the development of the extended construction diary, considerable effort was exerted on the analysis of information and its classification as well as for the definition of context parameters, in Menzel et. al. (2003a).

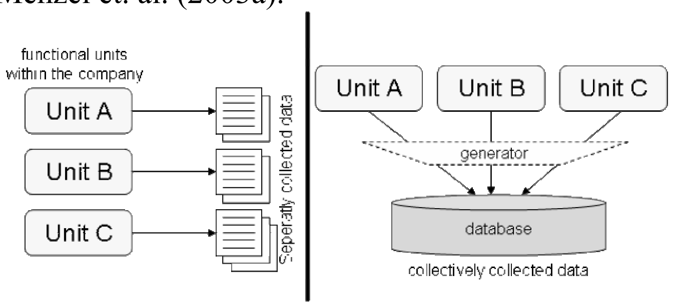

Figure 1: Different modes of data collecting at site

3.1.2 *Errors and omissions management*

The errors and omissions management (E&O) is a critical process for every construction company. Especially a short time before the hand-over of built artifacts, the number of errors can be very high, and the cost to for repairing them can increase in a short time. Therefore, a mobile, process-oriented software solution is needed, which can be used by most of the project participants.

The potential through the usage of mobile technologies arises from integrated data management, on-site data collection and immediate availability of information to all project participants, efficient data acquisition through the support of context-sensitive data acquisition techniques, and elimination of redundant data collection.

E&O processes were analyzed from different perspectives (as recommended in ARIS), namely: (1) the organizational perspective (actor), (2) the functional perspective (activities and events) and (3) the information perspective (documents and devices used).

As a result of the analysis phase it could be specified clearly who needs which information and where. Details of the analysis phase are described in Eisenblätter et. al. (2004) and Menzel et. al. (2004).

Figure 2 describes exemplarily one "shot" of the final process definition. As depicted in figure 2, many tasks such as data collection, forwarding, editing and attaching photos could be eliminated after the introduction of mobile applications.

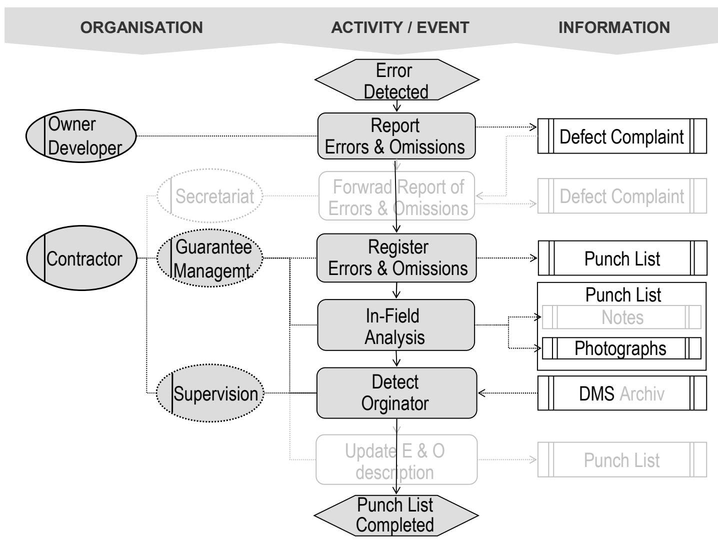

Figure 2: *E&O* Process.

3.2 *System design*

In the next step, single mobile applications need to be flexibly integrated into sophisticated information management systems. Existing IT-system need to be extended by the anticipated mobile business cases as defined during process analysis.

System design is based on the results from the requirement and process analysis (see chapter 2).

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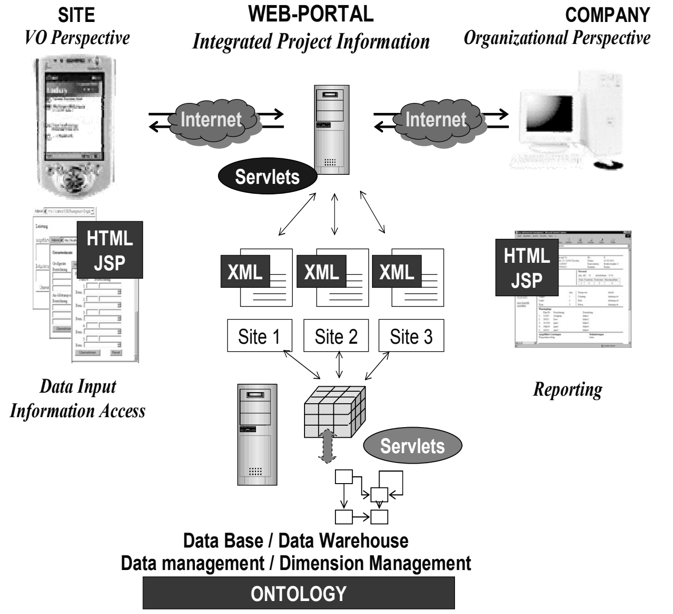

Figure 3: Infrastructure of the *IuK-System Bau*.

The system was designed as a web portal to allow easy integration into existing ERP-systems or to extend them. Access via mobile devices can be provided in online or offline mode through standardised interfaces ensuring secure data exchange.

Another design principle was to separate content from layout. This was achieved by using XML/XSLT technologies complemented by JSP.

Whenever possible, the system should work in online mode, securing up-to-date information and avoiding version or conflict management.

The user, working on construction sites, should be provided with context-sensitive services and information and not be overloaded with irrelevant information. Therefore, data is structured into applications, core data and classification data and managed in a multidimensional way by using the data warehouse paradigm.

Finally, the user shall not be hampered by inappropriate services and cumbersome in- and output techniques. Multi-modal interfaces were designed to address this requirement.

4 EVALUATION

4.1 *Evaluation goal and scope of field tests*

End-user involvement had a high priority in the *IuK-System Bau* project. The first prototypes were developed according to the principle of rapid prototyping and were tested in several field test cycles. The results of the field tests significantly determined the implantation strategy. The field tests were conducted to evaluate the functionality and usability of the software prototypes developed, including mobile devices and network types used.

The test methodology and test results are exemplarily described for test #1 (see table below).

Table 1: Overview of conducted field tests.

#	Type of site	No. of workers	Project costs	Company size	Region	Season
1	new building	~30	average	medium	city	Winter - Summer
2	renovation	~8	low	small	region	Winter
3	new building	~100	high	large	city	Winter

4.2 *Background of field test #1*

Field test #1 was performed on the construction site of the new building for the Department of Computer Science at the Dresden University of Technology. Construction activities started in autumn 2003 and are expected to be completed by autumn 2005. One of the project's industry partners was responsible as the general contractor (rough construction).

The construction site is situated in the southern part of the main campus of TUD. The building is a three-storey building with an underground floor. The building is composed of three main wings (west, middle and east wing) which are connected by so-called connectors. The wings are enclosing a glass-covered atrium and a u-shaped glass-covered foyer. The site covers an area of 100 m x 170 m. The foundation and the rough construction were constructed by one of the *IuK*-project partners. The tests of the mobile E&O management application were performed between January and August 2004.

During the rough construction phase a total of 7 companies were involved in the construction process. Approximately 3 or 4 companies were working at the site simultaneously. The industry partner of the *IuK-System Bau* project acted in the role of a general contractor by coordinating and controlling its sub contractors. The site is situated within the city and is covered by GPRS and UMTS networks.

4.3 *Field test organization and test methods used*

The evaluation phase was divided into three steps: (1) preparation of tests, (2) tests, and (3) analysis of test results. During the preparation phase a wireless network was installed and the devices were set up. Further, the overall evaluation criteria and the parameters to be observed (actor, device, network, location, task and time) were defined, see table 2.

Table 2: Instances of context parameters.

context parameter	instances
actor	foreman, construction manager, sales manager
device	PDA, rugged PDA, Tablet PC
network	GPRS; UMTS, W-LAN
location	in-house work, field work,
time (construction progress)	excavation, foundations, placement of formwork, reinforcement, concreted, replacing of formwork, finishing.

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Table 3: Tested combination of device and network type.

	MDA	Toughbook	Tablet PC
W-Lan	X	-	X
GPRS	X	X	-
UMTS	-	-	X

The intention was to evaluate the prototype in different situations (working contexts). Therefore, situations with combinations of several parameters in different contexts were defined, see table 3.

Strong efforts were dedicated to the preparation of the test personnel including: motivation, introductory seminars, preparation of tutorials and discussions during field-tests. Additionally, schedules were provided to the test personnel, specifying exactly the time when which device had to be tested and which task needed to be performed. Finally, an online questionnaire was prepared and was accessible as web-based application. The test persons were able to consult an assistant from the research group at any time during the test, who visited the site, answered question, downloaded and analyzed the results.

4.4 *Network tests*

4.4.1 *Goal and test method*

The network tests covered three different network types: (1) GSM/GPRS, (2) UMTS and (3) W-LAN based on the IEEE 802.11g standard. The goal of the network tests was to evaluate the availability and quality of service, installation efforts and operational costs for the company. Additionally, a special focus was placed on observing the change in availability and performance of the network due to the construction progress and the change of the building's shape. The results of the network tests will guide decision makers in construction companies in choosing which type of network is applicable in specific working situations. We have conducted two different network tests.

Test 1 intended to measure the relationship of signal strength and time to connect to the network as well as the response time of the web portal. The measurements were taken on site at 45 points weekly. Together with the technical parameters we documented time, weather conditions and battery status of the mobile device used. The construction progress was documented in sketches and photographs.

Test 2 intended to document the usability as experienced by the test personal while accessing the software prototype. The results were obtained through interviews and questionnaires.

In preparation of the field test each network type had to be made available at the site. GPRS and UMTS were available from different network providers. W-LAN required the installation of a hotspot at the site. Several alternatives were planned; figure 4 shows the final topology.

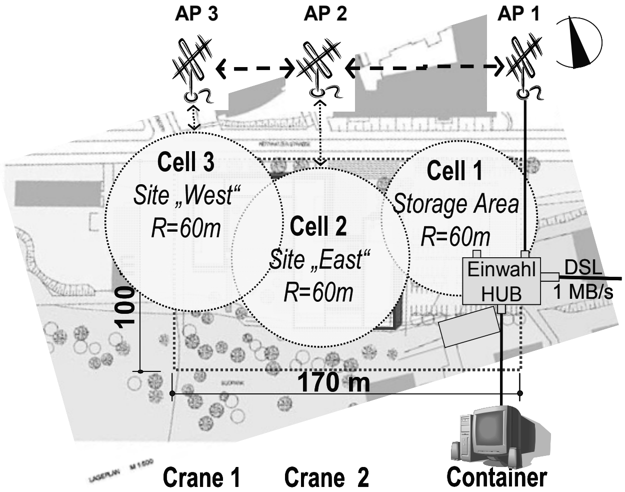

Figure 4: W-Lan topology with three APs at site.

The Internet access was provided by a DSL-connection (download with 1024 kbit/s, upload with 256 kbit/s) which was spread over the site area by three access points (AP). One AP was installed in one of the construction trailers, the two others were installed in the crane cabins. The installation of AP at the highest level of the site (see figure 4) assured network access at least at the top working-level during rough construction.

4.4.2 *Results*

The tests have proved that all three network types provided a sufficient download and upload speed for running the software modules. Table 4 summarizes the results for the different network types.

W-LAN networks have big discrepancies. On the one hand, W-LAN provides the fastest data transmission rate. On the other hand, it requires relatively high investment and maintenance efforts. Due to its dependence on electricity the reliability of W-LAN was less stable than the two other network types. Whenever the AP at the first crane was out of service, the other AP was affected because of the W-Lan bridge installed on crane 1.

While the costs for using GPRS or UMTS access can only be estimated, there is no cost for using the W-LAN in case of internal communication. However, the costs for the W-LAN are comprised of investment and costs for maintenance and operation.

Table 4: Comparison of different network types.

	WLAN	UMTS	GPRS
dialing-in time	very fast	fast	satisfying
site-build-up	very fast	fast	satisfying
network installation efforts	middle	low	low
device configuration efforts	low (only insert card)	low (only insert card)	minimal (GPRS is pre-installed on the device)
availability	good	very good	very good
costs	middle	very high	high

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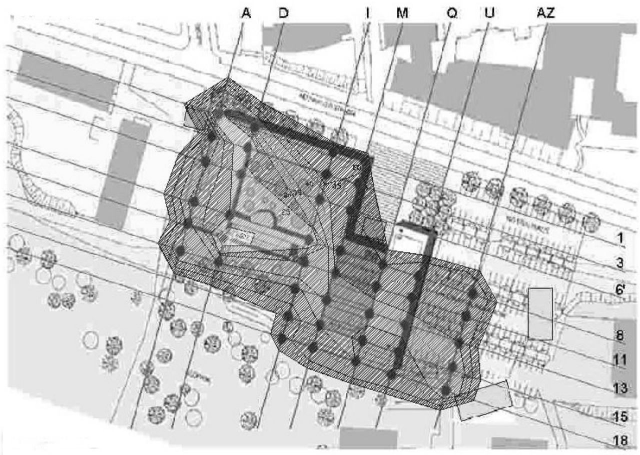

Figure 5: Iso-line representation of the LanCom Monitor-tool.

The authors predict that in case of intensive usage over a longer period of time W-LAN networks are more cost-efficient than GPRS or UMTS. The breaking point cannot be specified generally. It has to be determined on a project-specific basis.

During the comprehensive W-LAN tests we have measured varying signal strengths of between 20 % and 50 % with an average of 38 %. With a data transmission rate of about 11 MBit, the rate remained high constantly during the measurements, which confirmed the usability results of the test personnel. The W-LAN was the most preferred network type of the test personnel because of the fast response time.

The graphic representation of the signal strength (figure 5) shows that highest signal strength (darkest color) was achieved at the border of the construction site, while the center had the lowest values (lightest color). The reason was the location of the AP in the middle of the site at 15 m height and the directed transmission.

4.5 *Mobile device tests*

4.5.1 *Goal and test method*

The main goal was to evaluate the usability of different types of mobile devices for their usage on site. The following types of devices were tested: (1) Personal Digital Assistant (MDA III), (2) Rugged PDA (Panasonic Toughbook 18), and (3) Tablet PC (Fujitsu Siemens Stylistic ST 4110).

The tests were conducted in a two-step process. In the first step, technical paramenters such as processor type, clock frequency, storage capacity, battery type, display size, interaction means, operating system and built-in camera, were ranked by the test personnel according to the necessity for their work.

In the second step, the ergonomic criteria of each device were evaluated during usage: size and weight, functionality of the display, functionality of interaction devices and robustness of the device.

The focus of this test was on determining whether specific roles of an actor prefer a particular device.

4.5.2 *Results*

The PDA (type 1) received the highest appreciation from the test personnel. The rugged PDA (type 2) was evaluated as very attractive by foremen and construction personnel. In opposition, the Tablet PC (type 3) was evaluated as not suitable for usage on site by all test persons. Results summarized in table 5.

The weight and size of the PDA was very convenient for the test persons so that, in opposition to the rugged PDA, the test persons stated that it is no problem to carry the PDA the whole day. The advantages of the rugged PDA are its robustness and comfortable handling for hard-working personnel, e. g. by the carrying loop. The Tablet PC was evaluated as too heavy and bulky.

The displays of the PDA und the rugged PDA have only minimal differences and were ranked as ‘good’ by the test personnel. The small size of the displays was no restriction because the GUIs of the software modules were optimized to that size.

There was no problem using these devices in bright sunlight. The Tablet PC has a bigger display size; however, it was disqualified because it could not be used in sun light.

The preferred interaction mode for all devices was the pen in combination with the soft-keyboard. While there were no problem in using the keyboard with the PDA and the rugged PDA, usaging the keyboard of the Tablet PC was not as easy. The extra hard-keyboard on the rugged PDA was, unexpectedly, used rarely by the test personnel.

Table 5: Evaluation of mobile devices.

	MDA III	Toughbook 18	Stylistic
size, weight	+	0	-
display	+	+	+ / - (in sun)
interaction means	+	+	0
robustness	0	+	-

Legend: (+) good, (0) satisfying, (-) bad

4.6 *Software tests*

4.6.1 *Goal and test method*

According to the software evaluation approach proposed by Böhm (1981) and Balzert (1998) the prototype was evaluated in two tests.

The functionality test incrementally assessed the functionality of each single unit (graphic user interface). The test persons had to determine whether the provided functionality and data were appropriate and which were missing.

Business-process oriented test focuses on testing the application developed within a complete business-process sequence. Evaluation was performed by using usability criteria defined by the IsoMetrics technique. This technique provides a user-oriented, summative as well as formative approach to software evaluation on the basis of DIN EN ISO 9241,

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Part 10. The test covers the evaluation of suitability of task, software handling (controllability, learnability, conformity with user expectations), and software performance (error-tolerance, individualization and self-descriptiveness).

The evaluation of each item is assessed on a five point rating scale with a further 'no-option' to reduce arbitrary answers. The IsoMetrics design provides information that can be used within an iterative software development.

4.6.2 *Results*

Due to the incrementally conducted test of functionality the final prototype presented a well-balanced prototype.

The results of the business-process oriented test confirmed good usability of the overall prototype. The criteria suitability of task is an important indicator for the well-balanced design of the prototype which integrates and spanns over all aspects. The graphic user interfaces (GUI) and command sequences were evaluated as 'good'. In some cases, the test personnel requested entering free text instead of choosing from a list of pre-defined text blocks.

Software handling was evaluated as diverse. Users requested improving the controllability criteria. They especially asked for less static GUI sequences. The conformity with user expectations criteria and learnability criteria were evaluated as 'very good'.

The criteria in the category software performance were generally marked as good. Especially the error tolerance critieria received good marks because test personnel appreciated the highlighting of errors and adding advices. At the beginning of the tests, the prototype did not provide sufficient means for individualisation. Indeed, web applications typically do not provide many means for individualisation. One example for the requested individualization is the configuration of columns in *E&O*-reports.

5 SUMMARY

As one major result of the field tests an implantation strategy and related guidelines, especially focusing on the needs of SME, were developed.

5.1 *Scope and goal of the implantation strategy*

The implantation strategy aims at the provision of experience values and best practise cases to design and introduce mobile technologies in SME in the AEC sector. The strategy consolidates the results of the project, especially the findings of the field tests. Furthermore, it explains the prototypically developed web portal. The strategy is strongly end-user oriented with the intention to serve as a systematic decision base for company owners of SME.

The strategy is structered into three categories: (1) mobile devices, (2) wireless networks, and (3) mobile services. Each category is described by relevant criteria and their interrelationship. The categories and criteria relate to the context parameters defined in Menzel et. al. (2004). Criteria are structured hierarchically and have functional dependencies. Most relevant criteria in each category summarized in the following sub-chapters. For example, there is functional dependence between the availability of network and mode of operation because, whenever there is no network available, the mode 'offline' is the only one available.

5.2 *Categories of network types*

The availability of a wireless network connection is a pre-requisite for the usage of mobile online services on site. Therefore, the availability of a network is a knock-out criterion. Relevant context parameters are the location and the application (amount of data).

Further selection should be based upon the following criteria stated in table 6.

W-LAN might be the suitable network type in long term projects or rural areas because of low operation costs, high bandwidth and independence of commercial mobile telecommunication networks (GPRS, UMTS). For shorter usage time periods and a small amount of data to be transmitted, GPRS or UMTS might be more economical.

Table 6: Evaluation criteria for network types.

network types															
technical criteria			quality of service						economical criteria			environm. criteria			
transmission rate	range of signal	etc.	signal strength	data flow rate	delay	reliability	dialing-in time	etc	investment costs	maintenance costs	operation costs	type of site	type of region	etc.

5.3 *Categories of mobile devices*

The selection of the appropriate mobile device is strongly influenced by the context parameters actor role (which determines the task and software module), personal preferences and location (weather conditions).

The category can be characterized by the criteria set in table 7. The most relevant criteria for field personnel are size and weight (easy to carry, convenient to handle) and display characteristics (usable in sunlight). Technical criteria were only of secondary interest; in particular, the different types of mobile devices do not significantly vary in their technical criteria. Robustness might be relevant for actors permanently working in the field.

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Table 7: Evaluation criteria for mobile devices.

Mobile devices	technical criteria	processor speed, storage capacity, number and type of interface slots and operating system
	display criteria	size, resolution, colors, quality
	navigational criteria	type, mode
	connectivity criteria	build-in communication protocols
	usability criteria	size, weight, robustness, temperature range, battery duration
	economical criteria	costs for investment, maintenance, operation (software licenses, etc.)
	functional criteria	data-voice-integration, document edition, personal information management appl.

The project defined following three types of mobile devices, see table 6.

Table 8: Types of mobile devices.

PDA/Smartphone	Rugged PDA	Tablet PC
classical PDA or Smartphone 	protected from dust, water and shocks, works in larger temperature range 	ability to flip the touch screen; 

5.4 *Categories of mobile services*

The category *Mobile Services* is the most complex category. It supports the user in the specification of the final end-user application and indirectly supports the underlying IT infrastructure. However, a thoughtful in-depth analysis of business processes and identification of re-engineering potentials including mobile use cases are pre-requisites.

The analysis should be structured along following 7 defined criteria as shown in figure 6.

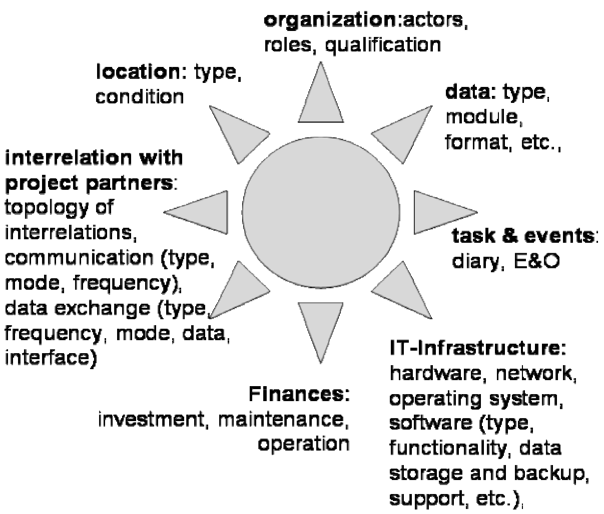

Figure 6: Evaluation criteria for category mobile services.

Exemplarily, specification of data is a major step. There the data available in the existing IT-system has to be described in terms of data type, mode, etc., as well as the data that needs to be exchanged. In the advent of *e-Business and virtual organization* communication and data exchange plays a major role, which requires interoperability of software systems by standardized interfaces and protocols in SME.

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Web-based integrated construction management solution

K.U. Gökçe & R.J. Scherer
Institute for Construction Informatics, Technical University of Dresden, Germany
H.A. Dikbaş
Project Management Center, Istanbul Technical University, Turkey

ABSTRACT: Construction projects are becoming more and more sophisticated, as a result of increased client requirements, tighter budget and time frames, larger number of participants and more complex work processes. However, especially in the area of construction project management (CPM) these growing requirements are not yet sufficiently addressed by today's IT. Even though several systems integrating CAD, ERP and CPM tools have been developed and brought to market over the last years, there is still lack of efficient data and process interoperability for the purposes of CPM. Also, solutions are mostly proprietary, taking little account of established standards for the improvement of the quality of the product and the management processes.
In this paper we analyse CPM processes in terms of the needed applications and on the basis of generalised industry requirements. We describe the construction management life cycle model and suggest an IT framework for an integrated CPM system that can bring together design, ERP and CPM tools on the basis of standardised shared data (IFC) and standardised quality management procedures (ISO 9001). Reported is work that started at the Istanbul Technical University on more practical terms and is now continued, generalised and expanded at the TU Dresden in the frames of a PhD study.

1 REQUIREMENTS TO INTEGRATED CPM

Today, it is generally believed that the integration of different types of software applications is a key instrument to improve the efficiency of the construction environment. However, even though several systems integrating CAD, ERP, and CPM tools have been developed and deployed, and the interoperability through connection of different types of products and CPM processes has led to considerable cost and time reductions, complete and generalized industry requirements based on standard models are not yet available. This significantly decreases flexibility, the information exchange between different systems, multi-stakeholder collaboration and, last but not the least, inter-enterprise cooperation and knowledge transfer. In spite of its potential, the upcoming common project model IFC of the International Alliance for Interoperability (IAI 2005) is practically not used for construction management purposes.

On the other hand increasing demands of quality in the AEC sector force construction companies to observe established guidelines for better quality management and product outcome. Accordingly, most companies have engaged with ISO quality management standards and established their process structure in accordance with (ISO 9001:2000). However, this trend is yet purely supported by CPM software.

A further issue that deserves consideration is the Internet. Collaboration through the Internet supports concurrent management of construction activities and enables achievement of better quality and shorter time to market. During the last decade established and new start-up companies continuously increased their use of the Internet for management applications. However, many business plans were not accepted as feasible because they were not grounded on a standard-based collaboration system.

In accordance with these briefly outlined issues, in the next sections we discuss major requirements to *web-based integrated management solutions* that are to be observed in order to foster successful application.

1.1 *Requirements from Concurrent Engineering*

Information technology has a decisive effect for the improvement of both the organizational and the technological infrastructure of construction projects so as to facilitate the effective application of concurrent and collaborative engineering practices.

Valuable steps for concurrent engineering in the AEC domain have been achieved in product model based integration (by ISO 10303 STEP, IAI/IFC and many European projects such as ToCEE, ATLAS,

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VEGA and others), in process modelling (by the CALS, IRMA and GPP initiatives, as well as by projects like eConstruct, OSMOS and ISTforCE), and in workflow developments and electronic document management - by the WfMC and several commercial and academic electronic document management systems (cf. Amor 1996, Scherer 2000, Katranuschkov 2001). Especially the industry driven IFC/IAI initiative can be identified as a major contribution to the standardization of concurrent model-based working processes.

However, in spite of all achievements for managing the process, product, documentation and communication, the organisational and information infrastructure in the AEC sector is still highly fragmented.

In particular, when the aspect of concurrent engineering is observed, the lack of standardized product and process models appears as a major handicap. Collaborative work heavily depends on parallel activities and information sharing during the design and construction processes. Accordingly, the specific characteristics of the construction environment have to be defined. Based on observations from (Amor et al. 1997), we can categorize these characteristics as follows:

1 Each major construction project is in fact an example of a virtual enterprise. It is quite common to have projects where the architects and engineers are from different countries, and the virtual product (i.e. the bid documents) of hundreds of hours of high-skilled labour exists as a complete package for the first time in the blue print shop. Also, in no other industry would a team of such breadth be routinely dissolved after executing only a single copy of the product.

2 Through the increased use of IT in the last years, architecture and engineering have become typical information based professions, requiring - because of the nature of their work - highly decentralized data management solutions. However, communication and data exchange in a project happen often between different organizations, operating within different domains of AEC. A large variety of heterogeneous IT tools and a wide range of technologies are being used, and hence the needs of sending and receiving applications are not a priori predictable.

In this context, to manage a building project in collaborative way requires to establish adequate software support, a general process methodology and an overall architecture for the technical work in the area of the design of buildings, construction process planning and project management. To fulfil these requirements, a conceptual framework which allows different partners to use the common processes and interrelated interoperable models need to be defined, and a web-based integrated management system using ISO quality management standards supported by CAD, ERP and CPM has to be realised.

1.2 *Requirements for Interoperability*

In the envisaged interoperability framework the activities and information flows should ideally cover the whole life cycle of a building. The product, the document and the information flow have to be defined under accepted processes. In this context, a feasible methodology for interoperability should deal with:

1 *The IFC model of the IAI initiative* (IAI 2005) (for a hierarchically structured product model).

2 *The ISO Quality Management System* (ISO 9001) (for the existing real-world process specification for managing the quality requirements of outcome)

3 *Web-based integrated methods*, encompassing the product and process information exchange within the CAD and CPM systems that support the IFCs.[*)]

2 THE CONSTRUCTION MANAGEMENT WHOLE LIFE-CYCLE MODEL

The specific requirements and the highly distributed nature of the construction industry, and the independently used systems for management processes provide the rationale for setting up the basic principles of the proposed system.

In this context the construction management whole lifecycle and the operational ICT framework can be defined. Their major characteristics are outlined in the following sections. The whole lifecycle model is shown on the high level in figure 1 below.

Generally, a construction project proceeds through the following stages: (1) feasibility & design, (2) preliminary preparations (measurement, bill of quantities, budget etc.), (3) planning & execution, (4) realization, and (5) evaluation of the outcome. These stages vary for different countries, but the basic principles are the same. In all stages specific databases and algorithms are used. All these databases must keep the information about their function and content in suitable structures and algorithms so that they can be further reused by the other stages whenever required.

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*) Whilst not yet deployed in practice, examples for such methods are provided by the Eurostep Model Server (Eurostep 2003), the SABLE project (Houbaux et al. 2005), and in the work of Weise et al. (2004).

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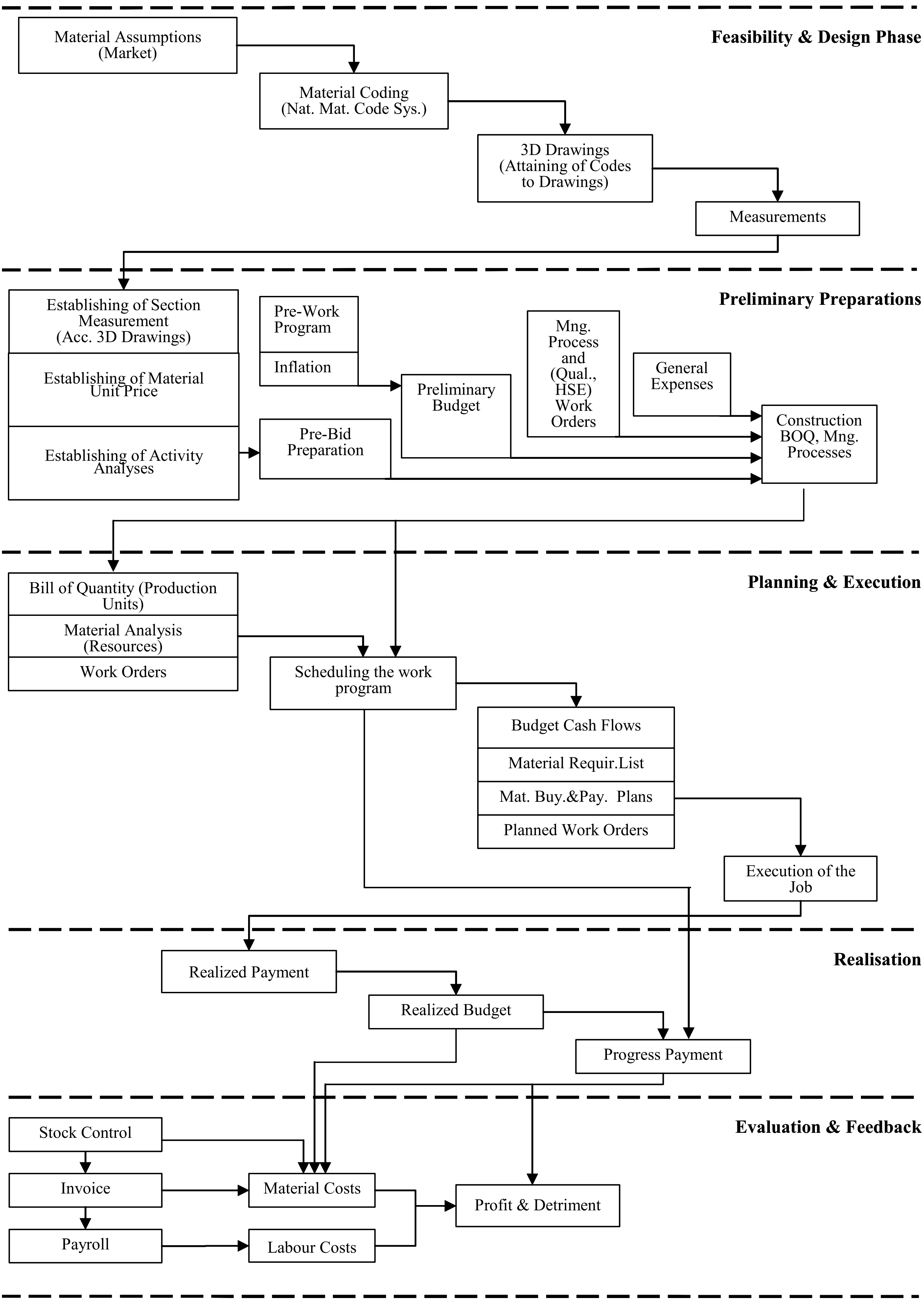

Figure 1: The Construction Management Whole Life-Cycle Model.

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In the *Feasibility & Design Phase*, the architectural and structural drawings, and the installation schemes of electricity and plumbing provide the database of the initial processes of the project. These schemes and drawings are the inputs for the technical applications defining the construction details, the measurements and the section lists. 3D drawing models with their identities can be established with the assistance of other databases. For example, door, window, decoration objects or other technical drawings are taken from the software object libraries of the design software (such as Nemetschek's Allplan or Autodesk's AutoCAD), the material codes can be taken from national/international code systems or from special databases etc. Combining these outcomes allows to visualize a project three dimensionally, and – more importantly - to report and export the *quantity surveying and the section analysis* in a desired format that can be used in other stages of the CPM process.

In the *Preliminary Preparations Phase,* after the quantity surveying is finished, cost estimates can be established. These estimates, typically prepared on the basis of the construction diagrams and the technical specifications, are actually the pre-budget in terms of quantity and finance.

In this context a proposal should be prepared based on the cost estimation and conforming to the owner's requirements. Measurements should be checked, recalculated and classified. Based on the production analysis, unit prices are calculated, and market values are checked. At the same time, with a speculative work schedule, the effect of inflation, the budget and cash flow tables have to be done. This requires collective work in the company. One group performs the quantity surveying and creates the measurement database, another one does the market research and creates the unit price database, a third one makes the construction cost analysis with respect to the company standards, and a fourth one prepares the work schedule and creates the budget and cash flow tables. These databases have to be inter-related. Each data produced in one group is needed by another group, i.e. highly cooperative work is required. Hence, an approach of integrated construction management tools is required that can support reliable bi-directional information exchange between the CAD and the CPM applications.

In the *Planning & Execution Phase* the planning of the activities or designation of the work order (pursuing of work order), identification and assignment of the appropriate labour and material resources, determination of the pre-budget and determination of the real-budget for the progress payment is done. For managing of the execution processes at the jobsite the quality management, technical inspection, contract and HSE management procedures should be followed.

Construction planning systems (such as Primavera, Suretrak, Artemis etc.) have the ability to schedule and report the allocation of the resources. To achieve that, activities should be defined with

– the quantities of their resources, and
– the monetary values of these resources.

These items can be tackled in the *preliminary preparation phase.* They can be re-used within these two phases if adequate information exchange can be established.

It is important to have a decision about material purchasing. It should be known which material is going to be used when and in what amount. The material requirement list with the amount and work program received from CPM helps to take material purchase decisions so that a payment plan can be easily created. Pre-budget can be estimated based upon the income and expenses which were already determined in the proposal, according to the values of a CPM solution. The income is related to the production and the sales price of the production at some future period. The distribution of the production over time is determined in the work schedule. The material requirement which is also determined in the work schedule is the budget expense and can be retrieved and reported periodically. To calculate the pre-budget and the real budget the resource costs of the activities, the estimation of the inflation, and the sales prices of the productions are required.

The above data is found in the *unit price and analysis* databases. The ***"****Pre-budget" and "Real budget****"*** reports are created using the data received from these databases and the CPM software.

In construction practice, most projects are easily managed according to a CPM program by continuously consulting the work orders. Such work orders can be reported automatically every morning. They provide the list of tasks to be performed during the day or week by any unit or technical personnel, and they can be reported and received easily.

Project, cost and *period* have the dimensions of quantity, time and money and should be examined by data evaluation programs based on arithmetical algorithms. These concepts should be considered under the title "*management and planning*". The related processes depend on people's ability to manage, software and tools that are used, and the direction of management decisions.

Concepts of *quality, agreement* and *HSE* should be considered under the title '*supervision*'. They are not limited by the 'talents' of the manager. Rather, they are the objectives that are determined by agreements, standards, and contracts. There are no formal arithmetical algorithms for their determination, but they are conforming to heuristic rules, methods and standards. Related to this approach is the '*management process layer*'. It will be discussed in the following sections.

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In the *Realization Phase* actual payments, realized budget and progress payments have to be considered. During the calculation of the planned budget, purchase decisions are taken, payment plans are formed and the resulting cash flow is foreseen.

Real payment is something different. On the construction site, the necessary purchase decisions are taken and a budget is estimated. However, the real budget is calculated not based upon the demand from the construction site but also the demands from the headquarters. From headquarters viewpoint all projects are considered as a whole, and the payment plan is arranged depending on the degree of importance. In other words, real payments are made according to the possibilities decided at the headquarters, not according to what is required at the construction site. At that point, the *"Real Budget"* is formed. However, it cannot be certain that the central management takes the right decisions, and it is hardly possible to compare the planned budget, the required budget and the real budget and to inform the management about the ratio of the realized portion of the work to the planned. Therefore, ad-hoc co-operation forms should be set up so that all participants in the project can reach their own project data and can easily share this with the other units.

On the other hand, progress payment is a partial payment paid by the owner, verifying that portions of the work have been accomplished. Basically, it is an invoice showing the quantity of the realized construction, the unit prices of the construction items and the cost of the realized construction. The conditions, payment intervals and the format of this invoice are defined in the agreement.

Related with this, if the work schedule is appropriately followed, all work orders can be given by the software, and all changes related to the activities can be updated daily. Thereby, the work schedule can be also the source database of the progress payment reports.

In the work schedule, we can easily follow when and in what amount production will be or has been made, i.e. the portion of the construction completed within a certain period can easily be figured out using the work schedule. The evaluation of this quantity data with the prices in the analysis or unit price database provides the content of the invoices *"progress payment"*.

In the *Evaluation & Feedback Phase* the cost of each construction item is defined and it can be tracked which invoice was issued for what construction item. A database can be established to reflect that simple relationship. Tallying can also be processed in the same database, i.e. which worker worked for what construction item on which day. The construction item costs and the labour costs can also be processed in the same database to calculate the "*real construction costs*" and the "*real labour costs*". Also, the actual costs of all resources during the realization phase of the project have to be determined (for example, material and labour costs are determined from the stock records and the tally lists).

The analysis of each construction item can be compared within the proposal to provide the values 'as estimated' and 'as realized'. This comparison clearly reveals the profit or loss during the construction of each item. Another advantage of making the comparison is that the stocks are continuously kept under control. Following the real stock movements enables to determine the material costs in those analyses better, and to follow the purchases and excess material amount more consciously.

The information required for these purposes must be entered in the system and reported in different formats. Otherwise, this knowledge gained by experience is going to be forgotten. At the completion of each project, recording the experience in the firm analysis and the firm unit price database ensures a strong basis for future proposals and decisions of the company.

Such a database represents the so called "*firm memory*". It enables the users to conveniently access various types of important information such as:

- construction analyses,
- unit prices and market values,
- technical specifications,
- planning of execution,
- budget, stock, payroll, profit and loss records,

and re-evaluate the work of a finished project.

According to the whole life cycle model shown in figure 1, the activities and information flows to be supported in the targeted integrated CPM solution should cover most the whole life cycle model of a building. In this broad scope, various types of information entities have to be considered in their inter-relationship: (1) the information about the constructed facilities, including construction products, processes, documents, regulations, contractual requirements etc. (2) the information about the model itself including the information representation (files, databases), the information processes and the components of the environment such as servers, clients, users, applications etc., and (3) the information about the information, including concepts like ownership, access control and versioning.

Therefore integration of the inter-related information aspects of a building project into a consistent conceptual framework is of primary importance. These aspects are: the product, the document, the information flow and the process models.

3 SUGGESTED OPERATIONAL FRAMEWORK

The operational framework has to be established according to a coherent process and information exchange paradigm. We suggest a layered structure,

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comprised of 4 clearly defined layers: (1) Application Layer, (2) TSD Layer, (3) Management Process Layer, and (4) WPA Layer. They are described in more detail in the following sections.

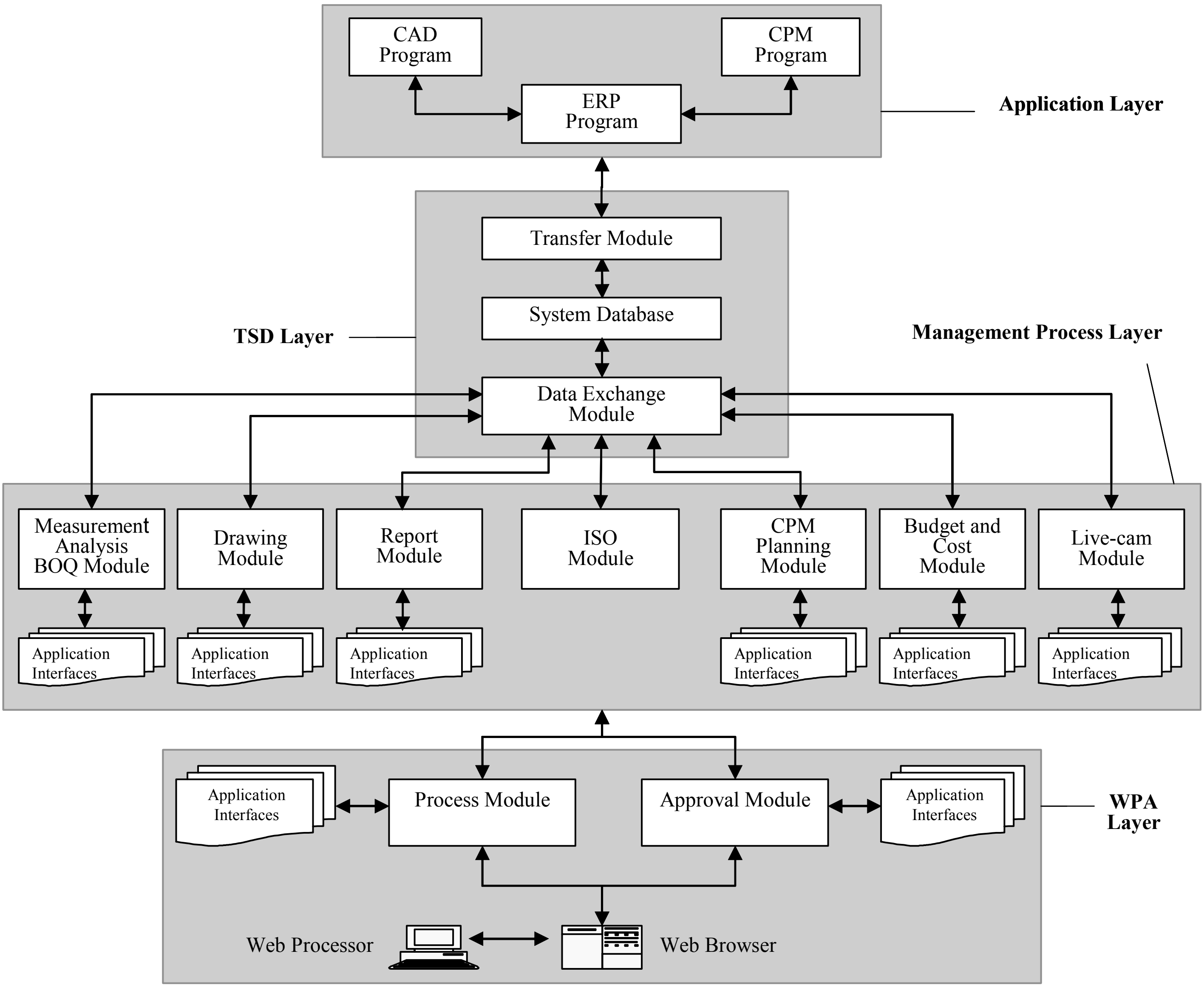

Figure 2: Web-based integrated CPM solution supported by quality management, design, ERP and planning Systems.

3.1 *Application Layer*

The purpose of this layer is to support different types of project activities, performed with the help of CAD, ERP and CPM programs. The main target is to combine the construction site and project partners' databases, thereby allowing improved project/cost control, increased work efficiency and fast response to changes within the construction environment. The layer is structured and established in accordance with the interoperable CAD-ERP-CPM environment outlined in figure 3.

On the basis of experience gained from studying a number of state-of-the-art systems, the method of establishing a collaborative work environment that is grounded on an interoperable system should fulfil the following objectives:

1 Generalize and formally describe construction project management processes comprising the whole construction management lifecycle in order to support interoperability over a broad spectrum of applications,
2 Provide a common information model for construction project management based on the data schemas of the IFC standard, thereby ensuring the needed integration of product, process, cost and management data,
3 Provide interoperability methods to integrate legacy systems,
4 Provide algorithms for completeness check and an assistance system based on context analysis to interactively establish completeness.

The approach is based on using and appropriately combining methods for requirement analysis (quality function deployment, critical success factors, use case analysis), process modelling (IDEF0, UML), and STEP-based product modelling (EXPRESS) - to identify and formally define *necessary IFC extensions*. System APIs are conceptualised using the

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object-oriented modelling method, and the system itself is established as a client-server environment, integrating the component tools as services via a common GUI implementing the Web Services concept (Vasudevan 2001).

In preparation to the actual realisation work an extensive study of existing systems, earlier standardisation efforts and applicable integration and interoperability methods are being performed.

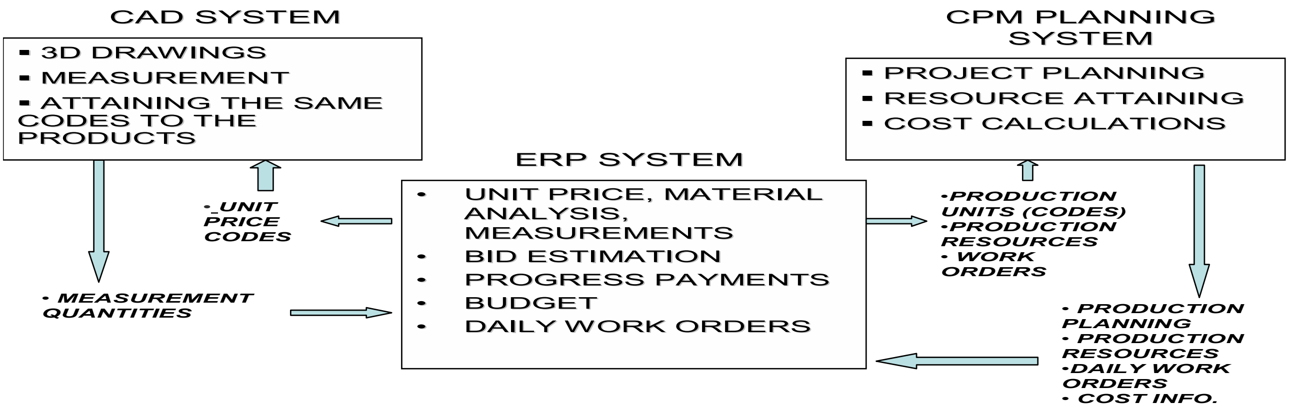

Figure 3: Integrated client-server architecture of the Application Layer.

3.2 *TSD Layer*

This layer consists of a Transfer Module, a System Database and a Data Exchange Module. The information that can be obtained from the application layer is stored in the *System Database*. This information should cover the identified needed outcomes of the CAD, ERP and CPM programs. The *Transfer Module* supports the data exchange between the *Application Layer* and the *System Database*. Assuming that IFC data can be exported by the involved applications, this can be done with the help of a general-purpose API in a convenient format (using ISO 10303-21 files and/or ifcXML). Information is transferred to the *Data Exchange Module* which is the coordination module for the below layers, ensuring synchronous and asynchronous information flows in a standardised, regular way.

3.3 *Management Process Layer*

The Management Process Layer consists of 7 different modules that can perform and be managed separately. Five of them, namely the *Measurement/BOQ Analysis Module,* the *Drawing Module,* the *Report Module,* the *CPM Planning Module,* and the *Budget and Cost Module* include and further process the data obtained from the *TSD layer.* Additionally, a *Live-Cam Module* can be provided to track execution on the jobsite, and an *ISO Module* can be included for process support in accordance to *ISO Quality Management* procedures. This module would also allow to observe the approval process within the partner organisations and within the applications.

3.4 *WPA Layer*

The WPA Layer provides the facilities for (1) execution of the management processes and the related applications via the Internet, and (2) presentation of the obtained results to all stakeholders via a common Web Browser. The process workflows can be carried out using a standard based schema, and on every step the information can be checked and approved by the responsible persons who are attained by the project organization.

3.5 *Prototype Implementation*

The suggested framework is prototyped in the frames of a PhD thesis '*Web based Integrated Construction Management System for ITU Campus Construction Sites',* carried out under the supervision of Prof. Dikbas (cf. Yitmen 2001). The implementation is based on proprietary interfaces. Planned further work involves realisation of IFC support for the data exchange and ISO 9001 support for process. Figure 4 below illustrates the workflows within the system and provides example screenshots from its use.

4 CONCLUSION AND OUTLOOK

In this paper we suggested a general framework for integrated construction project management, which is based on clearly defined collaboration between project partners. We described the developed construction management whole life-cycle model related to the general workflow schema of the processes, and outlined a conceptual client-server environment architecture that can fulfil the identified requirements.

The goal of the system, currently under development, is to handle various types of information coherently, including product, process, and management data, and to provide seamless information exchange between the actors and tools in the process.

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This development is not done from scratch. Related with the suggested approach is the ProIT project which also addressed development of product model based process and modelling its data exchange. ProIT compiles design guidelines needed in product modelling and establishes model structures for the re-use of product libraries (cf. ProIT 2004). It can provide valuable input to our further work.

Another effort that calls for close consideration is the SABLE project which has developed a set of APIs to access IFC model data in a client-server environment (Houbaux et al. 2005). Along with emerging IFC import/export functionality in legacy applications this establishes a good foundation for coherent IFC-based implementation of the outlined conceptual framework.

Thus, further development need is seen especially in the novel formalisation of ISO 9001 procedures, their realisation within the system and integration with the product data.

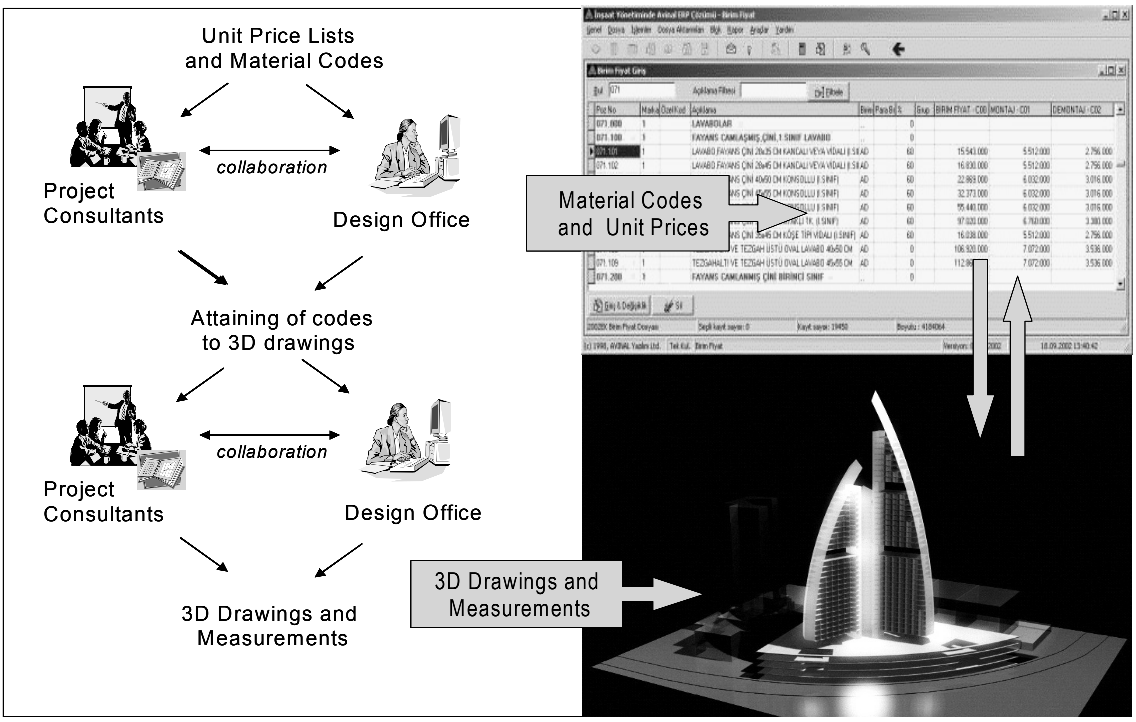

Figure 4: Schematic presentation of the workflows in the prototyped integrated CPM system.

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Learning Construction Decision Making with Arbitrator - Competing and Evolving in Dynamic Role Interplay

Kun-Tai Kao & Teng-Wen Chang
Graduated School of Computational Design, National Yunlin University of Science & Technology, Douliou, Taiwan

Ih-Cheng Lai
Department of Architecture, Chaoyang University of Technology, Taichung, Taiwan

ABSTRACT: Among construction process, decision making is often depended on different construction methods invoked within different events occurred. The re-action sequence is hard to predicate and hard to reproduce in different situations, also. For resolving this problem, we adopt a model called Dynamic Role Interplay Process (DRI). Based on the mechanism of DIM (Dynamic Idea Map) (Lai and Chang 2005), competing learning and evolving learning between different roles, and then the knowledge within roles will involve evolving learning. We adopt learning metaphors in design sequence generations. Competing among design events and concepts are treated as the agents who are competing for surviving in the sense of genetic programming. And Roles start to evolve to different knowledge or preserving the core ontology of design for the evolving learning concept. Each process follows the metaphor of natural selection and design problem solving paradigms in design domain. A simulation agent-based system is implemented in CELA.

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1 INTRODUCTION

1.1 Construction decision making

A successful construction process depends on satisfaction on many different and often conflict problems. Many researches have addressed this problem with management approach. However, since situations change dynamically and unexpected sometime within minutes, a total solution or simulation for construction decision making is not even possible. Therefore, for addressing this issue, we re-frame the decision-making process differently by viewing every decision-made is a different situation. Then, the transaction between different situations might show some insights for a closer simulation in construction process. Therefore, we will focus on the interaction between different solutions and their reactions. In addition, the decision mentioned here is regarded as an idea (or a construction concept) for solving a particular construction problem brought up by certain situations before.

Regardless of the practical factors of construction process, it is a process that contains many interconnected distributed situations. Each situation has its own participants and triggers for another different situation. For our simplified purpose, we use a concept called *role-play* (Chang 2004, Chang and Lai 2004) for modeling such distributed inter-connected situations in the construction process. Such process is called *interplays*.

With this approach, construction decision-making is treated as different roles such as client or construction manager played by different actors to achieve a common agreement (construction decision) with different interplays.

1.2 Learning construction decision making

With the views above, we go further address one of key issue in making the simulation more closer to the chaotic reality of construction process—learning. With learning capability, the simulation for challenging the situated interaction among decision factors can be varied from time to time. As declared before, the situations of construction process cannot be analyzed full due to its characteristics. In addition, most of analysis is fixed, then, the resolution has to be discovered before the simulation. However, with some learning capabilities, the interplay can be more dynamic and vivid. This resolves the problem for supporting more distributed interplay situations.

1.3 Competing and Evolving Learning Decision

Among the learning, we discover two main metaphors: competing and evolving such that the domain knowledge of each role can be evolved or competed within the interplay process. Therefore, these learning processes or behaviors frame the possible solutions: *competing learning* and *evolving learning*. Through competing learning between different roles, and then the knowledge within roles will invoke evolution in its own knowledge bases. These two types of learning provide interesting insights for understanding the knowledge among the construction process in this paper.

For computational purposes, agent technology will work in coordination with a role-play like agent framework called *dynamic idea maps* (DIM) (Lai and Chang 2004). Each role has its functionalities and skillful knowledge to accomplish construction decision-making in different situations. In addition, DIM is used for representing the inter-connected structure of construction concepts described above.

1.4 The battle concept in competing-like behavior with construction decision making

For searching for suitable metaphor in framing our agent learning behaviors, we discover that "compete" is often used for describing the conflict and learning process during decision-making process. For example, while facing a particular design issue, design concepts are either competing with others for wining a particular design issue or the design concepts will be elaborated by others *better* concepts. Such design phenomenon that unleash in ideas association can be treated as the inter-connecting mechanism used for competing and invoking. Furthermore, the "battle" concept is the central concept for constructing our competing-like behaviors.

The observation we have is that competing among design concepts is treated as survival in the sense of genetic programming and the metaphor of design field. In addition, the battle concept uncovers the designers' mental reactions and physical behaviors during the interplay process. Practically, when dealing with certain construction problems, many design concepts battle with each other for wining the chance to solve current construction problem. The better or winner of battle will be adopt and further trigger another different battles. The capabilities of each role will be improved while learning from the winner or the "better" colleagues. This concept forms the basic behavior of our simulation.

1.5 Approach: arbitrator

To fulfill the battle among decision concepts, we use a special role called *arbitrator*. The construction concept for using arbitrator is to make the decision-making process clearer in the sense of battle or competing. No matter how complicate a competing process is, when it comes to decision: who is the winner, there must have a role that can judge the winning criteria or the comparison between two knowledge bases. The mechanisms and technology supports of Arbitrator concepts will be introduced in section 2.4 and the following sections.

With role-play, construction decision-making can be described as two set of roles: 1) the main controlling roles (DA in the sense of DIM): server, construction architect and 2) participating roles (the UA in DIM): construction manager, contractor and construction worker. With participating roles involved in the competing process, the construction concepts can be done via agent learning which needs a distributed computing environment and computational mechanism.

Following these concepts, a Competing and Evolving Learning Arena (CELA) within a distributed role-interplay environment is developed and tested in this paper.

2 BACKGROUND AND SUPPORT

2.1 Dynamic Idea Maps (DIM)

DIM originally is case-based reasoning framework for supporting idea association in the early conceptual design stage (Lai 2004). Furthermore, Lai and Chang (2005) integrate DIM with Dynamic Agent Role Interplay System (DARIS) for implementing distributed interactions of *linking* ideas in the process of idea association. Inspired from the mechanism of Acting Role Model (ARM) proposed by Chang (2004), DARIS is an agent-based system for implementing distributed interactions in a multi-designers collaboration environment. In DARIS, there are dynamic interactions through five different agent entities including the user agent (UA), the role agent (RA), the director agent (DA), the stage agent (StA) and the scene agent (ScA) within the three system layers.

Besides, DIM provides four components to integrate the mechanisms of various agents within DARIS. For linking ideas in the conceptual design stage, *knowledge representation* represents design ideas and memory organization within agents'. *Linking principles* provide the capability to allow agents to associate diverse ideas differently. Through *dynamic linking process* (or simply *linking process*) in the internal and external interplay, agents can dynamically interact various design situations. Finally, agents can engage in *linking interactions* for learning through competing and evolving. The details are described as follows:

1) Knowledge representation: In DIM, ICF schemata proposed by (Oxman, 1994) mainly represent design knowledge within RAs' long-term memory. Through integrating the three principles of idea association, each RA's design knowledge includes a set of maps: an ICF map for installing various idea entities and three knowledge maps functioned as dictionary. They are issue map, concept map and form map.

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2) Linking principles: three linking principles provide RAs' reasoning behaviors to link idea entities. The three linking principles are similarity, contrast and contiguity (Lai, 2004). Based on the ICF knowledge representation, each principle has an individual mechanism for textual matching to link dynamic idea entities within various RAs' ICF maps.
3) Linking process: according to different design situation within the distributed interactions, the linking process provides various agents' communication methods in two interplays: internal interplay and external interplay. Besides, these agents can dynamically interplay each other through different communication network topologies (including ring, peer to peer, star and cluster) based on the mechanisms of agent communication language (ACL) (Lai et al. 2005).
4) Linking interactions: linking interaction is a learning process among agents in DIM. Basically, there are two types of learning: competing and evolving. Competing among design ideas are treated as the agents (such as RAs) who are competing for surviving in the linking process. Furthermore, agents and ideas start to evolve to different knowledge or preserving the core ontology of design in the evolving process.

2.2 Agent learning using competing and evolving metaphors

Idea association can be considered as an ideas generation behaviors according to their individual long-term memory, as well as the knowledge from different participants (Osborn 1963). The purpose is to produce diverse design ideas that can serve as leads to development of possible design alternatives (Petrovic 1997). For making decision about selecting ideas (or concepts) in the process of idea association, participants always compete each other, and then the knowledge within the participants will involve evolving learning.

Basically, there are different computational mechanisms can handle decisions making problems, like if-then hierarchy (Jackson 1999), statistical optimization (Radford 1988) etc. However, these computational mechanisms can't effectively provide such learning support in the distributed collaboration environment. It is towards a real-time and automatic communication for supporting construction-decision-making.

Considerate with multi-agents system, the agent reinforcement-learning domain acknowledge can provide a suitable living environment and construct the agent framework of sequence or procedure during deign domain representation. As borrowed from GA (Genetic Algorithm) (Coley 1999), we adapt the metaphors of competing and evolving as well as mutation requirements in design generations. In addition, within the agent learning environment, Q-learning (Clausen and Wechsler 2000), learning rate concepts and WoLF-based learning algorithm (Bowling and Veloso 2002), have explored the possibility to allow learning occurred outside of self-knowledge (non-self-play). These form the base of our learning theory.

Based on the mechanisms of DIM, competing is learning about what RAs can survive and evolving is learning about the mutation of RAs' knowledge including RAs' skill learning and idea entity linking learning within the ICF maps.

2.3 How we approach

Finally, this paper follows four steps to investigate the competing and evolving in dynamic role interplay. The purpose is to develop a computational learning mechanism for decision making in the early conceptual design stage. These steps are 1) building learning mechanisms through competing and evolving among various agents, 2) constructing computational learning strategies and methods, 3) implementing the learning strategies and methods and 4) simulating an example to investigate the computational feasibility of the competing and evolving learning mechanisms for decision making. These steps are described in the following sections.

3 THE ARBITRATOR

Following the arbitrator concept, we construct an *arbitrator* to operate and manipulate construction concepts in construction decision-making of design domain knowledge representation. The arbitrator is comprised of five components: preferences training for search, competing method, evolution operators, learning strategies and selections procedures. One implementation of arbitrator (CELA) is shown in session 5.

3.1 Preferences training and search

The main purpose of training is to increase the alternative solutions in the same construction problems (ScA). The UAs (users) continuously construct the links of construction concepts when they are in dynamic interplays hosted by the DA to solve a particular construction problem in the same ScA. From the DIM, idea preferences adopt three principles of idea association: (1) Similarity; (2) Contrast; (3) Contiguity to build the ideas relationship links. The user (UA) will use these preferences to play. As ideas (construction concepts) link with preferences increase more and more in the same ScA, the construction problems will find more suitable solutions and RA's skills is improved in the meantime.

According to the results of learning practical process from dynamic decision-making association, arbitrator will collect interplay *degree* (details will

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be described in section 3.3) and construction concepts *links*. These variable obtainments have the effects upon construction resolutions because arbitrator trains the knowledge representation for outcomes which base on these. In the view of increased construction concepts, suitable construction references are getting more and clearer.

3.2 Search for preferences training

When one UA process learning procedure, arbitrator will search the RA's skill in the same ScA with the interactive UAs by the preference and continue following procedures. We adopt the lexical keywords comparison kind approach for the foundation of search to find the skills (construction solutions) which have the relationship of select preference or the focus on the specific ScA.

RA's skills described by ICF maps characterizations are represented by keywords in the system. One idea entity (thus the construction concept) is formed by three main keywords following the ICF maps and their each material, like text or photos, will improve the understanding ability to each UA. The information data model will be elaborated in section 4.1.

3.3 Arbitrator with battle concept

Since there are five agents in DIM to process interplay, the arbitrator is also a specialized agent on competing leaning and evolving learning purpose. Arbitrator, the agent, starts by these two types of learning procedures. And, arbitrator agent will be suspended and wait while the learning procedures are not invoked.

Competing environment which bases on battle concept is via agent acts to advance evolving learning and other procedures. Distributed agents system has the possibilities in a whole unbounded field for competing environment where RAs-RAs (many-to-many) using their skills to compete. It looks chaotic indeed, like the battle in Rome arena, slaughters and kills keep going and going. At final, some survivals will stand in the arena. That presents the survivals with the superiority to survive.

In CELA, the arbitrator simply plays a judgment agent. That is to say, arbitrator in CELA will not participate in the competing but take determinations and manipulate the learning process instead. In addition, we will only focus on one-to-one battle with its simplest representation. However, the complex battle matches such as RAs-RAs (many-to-many) can be represented is by the combination of one-to-one RA-RA (1-1) competing process.

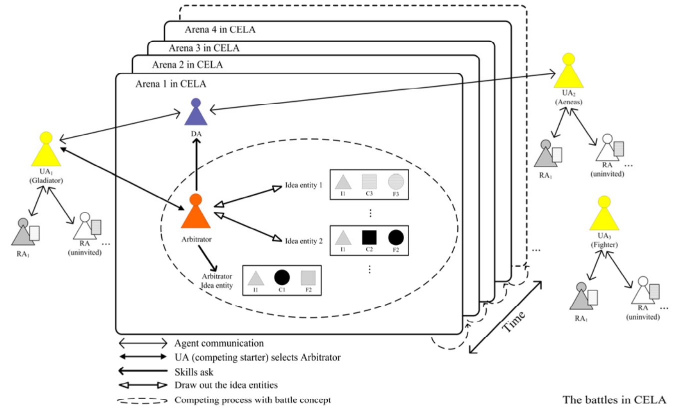

Figure 1. Arbitrator with battle concept

In the agents battle view:
1) One UA starts the competing process.
2) The arbitrator is selected.
3) Arbitrator takes one RA's ideas entity (construction concept) from UA and one *RA's concepts* from the other *UA*.
4) The two idea entities enter the competing arena.
5) Arbitrator continues other processes.

This will show in Figure 1. (Selections mechanisms will describe in the following sections.) The performance of arbitrator agent performance will be realized in the system. According to the preferences selections and degrees form ideas linking. Arbitrator will determine wining construction concepts. But the arbitrator gives only suggestions not the decision itself. The final decisions are still decided by the human.

3.4 Evolution operators

The main evolution operator is based on the *degree* concept. Degree represents the variable values associated with ideas linking preference, solving in the same design issues and design requests of construction problems. Arbitrator itself will only include one single idea entity to be the decision reference.

The arbitrator takes the preference, two idea entities, and then advances to search the degree of two idea entities to judge which one is better and suitable on the moment (1-1, RA-RA). This will further decide the winner for survival in the match of arena within a particular design issue. Image that, each RA-RA competition needs some way of judgment, even the RAs-RAs.

Therefore, the win or lose should be decided by an authorized third agent, here is the arbitrator standing for with the help of degree. With degrees modifies and promotes the evolving learning gets more construction concepts inspirations and increases the RA's skills in the same construction design problems. The range of degree variable will describe in section 4.1 and the modification of degree is using computational programming to attend the purpose.

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3.5 Evolution procedures

How the degree be modified? Since the RAs' battle in the distributed agent system is chaotic, but the evolution procedures can be discussed in the well arrangement and concentrate on arbitrator who modifies the degree in evolution procedures and base on the competing starter's (one UA's) preference. The winning ideas entity increase value will under the arbitrator degree.

The degree modifications are illustrated with the condition of RA-RA (1-1) match and have three different statuses:

1) RA_1 lose, RA_2 win. The wining idea entity from RA_2 immigrates to RA_1, and the degree of wining ideas entity is increase.
2) RA_1 win, RA_2 lose. Arbitrator continues the next ideas entities competition and sends the RA_1's winning ideas entity to RA_2. The yes or no acceptance is decided by RA_2.
3) The ideas entities of RA_1 and RA_2 are equal, no win and lose with the same degree. It seems a little weird here, but in design domain, their will have the close-fought ideas which means not the best and top resolutions exists but the suitable or better ideas can survival. Arbitrator pushes out two ideas entities in this round and continues the next competition.

These will show in the figure 2.

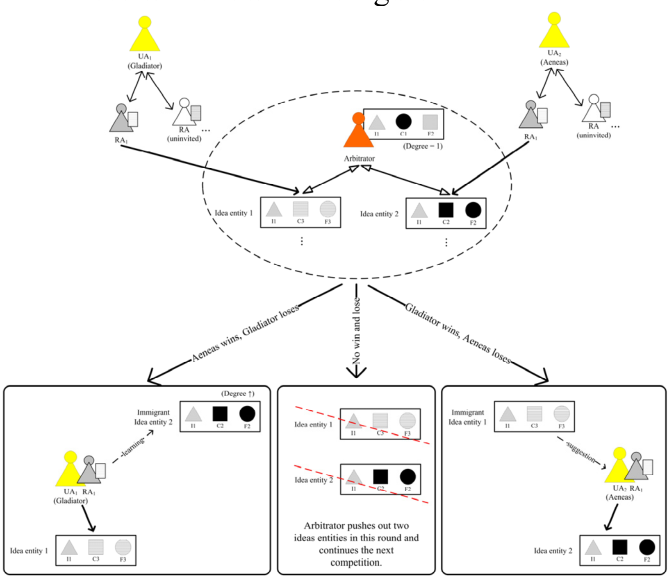

Figure 2. Arbitrator modifies the degree in evolution procedures during interactive interplay.

3.6 Learning strategies

The arbitrator handles the learning strategies following the arena environment with design domain. There are two parts of learning strategies and will show in the figure 3:

1) UA ideas linking preference learning: The Arbitrator searches the construction concepts by three preferences. The unsuitable findings will have large amounts in the beginning of learning, but after the competing and evolving repeat in the same design issues, arbitrator can make the linking more direct into the suitable solutions and gives the suggestions to UAs.
2) RA ICF skills learning: If the immigrants ideas entities survive on the lose RA, the concept map and form map can let the lose RA to learn new skills in the same issues maps. In the view of evolving programming approach, the learning metaphors show the need of representation hierarchies. RA learning the new skills is through the outcomes of preferences and learning or not is decided by the UA.

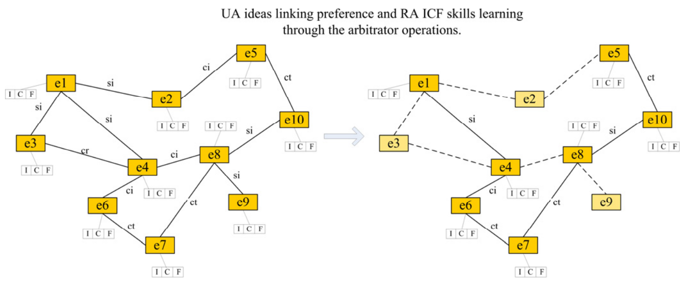

Figure 3. The RA's skills learning procedure are companied with the goal satisfaction learning strategy in arbitrator theory.

3.7 Selection procedures

With the learning strategies described above, selection procedures are the procedure to decide who the winner within the battles is. There are three selections: (1) human selection: Basically UA is selecting the winner with personal preferences, the results will be recorded to influence further learning; (2) natural selection: UA expresses the preferences via controlling strategies and allows system to decide who is the winner respectively; (3) Agent-auto selection: through the automatic mechanism, system will decide who is the winner and start the learning process automatically. These three selection procedures will show in the Figure 4.

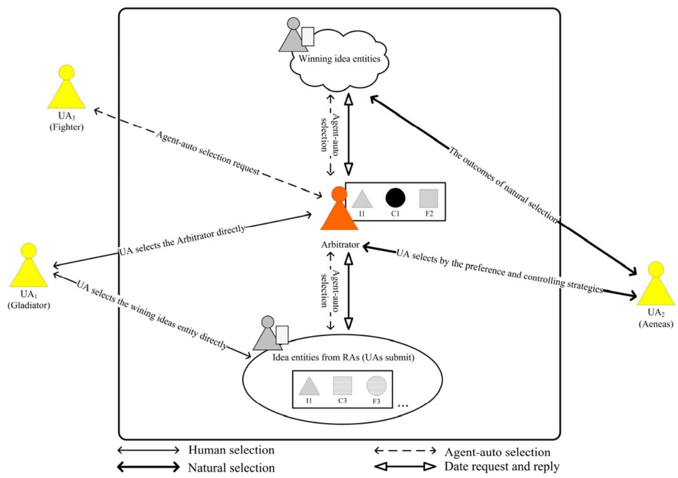

Figure 4. Three selection procedures with the arbitrator.

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4 LEARNING WITH ARBITRATORS

Base on the reinforcement learning in multi-agents environment and programming foundations, we construct an arbitrator theory to operate and manipulate construction concepts in construct decisions making of design domain knowledge representation. The arbitrator theory is composed by five components: preferences training for search, competing method, evolution operators, learning strategies and selections procedure. Arbitrator surrounds in the battle environment in CELA with judgment property.

4.1 The information data model

The ideas entities structure from ICF concept and ARM recognition theory for learning construction decision making and competing will show in figure 5. There will be focus on the I-Maps, C-Maps, F-Maps and it depends on the needs, even the entire ICF Map can be chosen to manipulate by agent environment. The ICF maps perform the RA's skills for the construction resolutions of constructors. The slots prepare to remain link references for further idea links inform and reply purpose. Idea links have the graph structures attributes alike in data structure. The main achievement of idea links perform is the links to I, C, and F Maps with the degree of ideas linking preferences. Degree is one of the measurements with the arbitrator. In the beginning of degree construction, the range is set between 0 and 1. The select arbitrator will be 1 and on the top. The ideas linking will be the RA skills relationships and connections.

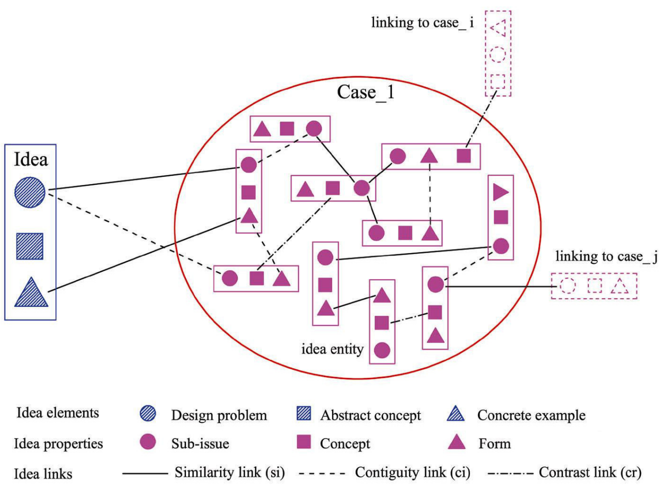

Figure 5. The ICF ideas entities and idea links.

For storage, search and using, the links take by the ID in RA's skills and these are like the knowledge representation of category design skills which built by the user, not the fixed linking association in the beginning of one ScA and it also means the training part of the construction problem through information data model is broadened within to enlarge the knowledge representations. The person owns design Maps acknowledge and construction decisions by himself. It will different from others construction concepts. Therefore, we adopt XML for individual person knowledge presentation, because XML has the clear hierarchy for ICF and idea links storage purpose. The potential reuse ability can accomplish ICF Maps and idea links which described above.

4.2 Competing learning with arbitrators

With the mechanism described in section 3 and the information data model above, competing-learning proposed by this research invokes a different dimension for solving the problems we have. The decision made by DA will be influenced by two stages of competing learning—internal and external competing learning.

Internal competing learning is a ring-type of communication. With arbitrator, there are two learning situations:

First, within the same construction company, everyone involved in a particular construction process is regarded as one UA. This is to say that there is one common goal for all UAs: to solve the problem with the interest of the company, therefore, the optimized solution or the construction concepts will be achieved by competing each other within the same problem. Arbitrator can act as a supporting agent for every group of UAs within the same construction problem. The outcome of the solution will be through the competing stage following the mechanism above.

Secondly, each participant can learn better solution via his/her own arbitrator who will help to compete or judge the suitability or practicality of the construction concept he/she has.

External competing learning is a peer-to-peer type of communication with each peer represents different company with association. With arbitrator, the learning objective can be achieved via cross-evaluation and critics over better construction methods in certain construction problems. Through competing, the better or more creative solution might be discovered or searched and learned. Furthermore, another possible learning situation is that each UA can learn how other UA reacts to the same construction problem with external competing process.

4.3 Evolving learning with arbitrators

In the evolving learning process, there are also two different situations: internal evolving learning and external evolving learning.

The differences occur when the events are different. In internal evolving learning, with the arbitrator and the degree mechanism, each construction concept generated within the competing process will be recorded and emphasized that will refine the knowledge in the agent as well as the company. Another situation is that the knowledge of participants for certain particular construction problems will be

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evolved and can resolve the better solution in the future. The degree for each stored winning cases will have a better chance to be selected later.

External evolving learning situation is another similar situation in our context since the concept of competing will evolve the knowledge locally and externally.

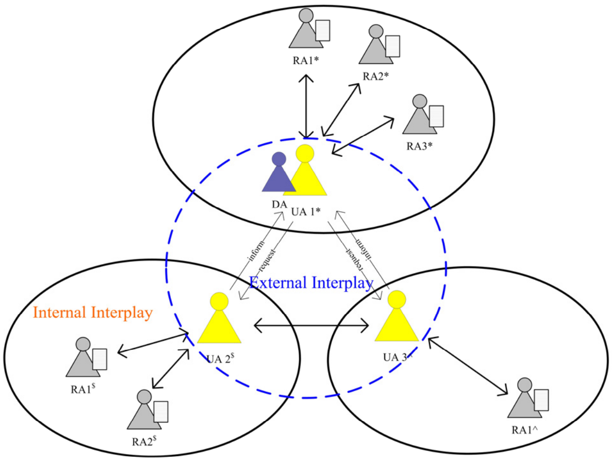

Figure 6. The internal and external circumstances in the interplay of competing learning and evolving learning

4.4 *Three selections with UA (User)*

The arbitrator should be chosen for competing process. UA uses the three selections procedures to build arbitrator, also. But the selection meanings here are different from the three selections in the arbitrator selection procedures. There are UA selections: (1) human selection: UA selects the arbitrator by personal favorites; (2) natural selection: UA chooses the preferences and allows system to decide who the arbitrator is; (3) Agent-auto selection: through the automatic mechanism, system will decide who the arbitrator is and start the competing process automatically.

5 IMPLEMETATION AND FEEDBACKS

5.1 *Technical support and possibility*

For implementing CELA, we need (1) a platform for dealing with multi-agent communications; (2) a knowledge representation for representing the information model described before; (3) a computational mechanism that can implement the competing, evolving and the selection procedures.

With the implementation requirements above, a system called CELA is proposed and implemented in this paper. For agent communication, an interplay agent framework called DARIS is used as our interplay environment. On the top of DARIS, we implement a specific agent called "arbitrator" who contains the capabilities described in this paper. Different RAs with construction concepts are also implemented in DARIS environment.

5.2 *Framework and implementation*

The framework of CELA (Competing and Evolving Learning Arena) is shown in the Figure 7. Basically, CELA contains three layers: representation, communication and learning mechanism layers. CELA, as an agent-learning environment, depends on many components from other theory such as DIM for linking ideas and DARIS for dynamic role interplays. Each component represents different aspects of interplays and contributes the features required for implementing CELA.

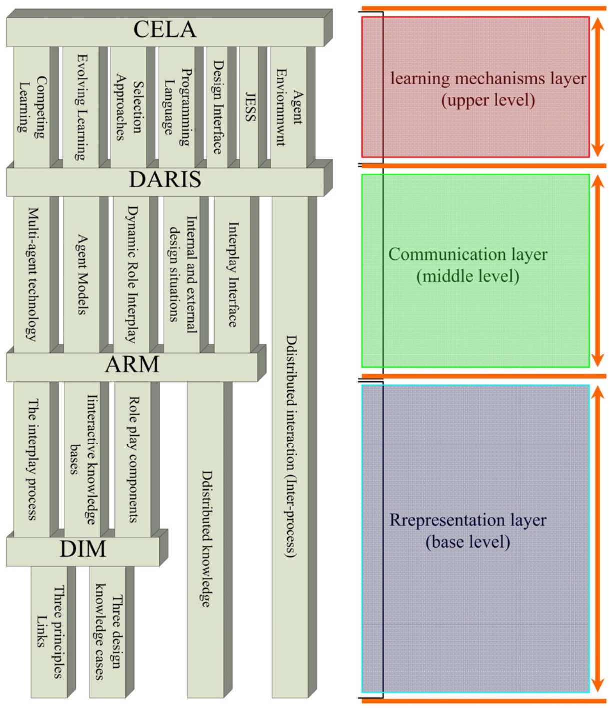

Figure 7. The three layer in CELA system

In addition, these three layers implementing the functionalities of arbitrator described in the section 3 and section 4. The relations between the arbitrator and the three layers are shown in Figure 8. This is to say that CELA has implemented the learning mechanisms and one specific agent (arbitrator) on the top of DARIS.

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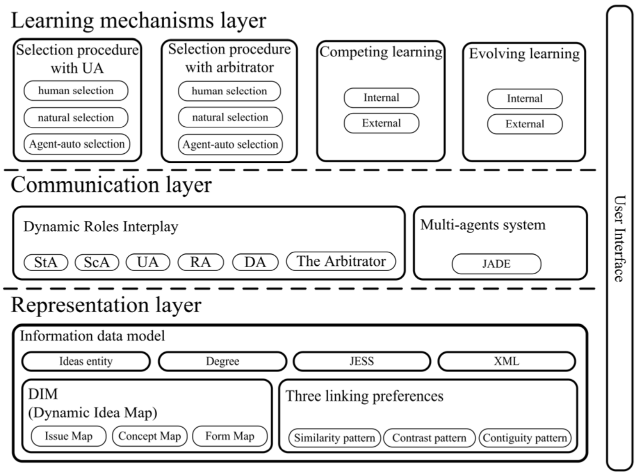

Figure 8. The framework and environment of CELA system

One implementation of CELA and its working status is shown in Figure 9. The programming language is Java with FIPA-like agent platform embedded in CELA implementation. The reasoning engine is JESS with XML extension.

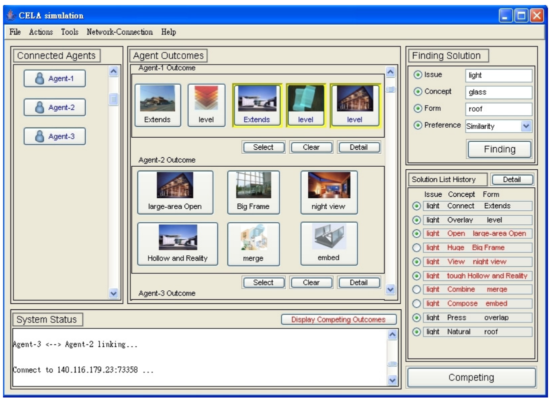

Figure 9. The programs implementation with user interfaces

6 CONCLUSION

A successful construction process depends on satisfaction on many different and often conflict problems. We address this issue by viewing each problem as individual construction situation. Then, a role-interplay simulation over construction concepts is proposed for understanding the computability of the finding suitable solutions from diverse resources.

Furthermore, based on an on-going agent based design system (DARIS), CELA proposed in this paper provides richer features: learning mechanisms and competing/evolving procedures on finding suitable or more alternatives on construction concepts with divergent participants. For elaborating these learning/competing mechanisms, a specialized agent called Arbitrator is described along with other interplay agents such as RA, DA and ScA. These agents simulate the competition and evolution among different knowledge that is often the most difficult part of construction decision process. Furthermore, in the agent lattice, each agent can only sense its local environment, and its behaviors of evolving and cooperation can only take place between the agent and its neighbors.

While giving the agent evolving mechanism, we also present several experimental results. These results demonstrate how the evolution of the distributed autonomous agents can enable the extraction of construction concepts features with the effects of behavioral parameters on the performance. In addition, the concepts feature extracted from CELA process are entirely determined by the locality and parallelism of the individual agents.

With the significances of agent simulation, the directions for the diffusion and self-reproduction of the agents are then able to be dynamically selected and evolved. With respect to real-life mechanisms, the proposed approach could have significant impact on difficult ideas analysis problems in various construction problems.

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Construction project supply chains and their use of ICT

G. J. Brewer, T. Gajendran & S.E. Chen
University of Newcastle, Callaghan, NSW, Australia

ABSTRACT: This paper describes the first stage in a much larger project, funded by the Co-operative Research Centre for Construction Innovation in Australia investigating the application of supply chain concepts in the context of the construction project to develop a model of supply chain interaction that is appropriate for investigating ICT adoption both within a single construction project and across the sector. It models the influences described in previous literature relating to ICT-related supply chain participant performance and further proposes an on-line, modified Delphi methodology to facilitate the asynchronous participation of an international panel of experts in the validation of the model. It concludes by reporting the findings from the study and directions for further research.

1 PROBLEM CONTEXT

Many observers have characterised the construction industry as being fragmented, information intensive and adversarial (e.g. Cox & Townsend, 1998). Ng (2000) attributed many of the industry ills to the quantity and complexity of the shared communication. Faraj (1999) stressed a need for common standards for the exchange of data, suggesting that these would address the questions of information and communication technology (ICT) uptake and integration, leading to shared common business processes (e.g. Yamazaki, 1995). Alshawi and Underwood (1999) predicted project teams working in a shared electronic workspace, outlining multiple benefits possible from such a move. The New South Wales Government (1998) echoed its desirability, highlighting both the complexity of the problem and the potential rewards of solving it. Egan (1998) and Finch (2000) observed that these costly investments had yet to fulfill their potential (Bulmer & Brewer, 2000). Downward cost pressures, increasing specialisation and technical complexity of projects create a demand for an integrated approach to ICT in the industry (Brown et al, 1996). However ‘islands of automation’ first identified by Kartham (1994) are still common, leading to an unacceptably low level of ICT integration across the professions and throughout the constructed asset's life cycle.

A number of factors are identified that explain the disappointing results from the use of ICT within the CI. These include:

– Inability to measure the benefits accruing from the use of ICT (Schwegler et al, 2001);
– Failure to deliver promised returns (Shafagi & Betts, 1997);
– Backing the wrong technology (Shafagi & Betts, 1997);
– Lack of standard protocols for inter-organisational communication and transfer of data (e.g. Yu et al, 1998);
– Difficulty of keeping IT investments up-to-date (Shafagi & Betts, 1997);
– Failure to integrate ICT into the core business processes of the organisation (Sarshar et al, 1999);
– Inability of the organisation to re-engineer business processes to align with those of their trading partners (Shafagi & Betts, 1997).

Implicit in most of these factors is the recognition that the best intra-organisational ICT deployment will fail to deliver optimal returns if the inter-organisational dimension is suboptimal. This in turn links the issue to the individual organisation's relationship with its trading partners.

Early commentators anticipated the integration of ICT across all sectors of the construction industry triggering revolutionary changes in the way in which firms relate to each other, curing many of the in-

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dustry's ills as a result. Rivard (2000) sought evidence for it across a series of surveys of ICT usage (Doherty, 1997; Howard and Samuelson, 1998; Futcher and Rowlinson, 1999, Samuelson, 2002). Nevertheless, the evidence for such a dramatic change is hard to find, with later commentators suggesting that revolutionary change is not possible in the current climate where business leaders remain sceptical about the full range of potential benefits touted by ICT promoters (Bulmer and Brewer, 2000). Key to this scepticism is the difficulty in ascertaining the nature and extent of the benefits gained from ICT investments, fuelled by the prevalent project-centric focus. The diversity of ICT systems and business processes within the industry, the amount of time, effort and resources that must be devoted to realigning an organisation's business processes with those of the rest of the temporary project organisation (TPO) are all seen as impediments to achieving full benefit.

2 TEMPORARY PROJECT ORGANISATIONS AS SUPPLY CHAINS.

McGeorge and Palmer (2002) identified key themes in Supply Chain Management (SCM) theory thus:

- Improved customer value and reduction of costs
- Strategic management of the chain of relationships
- Synchronisation of information, product and funds flow, and
- Competitiveness, market forces and innovation.

Improvements in these areas have been be linked to the effective use of ICT within a supply chain (SC), (DTI, 2001) making project information cheaper and more accessible in a timely manner. London and Kenley (2001) charted the development of the SC movement across the disciplines of distribution/logistics, production, strategic procurement management and industrial organisation management. They determined that the use of ICT in these areas would increase cost and time certainty (e.g. Latham, 1994, Flemming and Koppelman, 1996), increase value for facility owners and managers (e.g. Fischer, 2000), facilitate lean construction (e.g. Ballard & Howell, 1995, Cox and Townsend, 1998), and assist in the conduct business relationships (Ford, 1997).

The business process is traditionally a social activity conducted at an interpersonal level between human actors, but one that involves other non-human actants. Hakansson and Johanson (1992) postulated that SCs were industrial networks comprised of three elements, namely actors, activities and resources. They argued that each of these elements functioned as a network in its own right but that the outcome of their interaction was visible to an observer as more or less cohesive action. The network was scalable, and could equally be taken as a group of actors within a firm, an entire firm or an agglomeration of firms sharing a mutual interdependence such as a TPO. Lambert and Cooper (2000) presented a root and branch network for SCM that used three dimensions to describe the SC, namely horizontal structure - the number of tiers across the SC, vertical structure - the number of suppliers or customers within a tier, and horizontal position - the position of the focus company, relative to the poles of the SC. Their model also classified the nature of the Business Process Links between the various network actors.

There are synergies between these two SCM models. Both identify roles for human participants, activities/processes and materiel/resources. Both have been developed from the purchasing/logistics and marketing/TQM perspectives. Most importantly both regard the network as the most appropriate structure for modeling the SC. However, neither is specifically tailored to the CI or the TPO as a supply chain in its own right. A third model has been constructed (see figure 1) that places the project, rather than any single actor, at the heart of the TPO SC. This position is justified because:

- Industrial network theory allows for the delineation of a network to occur at any point from the individual upwards. Whilst it is accepted that the entire construction industry can be thought of as one large SC (e.g. AEGIS, 1999), it is held that the performance of TPOs can best be investigated by the use of a model that is defined by a permeable boundary at the project level.
- Such a model utilises the network perspective of Hakansson and Johanson (1992), and accommodates the focal company perspective of Lambert and Cooper (2000). Further, it places the project at the heart of the network (Jennings and Kenley, 1996, cited in Chen, 2000), a position that the authors feel is justified when it is considered that it is the project’s existence that triggers network formation.

This model accords with a fully ICT-mediated supply chain, where a project web site or an object model resides at the heart of all project communication and information flows.

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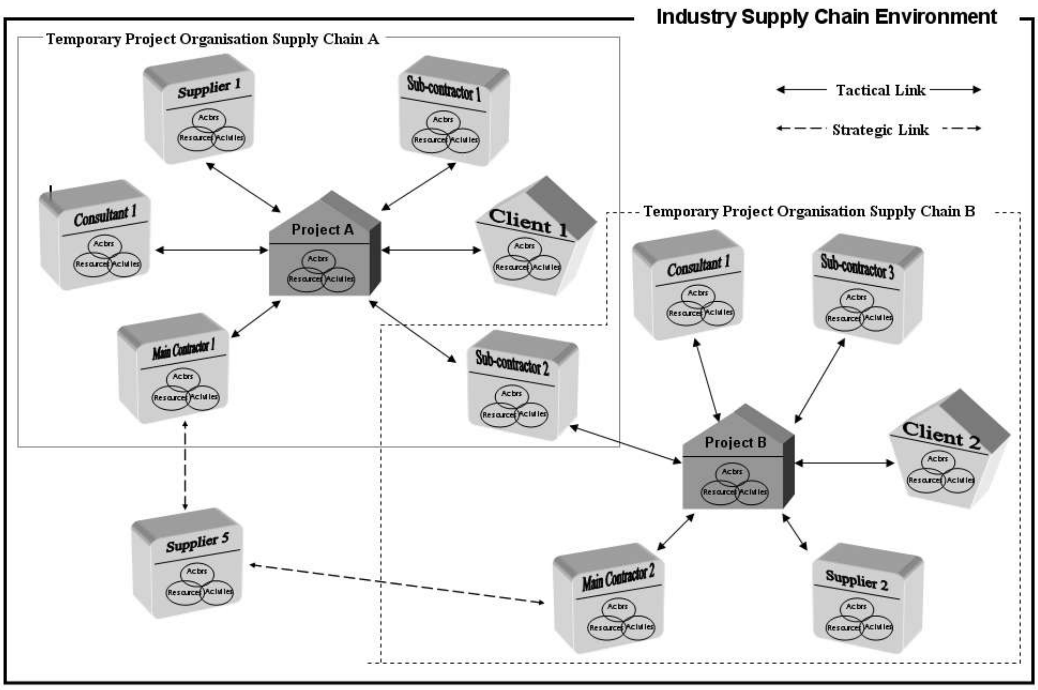

Figure 1. Project-centric supply network model

3 THE INFLUENCE OF ICT ON FIRMS IN A TPO SC

In order to explain why the CI persistently displays "islands of adoption" rather than the more homogeneous ICT integration found in other industries it is first necessary to identify the range of influences that have the potential to affect ICT uptake and integration by individual firms. To this end an exhaustive literature review was conducted during 2002, the results of which were subjected to meta-analysis. This identified influences that included:

- Management style of the ICT adopter;
- Technological considerations including ICT capability, causal conditions for implementation, shared protocols and perceived benefits;
- Resource management within the supply chain including, logistics, purchasing, implementation issues and attitude to strategic relationships;
- Supply chain performance including, customer satisfaction, supply time lags, productivity (perceived), ROI, relative technological competitiveness, innovation, and security monitoring and auditing;
- Power relationships including, ability to dictate SC protocols, ability to influence SC ICT, and threat to future business opportunities;
- Competitive position including, formation and maintenance of strategic relationships, and competitive advantage;
- Communication channels, both intra and inter organisational;
- Business attitude, be it proactive, reactive, or dictated by firm size;
- Monitoring benefits, the effectiveness of the various methods for ascertaining ROI;
- Training, both internal and across the SC; and
- Environmental factors including, experience, nature of suppliers and nature of customers.

From this a model was constructed (figure 2) that acknowledges the, often inter-related, nature of all these influences and noted that they could have either a positive or negative effect; in the parlance of this study they are viewed as either ‘success factors’ or ‘barriers’.

4 DELPHI STUDY: UNDERPINNING THEORY

Traditionally this process has been used for two purposes: exploration or confirmation of a concept(s). Delphi is particularly suited to exploring complex problems that require an element of subjective analysis (Kaynak et al., 1994; Mitchell and McGoldrick, 1994), especially in industries that are undergoing rapid change (Jillson, 1979). According to Linstone and Turoff (2002) specific applications include the following which appropriate to this study;

- Delineating the pros and cons associated with potential policy options
- Developing causal relationships in complex economic or social phenomenon
- Distinguishing and clarifying real and perceived human motivations
- Exposing priorities of personal values, social goals

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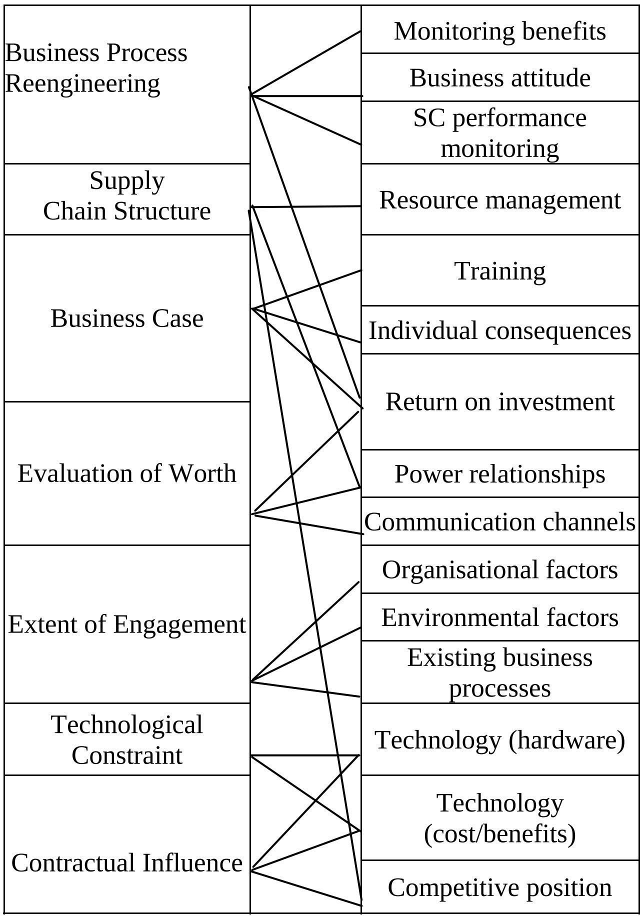

Figure 2. Emergent themes and sub-themes from literature.

The Delphi process is said to have two distinct forms, of which the most common is the conventional paper and pencil version, and the contemporary version referred to as the Delphi conference (Linstone and Turoff, 2002), which is a "real time" version of the conventional Delphi and can use computers to mediate the process (e.g. Bradley and Stewart, 2002).

Whichever method is employed, a Delphi survey is designed to obtain and distill the opinions of experts over a series of rounds, which move from the general to the specific, from diversity to consensus or polarity, requiring justification from those holding dissenting positions (Delbecq et al., 1986). Inter-round feedback should increase participant awareness of the issues and aid both convergence and/or polarity (Rowe et al., 1991). Irrespective of the details of design, there are three aspects to a Delphi study that separate it from any other methodology, namely participant anonymity, researcher-mediated feedback, and statistical group response, ensuring that all individual responses are reflected in the final outcome (Rowe et al, 1991).

5 DELPHI STUDY: IMPLEMENTATION AND ANALYSIS

A key determinant in the design of the study was the geographical dispersal of the invited panelists, who were located on three continents in both the northern and southern hemispheres. Familiarity with the Blackboard teaching platform provided an opportunity to facilitate asynchronous discussion in an online conference, using a threaded discussion forum. Access to a dedicated, password-protected area for participants was created, each of whom was issued with a personal account together with a pseudonym, thus guaranteeing their anonymity. Thirty invitations were issued and thirteen panelists recruited.

Participants were presented with seven statements (see Table 1) and asked to express their opinion and level of agreement/disagreement. The participants made their initial statements and then discussed differences of opinion until polarity or consensus was indicated. At this point a summary was generated to trigger further discussion, this being provided with a time limit. A further summary was generated, and returned for approval. This process concluded with a third round.

The survey data was collected in text form as anonymous postings to a series of themed, threaded discussions. These were collated into a database, with fields that also listed the various attributes of the author and the posting (who, when, thread title). Three research team members analysed the text passages for emerging attributes (keywords, developing sub-themes) in a coding process. The coding process utilised open coding for theme identification and axial coding for theme development. After each round of analysis the team would resolve coding conflicts at a meeting. The meeting outcomes would then form the basis for the summaries.

Three rounds of summary-generation occurred throughout the study. The initial round of summarisation used the seven themed threads, whilst the second consolidated these down to three 'super themes'. These were very general, representing, in the judgment of the researchers, the roots of the discussions. These were then developed using a 'branch and leaf' diagram (figure 2), which illustrated the sub-themes and their origins. This was intended to conclude the study and indeed, received qualified support from the respondents. However there was a common request for the 'leaves' to be given more substance. In response to this feedback the research team produced an augmented explanatory summary for each of the leaves.

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Table 1. Round 1 Delphi study content domains and trigger statements

Topic	Statement
Business Case	The decision to engage with an ICT mediated supply chain will, in all likelihood be a tactical decision, driven by the desire to work on a specific construction project, rather than a strategic, organisational decision.
Evaluation of worth	When evaluating the correctness of the decision to engage with an ICT mediated supply chain the return on investment, formation of strategic relationships and the opportunity to obtain repeat work will be of equal importance.
ICT Integration-Business Process Re-engineering	New communication practices and technologies are the most important trigger for Business Process Re-engineering (BPR) within an organisation. On the other hand, the interface between the organisation's older staff and those same technologies are the biggest inhibitor of BPR.
Supply Chain Structure	Supply chains in the construction industry form as networks, where the management of process links between participants from different levels in the project team is often of equal importance to project success (in terms of time, cost and quality). As a consequence, the main supply chain participants must pay equal attention to the management of relationships at all levels within the project.
Contractual Influence	The development of contract law is the main determinant of the type and quality of relationships within a supply chain. ICT has, and will continue to have a marginal influence on the development of these relationships, and will have no appreciable effect upon the nature of future contracts.
Extent of Engagement	Maximum benefits will not be derived from the management of ICT mediated supply chains until all participants, including suppliers and sub-contractors engage electronically.
Technological Constraint	Much of the lack of enthusiasm to engage with ICT mediated supply chains hinges on the lack of standards and protocols for communication.

6 RESULTS

The following sections describe the findings for each “leaf” in figure 3. They were derived from the final round of Delphi contributions accepted by the panellists as a true representation of their final position, by consolidation of individual coding undertaken by the research team. A subsequent comparison was conducted by the research team to establish the extent of correlation with the literature review, thereby identifying the new issues and influences uncovered by the study. These are reported in section 7.

6.1 *HUMAN FACTORS*

The success of Information and Communication Technology (ICT) uptake and integration (both intra- and inter-organisational) depends upon the existence of a receptive and committed culture (be it internal or external). This culture displays the following characteristics:

6.1.1 *Relationships*

Increased willingness to form and maintain relationships with supply chain partners at the interpersonal level – even when they are mediated electronically. However, it is not clear that these relationships will all become stable and long-term, nor is it clear that this would be a desirable outcome.

6.1.2 *Comfort with Technology*

Familiarity with, and acceptance of ICT communication channels at all levels and within all functions of the business, which is enabled by training.

6.1.3 *Training*

Responsive, needs driven and easily accessed; available to all, in a way that is appropriate to user needs.

6.1.4 *Competing Demands/Personal ROI*

Organisational culture should be sensitive to the way in which staff operating in a dynamic, high-pressure project environment might regard the time commitment required to come up to speed with new innovations. It is desirable therefore that there is a demonstrable benefit to engagement at the individual level.

6.2 *BUSINESS PROCESS*

Within an organisation, the commitment to Business Process Re-engineering (BPR) has to predate the introduction of ICT, but for the effect of BPR to be maximal alignment of BP is required across the supply chain of which the firm is a member. They will initially be driven by self-interest. This may manifest itself in decision-making driven variously by Return On Investment (ROI), project goals or strategic objectives. However, in all cases, a top-down willingness to try something new, with a clear out-

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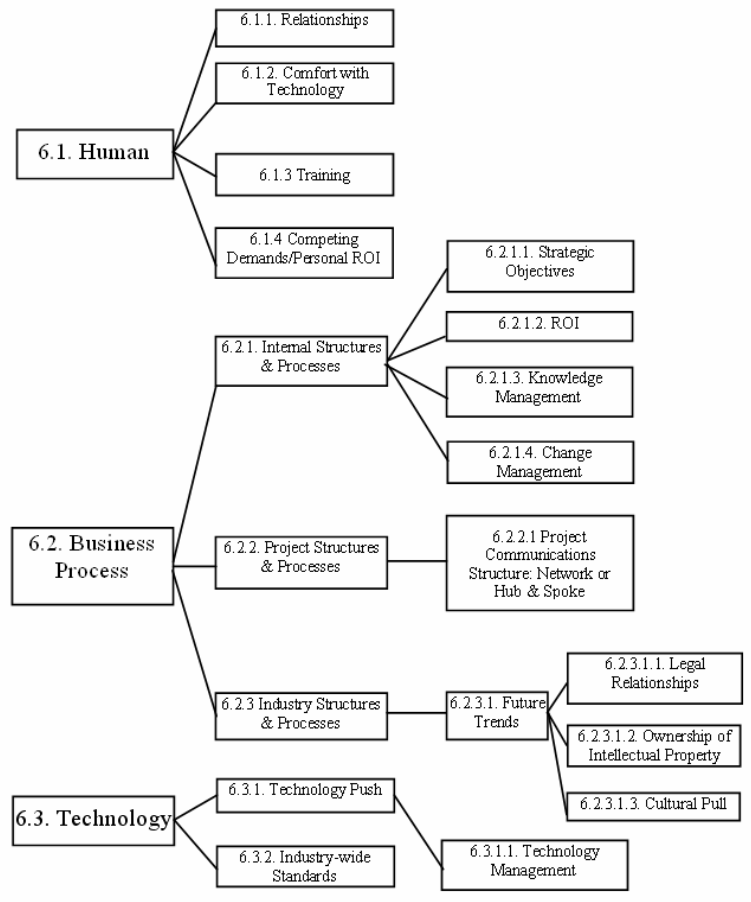

Figure 2. Branch and Leaf diagram

come in mind, is required. These principles may be experienced at three levels:

6.2.1 *Internal Structures & Processes*

These relate to the firm's internal structure and the way in which its formal processes are designed to operate and interact with its trading partners.

Strategic Objectives

These must be formulated at the highest level and be adequately resourced - these might require ICT e-nablement, or view ICT as a strategic objective. Ty-pically they will involve a degree of strategic a-lignment of the supply chain

ROI

The concept may need to be re-conceptualised as something more akin to a key performance indicator than an accounting process – though some ICT champions may have difficulty in overcoming the project profit focus of their organisations.

Knowledge Management

Capture of "lessons learned" may be facilitated by the use of ICT, leading to accelerated organisational change.

Change Management

This must be planned and cannot be abandoned to ad-hoc, reactive processes.

6.2.2 *Project Communications Structure*

The relationship between the organisation type (lea-der or follower) and the way it equips itself (techni-cally and culturally) is clearly linked. Whilst Net-work-like structures may be conceptually desirable, Hub & Spoke structures are a natural consequence of power-based relationships – successful organisa-tions will adapt to either.

6.2.3 *Industry Structures & Processes*

These relate to the aggregated effects that all of the individual firms' experiences in various TPOs across the construction industry have upon the development of the legal, technological and social networks that regulate industry activities and define industry cultu-re.

Future Trends

The industry is at a time of change, initiated in part, by the advent of ICT technologies. This will result in structural alterations to the industry, which will like-ly be felt first at the higher end, particularly in rela-tion to:

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- *Legal Relationships*
  Should be closer, longer-term, enshrined in contracts that emphasise assertive rather than adversarial relationships; triggered by the need for business process alignment enduring beyond the current project.
- *Ownership of Intellectual Property*
  New business models based upon the equitable creation and distribution of wealth created by ICT use and integration.
- *Cultural Pull*
  The desire to maximise benefit to ICT-enabled industry participants across the industry, resulting in an industry-wide restructure.

6.3 *TECHNOLOGY*

Interoperability between diverse systems is a vital key to widespread ICT adoption. The current 'hub & spoke' supply chain (SC) model, with the hub bearing the majority risk/cost of implementation, will be replaced by a situation where all SC participants carry a portion of the costs as the price that they pay for their increased profitability. Two competing forces are at work in this regard:

6.3.1 *Technology Push*

The pace of technological change is partly driven by ICT developers who wish to gain competitive advantage in their industry.

- *Technology Management*
  Construction industry ICT users must plan and monitor implementation and critically evaluate developments, introducing change to their organisation as a measured response to environmental change/strategic fit rather than as a "knee-jerk" to the latest fad or scare.

6.3.2 *Industry-wide Standards*

This is again driven by the ICT industry, but also by construction users hampered by poor levels of interoperability. Whilst it is the industry 'Holy Grail', innovators and/or early adopters will not wait for its development.

7 DISCUSSION AND CONCLUSIONS

Comparison of the literature and Delphi result models (e.g. figures 1 and 2) shows an overarching commonality of issues. However, the emphasis placed on the various issues indicated by the 'leaves' populating the result-driven model are significant in that they indicate where most effort should be directed for firms considering engagement with an ICT mediated supply chain. Detailed analysis of the panelists' responses also revealed strength of feeling when supporting or refuting the more contentious trigger statements. Most striking amongst these were the defence of older employees as being just as capable of adapting to new technology, and the polar positions adopted by the panelists when considering whether ICT was a strategic, long-term investment, or whether an ICT investment must be capable of recovering full investment costs over a single project in order to be considered a 'success'.

Legal and technological standards tailored to the needs of the ICT mediated project were given broad support, although in both cases there was support for the notion that those at the leading edge of the innovation wave would not wait for their development, preferring to adapt existing mechanisms until the arrival of better alternatives. This did not alter the likelihood that such ICT deployments might engender greater risks for participants and result in suboptimal outcomes.

The most striking finding was the presence of relationship issues across all three major areas defined by the study. At the human level, ICT was recognised both as an enabler (geographically dispersed project teams) and a possible inhibiter (loss of face-to-face contact). From a business process perspective the nature of ICT was seen as a possible trigger to/enabler of strategic business relationship formation and maintenance, but that this was not an inevitable consequence of its use. However, structural/cultural changes within the industry were possible, initiating at the top of the industry and permeating downwards over time. The introduction of technology into a firm was expected to trigger similar changes, especially when phased in as part of a managed process.

This paper has identified the problems associated with participation in ICT mediated SCs in a construction context, describing a model of TPO SC structure that is appropriate for investigating and analysing real cases of ICT uptake and integration across a CI project team. It has identified a range of issues, both positive and negative, that influence the success of uptake and integration in that context, confirming and extending it by reference to an international panel of experts, constructing a complete and contemporary model of influences that be further investigated in order to validate it using surveys or case studies. As an investigation of current thinking on the subject it is believed to be of value to practitioners, ICT developers and policymakers wishing to understand the concerns and attitudes of their trading partners, markets and customers.

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An integrated system for conceptual cost estimates

S. Alkass
BCEE Department, Concordia University, Montreal, Quebec, Canada

A. Jrade
CCE Department, Western Michigan University, Kalamazoo, MI, USA

ABSTRACT: Construction projects pass through several phases during their life cycle. However, during the initial level where feasibility studies are conducted, conceptual estimates are generated to assist decision makers in approving or rejecting proposed projects. The common practice followed during this level starts by consultations between owners, practitioners and experts with the deficiency of documents, specifications and drawings. Own experience and wide range of assumptions control the preparation of conceptual estimates, where extensive assortment of errors and unsound decisions are anticipated to occur. Therefore, the availability of accurate cost data is necessary to overcome this problem. This is achieved by the relevance of Management Information System, where cost data and 3D-CAD drawings can be stored and manipulated to fit user's needs. Moreover, decision makers are in need for a reliable system to use during the feasibility stage of new proposed projects. This paper presents the design and implementation of a decision support system, which helps in selecting the best project type given the budget. The system integrates 3D-CAD drawings with relational databases so that any modification in the drawing's parameters such as: floor area, floor-to-floor height and building perimeter; will result in the generation of a new conceptual estimate taking into consideration the required adjustments.

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1 INTRODUCTION

Preparing parametric cost estimates is a challenge for cost engineers and estimators. Owners normally require accurate estimates of the cost of constructing a project originated on initial ideas without supplying physical documents. At this stage, wide range of assumptions governs the preparation of such estimates. Parametric estimate is usually prepared before the facility is designed, and must therefore, rely on the historical cost data collected from similar projects built in the past (Hendrickson, 2000). Bajaj et al. (2002) judge parametric cost estimates as being quiet accurate if the historical data are properly captured from the source. Parametric cost estimating process may generate reliable cost estimates by using factors based on engineering. These engineering parameters are generated from historical cost databases, construction practices, and engineering/construction technology (Meyer and Burns, 1999). On the other hand, one must first have a few available parameters and cost data for a completed project that is comparable to the new project. The simplest method to establish the reasonableness of a facility costs is to identify the costs of similar projects and compare these costs with the cost of the new facility (Melin, 1994); (Ellsworth, 1998). The parametric approach to cost estimating is a procedure involving the use of constant parameters (with variable values) as a reference for other variables (Melin, 1994). These parameters include physical properties that describe project definition characteristics such as size, building type, exterior closure materials, roof type and material and number of floors (Meyer and Burns, 1999). However, these parameters can be extracted directly from the 3D-CAD drawing with slight modifications to the drawings. The most common methods used in approximate estimates is the square-foot method, where historical building costs data are used to get an estimate of the cost per square foot of the type of building under consideration. The estimated unit cost is then multiplied by the gross floor area of the proposed building after being adjusted for factors as location, size, height, perimeter and inflation.

The availability of historical data is indispensable for the preparation of parametric cost estimates. Nonetheless, this data has to be properly organized and convenient for cost engineers and estimators whenever needed. That is realized by applying Management Information System in the course of Databases. MIS is a computer system capable of integrating data from many sources to provide data and information useful to support operations and decision-making (Hegazy, 1993). Management information is normally produced from a shared database that stores data from many sources. Thus data analysis and database design become critical to MIS design (Whitten and Bentley, 1998). A database is characterized by its simplicity of data management, independence of logical user views from the physical data storage structure, and the availability of simple but powerful relational operators. These characteristics translate into a collection of tables that are composed of rows and columns (Kibert and Hollister, 1994). Once the pertained databases are designed and necessary data are stored, these can be accessed and queried through using Structure Query Language (SQL). SQL allows sophisticated data management processes to be performed on databases that are based upon highly orthogonal yet simple principles (Kibert and Hollister, 1994).

This process could be automated through system integration to develop a Decision Support System (DSS) to assist users in making major decisions regarding the feasibility of proposed projects. Decision Support Systems are computer-based tools that help managerial decision-making by presenting information and interpretations for various alternatives, such systems can assist managers in making strategic decision (Pal and Palmer, 2000). DSS are becoming significant to the construction industry where data warehousing is one of its prime parts by providing an interaction of storing, retrieving and manipulating any type of data. DSS has made significant contributions in the data/knowledge storage and in the communication of results to the end user; i.e., databases are principle components of all DSSs (Nemati, and al., 2002). Courtney (2001) describes the decision making process as consisting of three phases: intelligence, design and choice. The first is used in the military sense to mean searching the environment for problems, that is, the need to make a decision. The second involves the development of alternative ways of solving the problem, and the third consists of analyzing the alternatives and choosing one for implementation. Whereas, Pal and Palmer (2000) consider three important approaches in the development of DSSs:

1 Rule-based reasoning (RBR), where the specialized domain knowledge is represented as a set of IF *[precondition(s)]* THEN *[conclusion(s)]* rule format.
2 Case-based reasoning (CBR), where the past experiences are used in solving a new case.
3 Hybrid (i.e., a combination of RBR and CBR).

The ability of such systems in processing knowledge has led to cost savings, faster decision process, and significant competitive advantage (Bonarini and Maniezzo, 1991).

This paper presents a methodology pursued in developing a decision support system that automates the preparation of parametric cost estimates after making essential parameters adjustments for building projects. Rule-based reasoning (RBR) approach is used in the system implementation. Modeling the preparation of these estimates is advantageous particularly when explicit methods and techniques are followed and the pertained parameters are normalized. The accessibility, types and sources of historical data do impact the accuracy of the estimate. Thus storing the required data into databases would speed the process of retrieving, querying and modifying practice when desired. The data used is based on R.S. Means Square-Foot-Cost Data published in year 2000. Microsoft Visual Basic 6.0, MS Access 2000 and AutoCAD 2000 were used in the implementation of the system.

2 DEVELOPMENT OF METHODOLOGY

The system requirements are set based on the literature review along with the characteristics to be considered in a practical system. The process of introducing a valuable methodology is considered in order to enhance the benefits of the system under its categorized requirements and development constraints. The methodology is divided into four steps of design and development. The first step consists of designing and implementing the system's cost databases. Theses are needed to generate parametric estimates. Another separate database to store 3D-CAD drawings to be used by the DSS is also developed. The second step encompasses the customization of AutoCAD drop down menus to meet the system requirements. Also to design internal modules that automate the process of retrieving necessary parameters from the 3D-CAD drawing and writing them to an external database designed for that purpose. The third step consists of designing a global module to be used as gateway to manage the project cost data retrieval and execute the required normalizations and calculations. Finally, the fourth step includes the design and implementation of a decision support system that aids users in selecting the most appropriate project together with its 3D-CAD drawing that meets the users requirements terms of budget.

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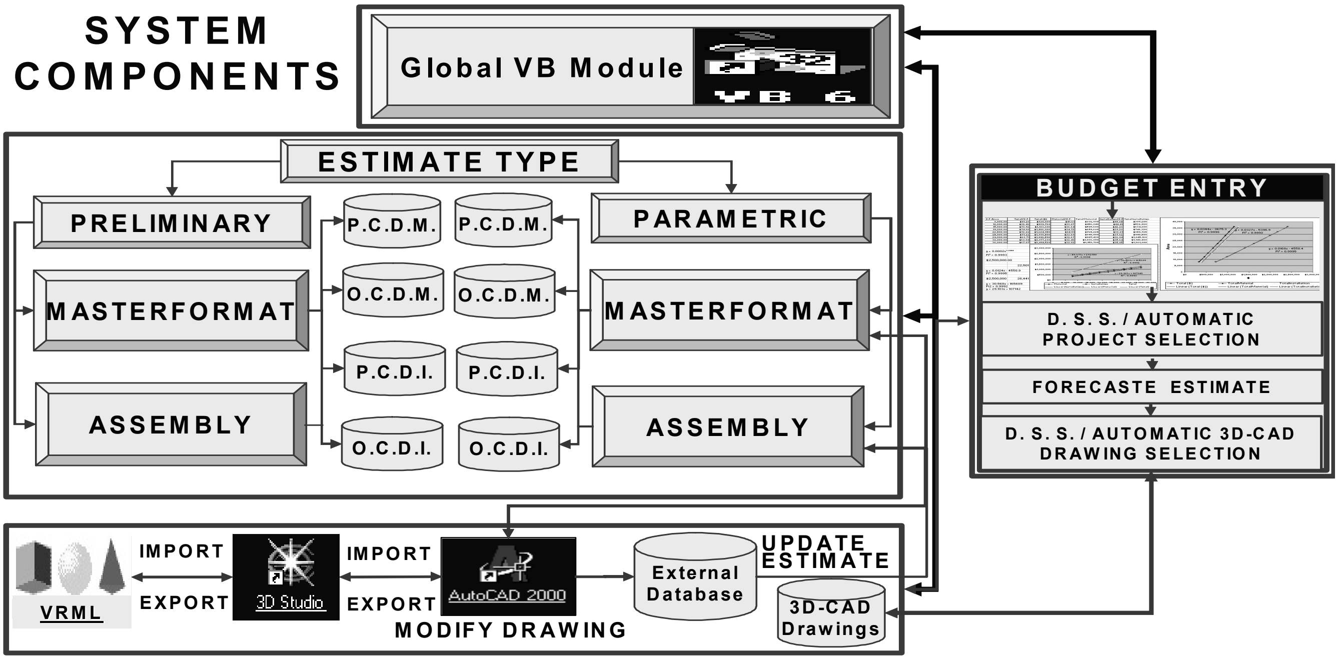

Figure 1. System Components

2.1 *System components*

The system consists of components designed in a modular format, incorporating a global Visual Basic module, which is considered as the gateway to access all other three modules and links four cost databases. These databases are managed by a database management system, which in this case is Microsoft Access. The system components are developed through four steps described in the following paragraphs. Figure 1 exemplifies the system components.

2.1.1 *Step one*

In this step all the pertained databases are designed and implemented in order to store cost data of previously constructed projects and from R.S. Means publications. In addition one 3D-CAD drawings database is developed so it is accessed by the DSS to select the closest drawing for the proposed project. Figure 2 shows the graphical illustration of the system's database development process. This process is divided into two parts: Conceptual Modeling and Data Model Implementation.

2.1.2 *Step two*

This step comprises the development of AutoCAD internal modules in order to automate the process of reading and writing the retrieved parameters from the 3D drawings. Moreover, a direct link between AutoCAD and an external database is established to accelerate the storing process of the extracted parameters. Finally, two additional drops down menus are added to the AutoCAD menu to make the procedures that are carried out by the internal modules easier. Figure 3 illustrates the AutoCAD modules and components.

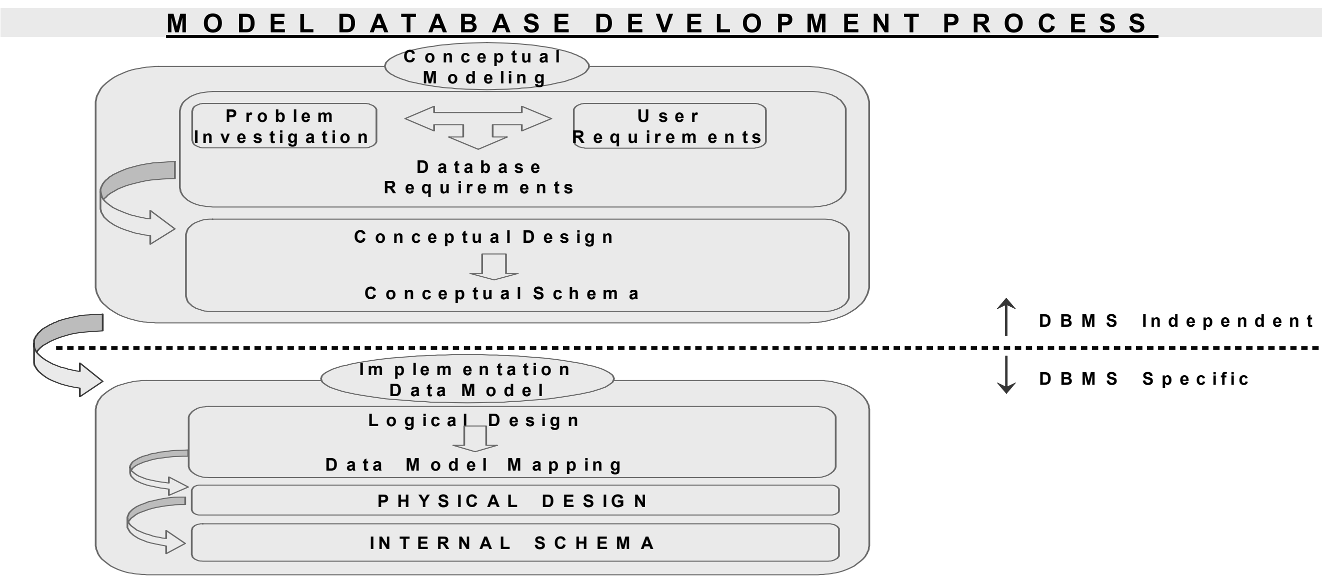

Figure 2. System's databases development process

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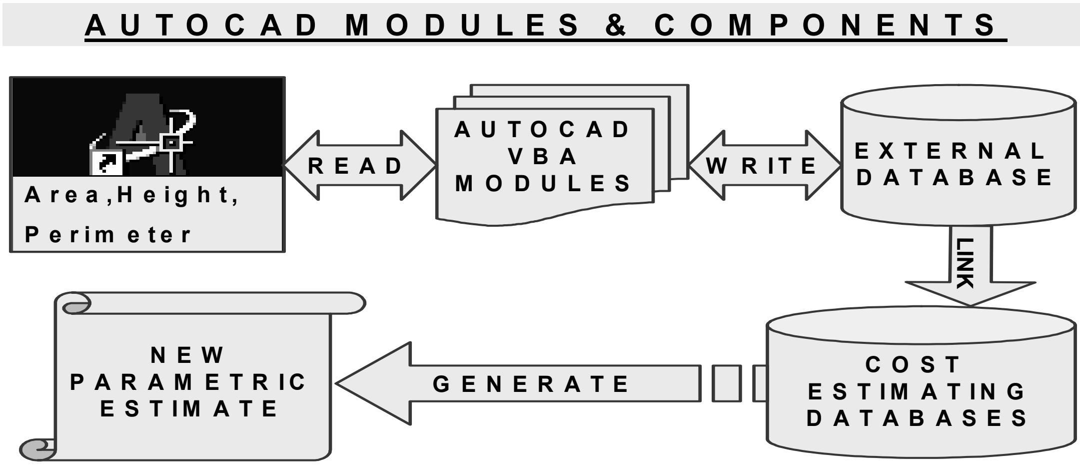

Figure 3. AutoCAD modules and components

2.1.3 *Step three*

This step covers the design and implementation of the global Visual Basic module. As shown in Figure 1, this module is considered the entryway for all other modules. Furthermore, this module executes all required calculations and cost adjustments needed after modifying the 3D-CAD drawing associated with the selected project. Figure 4 shows a screen printout for a sample form of all the calculations and adjustments carried out by this module based on the new parameters from the drawing.

2.1.4 *Step four*

In this step a decision support system is designed and implemented so that it provides the user with the best project and associated 3D-CAD drawing based on the budget entry. For this purpose, a rule base system has been developed containing a total of 80 rules related to the system functionality. These rules are divided into the following three groups:

In this step a decision support system is designed and implemented so that it provides the user with the best project and associated 3D-CAD drawing based

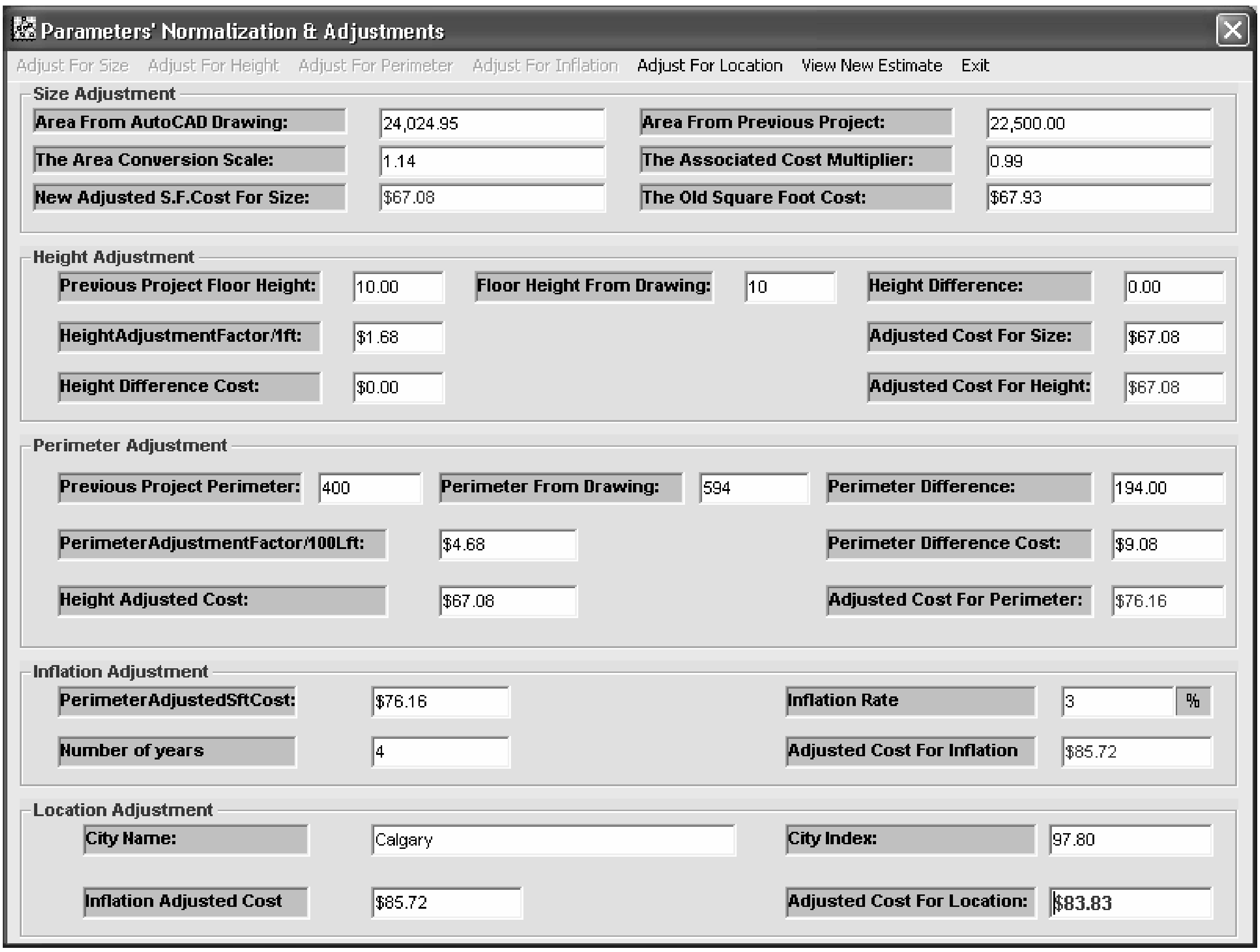

Figure 3. AutoCAD modules and components

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on the budget entry. For this purpose, a rule base system has been developed containing a total of 80 rules related to the system functionality. These rules are divided into the following three groups:

1 Wide, containing 25 rules
2 Intermediate, containing 25 rules
3 Narrow, containing 30 rules.

Figures 5 and 6 show the Rule Based Reasoning workflow process and the Rule Base structure respectively.

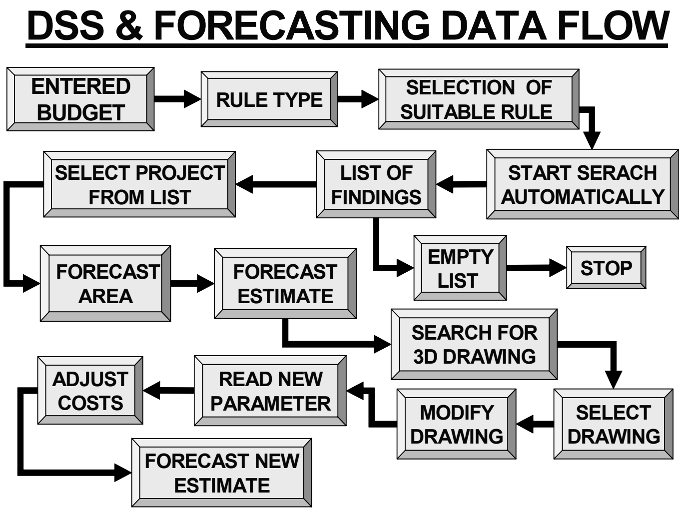

Figure 5. Rule based reasoning workflow process

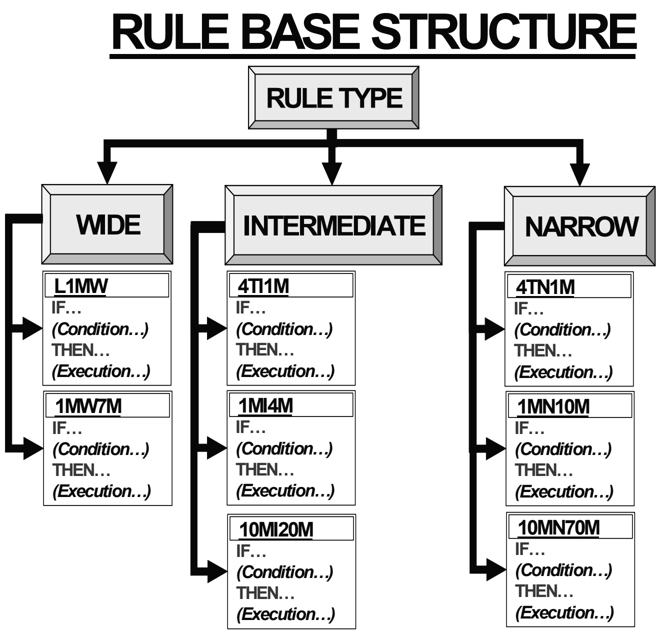

Figure 6. Rule base structure

Once the user accepts the project selected by the DSS, its area and related conceptual estimates are immediately forecasted using sets of linear regression equations derived for that purpose. Thereafter, the DSS selects a suitable 3D-CAD drawing from the specified database and makes it available for the user to animate and modify. Once the drawing is modified, the new parameters are read and accordingly a new estimate is generated.

3 CONCLUSION

A methodology to automate the process of preparing conceptual estimate has been presented. A decision support system that helps users in selecting a project and 3D-CAD drawing that meets the allocated budget and accordingly forecast its gross area and cost estimate is introduced. This system assists owners, architects, and cost engineers during the course of conducting feasibility studies for proposed projects. Besides its simplicity, flexibility, user-friendly and ability to allow the user to visualize a preliminary shape of the proposed project in 3D mode and to carry out any essential modifications in the sense of extracting floor areas or adding more floors. The development process is carried out using software applications known to the industry such as AutoCAD, MS Access, and Visual Basic.

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Facilitating the link between point-of-production workers and corporate ICT systems in construction

A. Thorpe, M.J. Ward, S. Bowden & A.D.F. Price
Centre for Innovative Construction Engineering, Loughborough University, Leicestershire, UK

ABSTRACT: Web-based project management systems (WPMS) are becoming more widespread within construction and have shown to be beneficial in improving communications and document transfer between project participants. However, the challenge of integrating point-of-production workers into such systems still remains largely unrealised. This paper describes current applications within construction that are addressing these challenges. The technologies employed vary from tablet PC's, PDA's to RFID tags. The paper examines in detail a web-based data capture and management system for piling works, utilising a site-based web server and wireless network. The system effectively allows for the expansion of existing WPMS to include construction site workers, whilst improving the management and understanding of the project in terms of quality, cost and progress. The paper also agues that improved data reliability and robustness can be achieved by integrating the point-of-production operations into corporate ICT systems.

1 INTRODUCTION

The use of IT on the construction site is becoming the norm rather than the exception, with many site 'knowledge workers' utilising PC's and laptops for the management of the project. Advances in communications now allow site managers to be permanently connected to corporate systems, remain in contact with the office through the use of e-mail and be fully integrated into the construction team via web-based project management systems (WPMS). However, existing time constraints on managers, often mean that data capture is still restricted to document based systems through the completion of standard forms, reports and spreadsheets resulting in:

- islands of automation;
- duplication of data entry;
- risk to data integrity; and
- limited or no re-use of data.

Much research, both academic and industrial has taken place into the implementation of process driven mobile computing on the construction site, addressing specific construction processes such as: site diary completion (Scott,1990); progress records (Cox et al., 2002); resource management (McCullough & Gunn, 1993); quality inspections (Cox and Issa, 1996); and health and safety audits (Hawkins, 2002).

However, the majority of this work has been aimed at extending the capability of the 'knowledge worker' through the automation of maintenance, inspection and reporting tasks, and at best only filtering down to the site foreman. Whilst such developments go some way to advancing a traditionally IT scarce sector, the burden of data collection on the construction site is still carried by a limited number of personnel. A fact that could be addressed with the implementation of mobile IT at the point-of-production.

Mobile computing technologies have already been successfully deployed for once only data capture at point-of-production across many sectors. Barcodes and RFID tags are commonplace in the retail industry, couriers readily utilise mobile computing for parcel tracking and signature scanning and PDA's are being used wirelessly in hospitals for accessing patient records. However, the widespread application of mobile computing on the construction site still remains an untapped potential with many point-of-production workers effectively prevented from contributing to the information flows that exist. Many reasons have been cited for this (Bowden and Thorpe, 2002; Ward, et al. 2002) including:

- perceived high initial equipment cost;
- perceived lack of rugged devices; and
- perceived lack of computer literate workers.

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This paper examines the current possibilities for integrating the point-of-production worker into corporate IT systems and presents a detailed case study showing how has been achieved.

2 CURRENT POSSIBILITES IN MOBILE COMPUTING

2.1 *Mobile devices*

Research into mobile computing in construction has tended to follow the development of new devices. From early notebook type computers (McCullough, 1993) to PDA's (Cox et al, 2002). Over the past five years the number and type of mobile computing devices has rapidly expanded mainly driven by the extended capability of the mobile telephone networks. Currently the main categories of devices on offer, in order of size are:

- *Digital Pen and Paper*: a system combining a digital pen with a co-ordinate system indented on paper. As the pen writes the pattern is stored as digital text within the pen,
- *Personal Digital Assistant (PDA)*: operated by touch-screen, typically 2.5 x 3 inches in size, basic PDA's allow a user to store and retrieve addresses and phone numbers, maintain a calendar, and create to-do lists and notes. More sophisticated PDA's can run word processing, spreadsheet and industry specific applications.
- *Palmtop computer*: a hand-held computer offering similar functionality of a laptop computer. They feature a full QWERTY style keyboard and a landscape display with dimensions starting at 2.5 x 6 inches up to 10 inch.
- *Tablet computer*: utilising a larger touch-screen display, similar in size to a laptop computer these devices are capable of offering full operating systems or those similar to PDA's. Web-tablets have been developed targeted specifically at providing wireless web-based entertainment or gaming.

Of these, the PDA, palmtop computer and tablet computer are all capable of expansion by 'add-on' peripherals such as barcode scanners and RFID tag readers and many include communication capabilities of Bluetooth, WLAN or GMS/GPRS.

However, there still exists a lack of rugged hardware at a reasonable price for the construction market, one solution to this is to protect a cheaper off-the-shelf device with a rugged case such as a 'pelicase' or 'otterbox'.

2.2 *Construction software*

The majority of mobile application software has been aimed at extending traditional office-based applications, such as word processing, spreadsheets, and accessing e-mails. Within construction, this has been mirrored by the large vendors of office-based construction software such as AutoCAD and Primavera, who have developed mobile versions of their existing software. In addition, a number of off-the-shelf mobile database tools have been developed aimed specifically at building surveying, snagging and inventory control. Such tools provide a basis for customizing the software to meet the users requirements.

2.3 *Auto-Identification*

Research into the use of auto-identification techniques in construction has been active since the late 1980's with the application of 1D barcodes (Bell & McCullough, 1988). The main use of barcodes within construction to date has been in materials management with barcodes now widely used on delivery tickets such as concrete. However, the main barrier to their widespread use throughout the supply chain has been the use of closed databases, with the data on the barcode often only referring to the unique ID within the database held by the supplier.

The future of barcodes throughout all industries is now being challenged by the adoption of smarter radio frequency identification (RFID) technologies capable of transmitting and receiving data.

2.3.1 *Radio frequency identification*

Until now, the main barrier to the widespread adoption of RFID throughout all sectors has been cost. However this is likely to rapidly change in the near future, with Wal-Mart, the world's biggest retailer, announcing plans for its 100 top suppliers to introduce RFID tags for tracking goods through its supply chain in 2005. Such widespread use will increase mass-production of the chips and could reduce unit costs to a few pence.

One example that has been explored for the use of RFID tags within construction has been in building maintenance, inspection and reporting (Yabuki, et al, 2002). When undertaking an inspection data from the RFID tag is uploaded into a PDA providing details of previous inspections and the type of work to undertake. On completion the user may upload any new changes to the tag ensuring that life cycle data remains with the building component.

"Tag and track" is a project that has been part funded under the UK's Department of Trade and Industry (DTI) ICT-Carrier programme. It aims to adapt and transfer technologies for RFID, Wireless communications and Web applications from retail

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and haulage industries to the manufacturing sector supplying to the construction industry.

"Smart chips" is a project run by FIATECH, a nonprofit consortium in the USA. The aim of the project is the successful use of AutoID technology in construction applications and to realise potential benefits not identified by individual companies but by the construction industry as a whole.

2.4 *Mobile Ubiquitous devices*

Mobile Ubiquitous devices combine a number of separate devices connected together using the body as the carrier. The main areas of research have been wearable computers and digital hard hats.

Research into wearable computers for highway and bridge inspections (Garrett, 1998; Garrett and Sunkpho 2000; Rebolj, 2000) have included a heads-up display, tablet computer, PDA, wearable computer pack and voice activated software. Commercial equivalents are now available through companies such as Xybernaut who specialise in wearable computing technologies and have developed applications for industries such as, retail, aerospace and telecommunications.

The digital hard hat has been the subject of research since the mid 1990's (Thorpe, et al. 1995, Liu, 1997) and involves a camera mounted on top of a hard hat and pictures relayed to the site office or head office using a mobile communications system. Thorpe's system included a head mounted display that could be connected to a computing device. Whilst, Liu used a touch-screen tablet computer connected to an operator with a camera producing images for inspection and reporting of infrastructure. Until recently, the technology required for efficient transfer of this information has not been readily available. However, Woh Hup Private Ltd, a construction company based in Singapore, are currently involved in a $2 million programme to develop a commercially viable digital hard hat.

2.5 *Automated data collection*

This technology allows for automated data capture and includes technologies such as on-board computers, built-in sensors or 3D laser scanners for applications ranging from earthworks estimating (Kanaan and Vorster 1998) to hazard identification (Changwan, et al. 2004)

2.6 *Identification of examplars*

Due to the fragmented nature of the construction industry and the traditional lag between academic research and industry uptake, discovering existing uses of mobile IT in construction is difficult. Even more difficult is justifying the benefits for its adoption. One such project attempting to rectify this is COMIT (Construction Opportunities for Mobile IT). COMIT aims to promote the business benefits from the implementation of mobile IT in construction (Bowden et al, 2004).

The COMIT project has identified eleven case studies of mobile computing applications in the UK construction industry (see Table 1). The most widely adopted hardware has been the PDA, with only one project utilizing a tablet computer. The majority of identified case studies have developed bespoke software solutions to meet their process requirements, with off-the-shelf software identified in only two of the case studies, these being:

- Case A: using PDA's and RFID tags for planning and recording service and maintenance of plant and machinery.
- *Case J*: utilizing a blackberry PDA and enterprise server for remotely accessing e-mails.

This suggests a lack of task-orientated software being developed for the construction market.

The majority of end-users identified within the case studies can be classed as '*knowledge workers'* who are likely to use the information that they are recording during their normal working duties. In such cases, the integration of the device directly replaces existing paper-based methods with the device becoming part of the users 'tool-for-the-job'. The case studies suggest that the use of mobile IT by the construction site production worker still remains low, with only three of the case studies identifying the end-user as the foreman or below.

It is commonly accepted that the use of IT will eliminate many of the problems directly associated with paper-based documentation: duplication, feedback, quality, exchange, awareness, illegibility, format, volume, cost, queries, and being 'out of date' (Murray and Thorpe 1996). Whilst such benefits were observed in the majority of the COMIT case studies, a number of indirect benefits emerged as follows:

- reports produced quickly and easily,
- better customer service,
- identification of trends,
- more efficient task allocation,
- reduced task turn-around time,
- improvements in the quality of work,
- increased accountability of staff,
- reduced supervision, and
- ability to track stolen equipment.

Whilst the majority of existing initiatives may be aimed at extending mobile capability to the '*knowledge worker'* the potential for the integration of the point-of-production worker with the corporate ICT systems remains. Following is a detailed examination of one such system.

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Table 1. Details of case studies captured by the COMIT project

Case study and Process	Hardware	Software	End-user
A preventative maintenance	PDA, RFID tags	Off-the-shelf	Maintenance engineers
B job allocation & timesheets	PDA	Customised	Maintenance engineers
C defect management	PDA	Bespoke	Site engineers
D fleet management	GPS tracker	Customised	Operations management
E monitoring site works	Tablet	Bespoke	Site operatives
F defect management	Digital pen	Bespoke	Foreman
G managing site safety	Mobile phone	Customised	Foreman
H timesheet & payment	Mobile phone	Bespoke	Site engineers
I earthworks examinations	PDA	Bespoke	Geo-technical engineers
J email & PIM	Blackberry PDA	Off-the-shelf	Senior executives
K field observations	PDA	Bespoke	Site engineers

3 THE SHERPA SYSTEM

The SHERPA system is a research project conducted within Stent Foundations Limited, a leading UK piling contractor. The project was borne out of the need to improve the quality and understanding of the progress of piling works through the implementation site data capture by point-of-production workers. Following analysis of existing practices and data flows a number of key issues emerged suggesting the use of a server-based central data repository and wireless data capture system, these were:

- multiple revisions of paper-based documentation;
- data transfer and inscription errors,
- just-in-time design data,
- real-time data sharing on site, and
- lack of data verification at the point-of-production.

3.1 *Hardware*

Semi-rugged Windows CE tablet computers were implemented for use by the site workforce to undertake data collection (Figure 1). The main drivers for the selection of the device were:

- usability,
- integrated WLAN capability, and
- cost.

Figure 1. Windows CE tablet computer

Twenty-five tablet computers have been in operation over a period of three years with the average life-span of a device being 18 months. The most common failure being damage to the screen, which could be repaired at less cost than purchasing a new device. This suggests that semi-rugged devices are more cost effective than fully rugged devices. In addition, the payback period is significantly less, and there is no 'tie-in' to justify keeping the device for longer than necessary, a particularly important factor in a rapidly developing market where faster, and improved devices continually emerge.

3.2 *Infrastructure*

Communication capability is provided by a site-based wireless network, which extends accessibility to the system beyond the site office to the point-of-production (Ward, et al. 2003).

The wireless network is based on the IEEE 802.11b/g wireless protocol and allows for the creation of a flexible, and re-configurable network through the use of one or a number of battery operated Wireless Network Cells (WNC). The WNC form a cellular network not dissimilar to mobile telephone network, allowing users to communicate to the site server or peer-to-peer via one or a series of WNC. WNC are typically placed on the piling rig allowing for the creation of a work zone around the rig and have also been placed on other strategic locations such as tower cranes, when available.

3.3 *Software*

All software is based on standard web-server architecture, with all web pages located on a central server located in the site office which is used to provide localised web services to site users via the wireless network.

In order to reduce capital costs, all software utilised on the server is open-source. A MySQL database is located on the site server with all data capture undertaken through specially designed web

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pages. An Apache web-server is used to deliver the content to mobile users via the web-browser located on their device. All web pages have been written using PHP (hypertext pre-processor), HTML (hypertext mark-up language) and Javascript. Server-side scripting such as database transactions and the creation of dynamic content are carried out by PHP, whilst Javascript is used for client-side interaction such as ‘on-click’ events.

3.4 *Data Capture*

Bespoke data capture pages have been written to correspond with the pile construction processes on the site and utilise easy-to-use, pop-up menus and keypads to aid in the data collection. The site data capture interface is divided into three distinct parts: navigation bar; menu bar; and data entry section (Figure 2).

Located on the right hand side of the screen, the navigation bar allows users access to the pile selector from which they can request the latest pile design details from the server for the current pile. Once a pile is requested the design details and construction tolerances are embedded within the navigation bar allowing them to be accessed by all data capture pages for data verification purposes and to be viewed by the user as required.

The menu bar is located on the left-hand side of the screen and includes a set of buttons, dynamically generated by PHP, each button relating to an individual data capture page.

The center of the screen is used for data capture. Users enter data by clicking on the relevant cell corresponding to the data entry to be made. An underlying continuous self-auditing process checks data entries, alerts users to possible non-conformances, and provides guidance on pile design requirements such as toe depth, cage position, levels and concrete volumes.

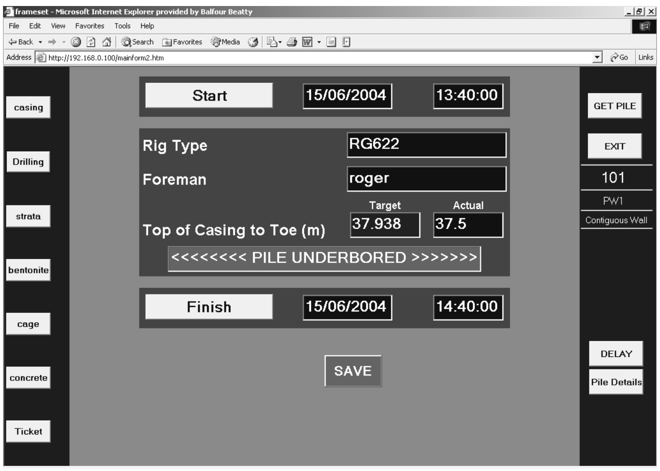

Figure 2. Bespoke web-based data capture page

3.5 *Data Management*

SHERPA allows for the real-time management of site data by the site *knowledge workers* who are able to access, maintain, manipulate and view pile design and construction data. The functionalities of the data management facility are described as follows.

3.5.1 *Contract settings*

Contract settings provide an interface for the management of static data sets such as, concrete mix types, piling rigs, augers and expected site soil types, many of which are used on pop-up boxes integrated within the data capture pages. In addition, contract specification and tolerance details such as horizontal and vertical pile position, support fluid, maximum allowable slump and reinforcement cage position can be maintained.

3.5.2 *Design schedule management*

One of the fundamental reasons for the design and development of the SHERPA system was the creation of a structured data source of pile design details, which could be accessed from the construction site during piling works. Emphasis has thus been placed on effective management and importing of pile design schedules. A single pile design detail is stored for each pile on the server, together with its corresponding revision, once a pile is completed, the design detail remains locked from further updates, thus ensuring integrity of design and constructed data.

3.5.3 *Analysis and reporting*

The reporting section allows for the collation and viewing of pile data in HTML format. A number of reporting functions have been provided. Pile construction logs provide concise details of each pile and comparison to the design data. This can be further augmented with an audit summary highlighting piles that do not meet specification or specified construction tolerances. In addition concrete analysis can be carried out for individual piles, groups of piles or specific rigs based on theoretical and actual quantities used and dates of deliveries.

A prime cost analysis for materials, plant, labour and steel can be produced based on pile production for any day or period during the contract. Income is calculated by pre-processing the tender and assigning plant, labour, concrete and steel values to each pile, whilst costs are recorded through the daily input of timesheets for labour, plant returns, concrete and steel deliveries. This provides knowledge workers with a 90-95% accurate assessment of the financial performance of the contract.

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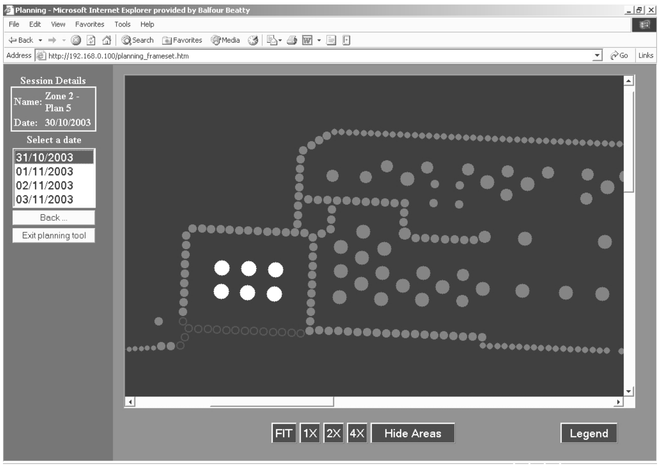

Figure 3. Visualization of site progress.

3.5.4 *Visualisation of progress*

A 'site viewer' has been developed through which a colour-coded 2D representation of the current site status can be generated using the coordinates and diameter of each pile contained within the database (Figure 3). The image created includes a pan and zoom function and colours each pile according to its current status: concreted; completed; or incomplete. Each site view image is augmented with an underlying 'click map' allowing additional pile data to be accessed by clicking on the required pile.

3.6 *System Implementation*

The SHERPA system has been implemented on various sites throughout the UK with the following observations made in respect of the component implementation and operation

3.6.1 *Wireless network operation*

Battery powered WNC have been successfully deployed on all sites and where appropriate have utilised piling rigs and tower cranes to propagate the signal across the site. A number of fundamental issues relating to the performance of wireless networks on the construction site have been previously identified (Ward, et al. 2004), as:

– uncontrollable spoil heap generation,
– variations in working levels, and
– construction of superstructure.

In addition, factors affecting the implementation of the WLAN in the early phases of the site have been observed as follows:

– the location of the site office may not be known,
– working areas may not be known,
– the site is chaotic in nature, and
– power and communications to the site office may not be in place.

3.6.2 *Site data capture*

All point-of-production workers were provided with on-site training in the use of SHERPA. Whilst users readily accepted the reasoning behind the system, there was a level of scepticism caused by previous failed attempts by the company in introducing site based ICT. When added to the early chaotic nature of the site this resulted in a protracted implementation and training phase. In addition, the following personnel related factors significantly affected the speed of implementation.

– literacy of users,
– transient nature of site staff,
– reduced site staffing levels caused by illness, and
– level of enthusiasm instilled by the foreman on site staff.

As the SHERPA system relies heavily on the successful implementation and operation at site level, the question of how to integrate the tablet computers into existing working practices was left to the site users. In response, the site users developed a system of lecterns onto which the tablet computer could be placed (Figure 4). This resulted in the positioning of the computer at the place of work rather than individualising the units, a common feature of many mobile computing applications.

3.6.3 *Data control*

The operation and control of the system was undertaken by the site staff, with specific tasks such as schedule importing, quality auditing, pile log generation, profile management and concrete delivery analysis assigned to a number of staff on larger contracts, but easily conducted by a single engineer on smaller contracts.

The web-based architecture allows any engineer to access the system 'license-free' utilising a web-browser on any machine within the site office. Where appropriate and site conditions allow, broadband connections have been implemented on-site allowing remote users and those in the head office to access the site server and get immediate up-to-date information on the status of the piling works.


Figure 4. Use of lecturns by site staff.

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4 ASSESSING THE IMPACT

A significant proportion of the control of a construction project is exercised by the point-of-production workers, where IT systems have been implemented for use by such workers, a number of distinct benefits have emerged.

4.1 *Improved quality of work*

The provision of a self-auditing system that assists the site worker in ensuring work is constructed to the specified tolerances has been shown to have a positive impact on the reduction of non-conformances on the site (Ward, et al. 2004). This has a positive financial impact on the contract and provides the client with greater assurance. In addition, there is the potential for the development of a self-certification culture, relieving the client of on-site inspection duties and therefore saving costs.

4.2 *Workforce productivity*

Research into the use of tablet and wearable computers by construction workers, (Elvin, 2003) suggests a slight reduction in productivity over those utilising paper-based documentation. However no difference was evident between daily outputs before and after the implementation of the SHERPA system. This is thought to be attributable to the process-orientated nature of the system which provides site workers with sufficient time to complete the relatively small amount of data input required. In addition, the reduction in defects from the implementation of systems such as SHERPA and consequent delays for rectifying work are likely to be a contributory factor.

Typically one to two hours per day are spent by the foreman collating and completing paperwork such as concrete records, concrete tickets and pile logs. This was eliminated in the SHERPA system allowing the foreman more time on the site to undertake a supervisory role.

4.3 *Improved workforce knowledge*

Providing point-of-production workers with process-related IT systems allows for a greater understanding of the main factors affecting the quality of construction, either through underlying self-auditing such as that observed in the SHERPA system or by asking specific questions of the user. Where previously consideration has been on the speed of production, the implementation of IT can be used to force site users to consider the quality of construction. In addition being able to access the correct information a the right time is essential to avoid rework.

Currently, many construction workers are excluded from the information loop providing guidance on current site progress in terms other than production or work scheduling. This is particularly true of financial information, which many companies see as sensitive. Such an approach reinforces the ‘them and us’ attitude between site workers and their *knowledge worker* counterparts. Systems such as SHERPA help to redresses this balance by allowing site managers to produce a variety of reports and graphs that can be distributed to the site workers helping them to improve their understanding of why certain management actions need to be taken and the benefits from doing so.

4.4 *Timely access to data*

Site office based personnel report the greatest benefit from such systems being the improved accessibility of data coming from the construction site. The capture of data at point-of-production eliminates duplicity whilst time for collation and analysis of data have also been found to be reduced. This improved accessibility and management of data in turn reduces the turnaround time for signing-off work and establishing grounds for payment.

4.5 *Better understanding of site progress*

Allowing point-of-production workers to contribute their process and production related data direct to corporate databases improves the understanding of site progress not only for the site *knowledge worker* but also for those workers residing at the head office. At best, head office workers are able to access point-of-production data in near real-time using a direct link to the site, whilst at worst a view of the previous days progress can be achieved when the transfer of data is by GSM dial-up.

Historically, project progress and costing has been based on accounting principles, with knowledge of project financial progress limited by the valuation process. Such methods allow for the concealment of real progress by site engineers and have a distinct effect on short-term projects that may be completed before the real financial picture can be made available. It is envisaged that through the capture of production data by the point-of-production worker difficulties caused by traditional practices can be drastically reduced.

5 CONCLUSIONS

Whilst, there are many efforts currently underway to integrate mobile computing into the construction

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workforce, many of these are targeted at the '*knowledge worker'* level of the business, the possible reasons for this are:

– the development of off-the-shelf task specific software,
– a more accepting workforce, which eases the implementation, and
– the IT becomes part of the users working tool.

However, the development and implementation of the SHERPA system has highlighted the ability to extend corporate ICT systems to the point-of-production worker.

Benefits to both site workers and *knowledge workers* have been highlighted which suggest a substantial improvement in the quality of work, accessibility to data and understanding of site progress. In addition, data visualisation techniques have been used to validate imported data, monitor site progress and assist with pile planning and sequencing tasks.

Whilst the example presented has been developed specifically for the piling works site, the SHERPA approach has the potential to deliver web-based project management support to construction site workers in a range of disciplines.

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Project teams and ICT: surfacing the critical success factors.

T. Gajendran, G. J. Brewer, S. E. Chen
University of Newcastle, Callaghan, NSW, Australia

ABSTRACT: This paper reports on the second stage in a project, funded by the Co-operative Research Centre for Construction Innovation (CRC-CI) in Australia, investigating the critical success factors for ICT mediated supply chains. It argues that Information and Communication Technology (ICT) adoption in the construction industry has yet to deliver its full potential, and that a need exists to identify and understand the factors that should be addressed to reap this full potential. It describes a national questionnaire survey that was conducted to identify the critical success factors that underpin the integration of ICT in supply chains. It establishes that organisational commitment, organisational attitude to communication, rights and duties, investment drive, guarantee/protection/assurance were all identified as being critical issues to be addressed by firms wishing to successfully adopt and integrate ICT into their supply chain operations. The paper concludes with recommendations for further research.

1 INTRODUCTION

The construction industry is often criticised for the lack of initiatives to improve practices and productivity. One major criticism is the fragmented nature of the industry (Cox & Ireland, 2002; Latham, 1994; Egan, 1998), which leads to inefficient communication among project teams. Among the solutions intended to address this issue, the uptake of Information and Communication Technology (ICT) was widely anticipated to increase the effectiveness of project delivery. However, it has been established that although the uptake of ICT to automate business processes has given productivity gains at an automation level (Egan 1998, Finch 2000; Li et al., 2000; Love et al., 2000), the full potential of ICT to integrate operations along supply chains is not widespread (Bulmer & Brewer,2000).

It is accounted that the dissatisfactory performance of ICT investments are not to be blamed on the uptake of ICT, but rather on the poor integration of ICT into the structure of construction industry processes. The failure to consider the 'temporary project organisation' and 'network relationships' that characterise the construction industry business environment by the focus organisations during implementation of ICT is a likely cause for unsatisfactory performance (Brewer et al 2003).

The model in Figure 1 illustrates the 'integration gap' between the business processes at work in the construction industry and ICT used to facilitate them, which arises if ICT is not mindfully integrated into construction projects and participant organisations. In addition, it introduces the notion that the level of integration intensifies from simple 'office-wide automation' to 'pan-supply chain process integration'.

For effective integration, an industry-wide understanding of generic factors that influence integration should be identified. Since supply chain concepts can be used to address the issue of industry fragmentation and communication, they can therefore provide a frame work to study ICT integration. It follows that high integration between ICT and construction industry business processes, along an idealised supply chain will lead to major performance improvements across the sector.

Little is known of the attitudes at the level of the individual firm as to 'what must be done, what must be attended to' in order for their involvement in ICT mediated supply chains to yield higher business performance and be considered successful in their terms. This paper explores the views and experiences of participants in ICT enabled project supply chains to uncover the factors that are critical for "success" in this context. The objective of the study therefore was to identify those factors that were considered of critical importance to a firm's successful participation in an ICT mediated supply chain.

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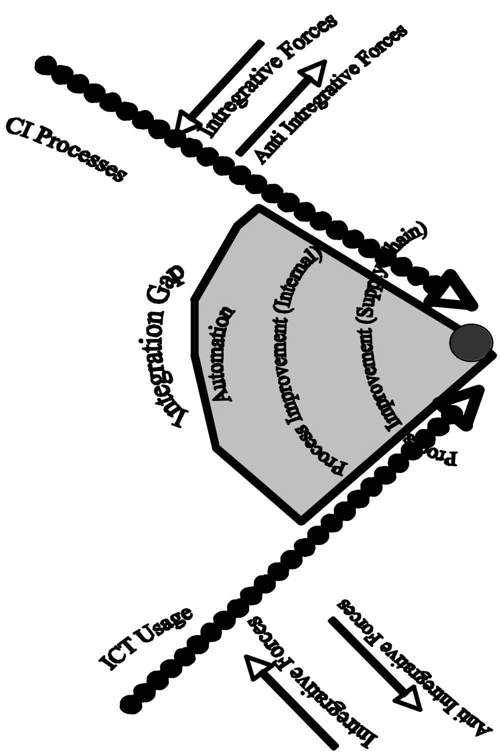

Figure 1 – Project focus to process improvement using ICT and SCM concepts (Modified from Gajendran et al 2003)

The findings revealed a range of five factors, which were identified as being important in achieving success and/or reducing the likelihood of failure in the operation of an ICT mediated supply chain.

2 ICT AND SUPPLY CHAINS

Agreement is yet to be reached on a common definition for supply chain management, however the key theme of supply chains is a series of linked relationships and processes (members, resources, information etc) beyond the individual organisation's boundaries, which add value to the system (Kauffman 2002). Supply chain management is about managing these chain-wide relationships and information in an effective way to achieve greater business efficiency. Within the supply chain, there is a constant flow of information that is vital to the effective functioning of the chain, which strengthens the role of ICT in the supply chain. To achieve this at the level of the project, different parties to the supply chain need to understand the business and information requirements for engagement with it. This process should continue throughout the project life cycle (Hassan et al., 1999) so that the participants will achieve their economic goals. It is evident that the urge to construct ICT mediated supply chains will increase in the near future as a response for organisational survival; therefore it is timely to establish the CSFs and best practice guides for such initiatives. Review of the relevant literature, together with the results from a previously conducted Delphi study of experts generated the candidate success factors (see Table 1) identified as influencing the effectiveness of ICT in supply chain situations.

Table 1: Candidate Success Factors overview

Management style	Participating, supportive and committed Senior management
Technological issues	ICT capacity (hardware & software), ICT compatibility with trading partners, organisations comfort with participants, training of participants.
Attitude to relationships	Trading partner selection methods, adoption of data and, communication structure, communication attitude, education of personnel, information sharing
Business attitude	Proactive continuous improvement (TQM, JIT, VM), Reactive Innovation laggard
Investment performance	Customer satisfaction, Return on Investment (ROI), Relative technology competitiveness
Security	Security monitoring and auditing, Willingness to share information, Intellectual property relights
Power relationships	Dominant dictator of SC ICT, threat to future business opportunities
Competitive position	Formation of strategic partnerships, competitive advantage relative to competitors
Individual consequences	Different role, different job skills, new concerns
Training	Recruit people with appropriate experience. Commitment of the organisation to support training.

Based on Akintoye et al (2000), Vakola & Wilson (2004), Nagi et al (2004), Crook & Kumar (1998), Angeles et al (2001), Goulding & Alshwai (2002), Angeles & Nath, (2000)

3 'CRITICAL SUCCESS FACTORS'

3.1 *CSF as a Concept*

Rockart (1979a pp. 217) defines critical success factors as:

'The limited number of areas in which results, if they are satisfactory, will ensure successful competitive performance for the organisation.'

CSFs as a *concept* is about the few key areas where 'things must go right' for the business to be competitive. Therefore, the identified areas must be managed properly to avoid suboptimal outcomes and the application of the CSF concept should make explicit the areas crucial for organisational success. As success is an elusive concept, the definition of success used in this project was not simply defined in terms of 'bottom-line', return-on-investment, or similar. Nor was it defined purely from a single stakeholder's perspective. Rather it used a holistic perspective and inclusive approach that emphasised that success from one stakeholder's perspective might differ considerably from another's. This sug-

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gests that rigour can only be achieved by using a wider, inter-stakeholder perspective (Bullen and Rockart ,1986).

3.2 *CSF as a methodology*

CSF as a *methodology* originally involved interviews with mangers and senior executives to extract their views (Rockart, 1979b). This was criticised for being overly difficult in application, suffering from a lack of validity when considering the effect of analyst - manager biases and difficulty in identifying the true causality of factors. Moreover, perceived CSFs could differ between organisations, and between managers within individual organisations. Therefore the identification of CSFs for an organisation or industry masts be approached with objectivity when trying to establish "generic" or "collective" success factors (Bullen and Rockart, 1986). This requires a sound research philosophy and theoretical/analytical approach to be adopted when conceptualising, analysing and establishing CSFs. Research methodology should consider the problem in context and suggest a research process, based on logical reasoning.

This research adopts the CSF concept and has taken a collective, multi stakeholder view along the supply chain to establish the CSFs. The research method described below utilised the foregoing to establish the conceptual and operational approaches required to surface the CSF for this project.

4 RESEARCH METHOD

Although this research is set in an Australian construction industry context, the identification of the candidate success factors took a broad perspective. A comprehensive review of the literature, combined with the results from a Delphi study with the international participants (researchers and practitioners) enabled identification of a full range of candidates success criteria for ICT enabled supply chains (Stage 1 of the CRC CI research project). However, establishing the 'generic' Australian context of CSF for ICT mediated supply chains involved obtaining views from a significant number of experienced practitioners to ascertain what they considered to be critical factors for success. Analysis should minimise the degree to which researcher subjectivity affects the findings, therefore quantitative research was considered to be most appropriate. The survey methodology and the statistical techniques deemed to be appropriate are discussed in detail below.

4.1 *Step 1- Establishing the broader critical success factors*

Step 1 was concerned with developing the constructs for the questionnaire. This was greatly influenced by the findings of the Delphi and literature. Each construct in the survey was assigned a logical measurement scale. A '0 to 100' Likert scale was used to capture the rating. This was used as it was felt to be convenient for the respondents to relate to a general 1- 100 scale.

4.2 *Step 2- Method of surveying and sampling*

The questionnaire survey was designed to target experienced industry practitioners. The target groups were the major stakeholders commonly found in project supply chains, namely clients, consultants (architects, quantity surveyors, engineers), head contractors and subcontractors. Establishing the population for the survey was extremely difficult as databases comprising Australia-wide lists of construction organisations were not available. Moreover, the population contained both participants with ICT mediated supply chain experience (who were considered suitable respondents) and participants who had little or no experience with them. However, the questionnaire accommodated both sets of firms by using a self-assessed ICT continuum that organised the ICT technology in a hierarchical manner based on complexity and usage. Only questionnaires from the middle and high end of the continuum were used to identify the CSFs.

The survey options of email, postal and online were evaluated for this research. Email was eliminated due to the ethics consideration - maintaining anonymity while the online survey disregarded due to sampling, bias and data validity concerns. Therefore, postal survey was chosen as the most appropriate method for collecting data. Once the data had been collected, the following tests were identified as being the most appropriate to perform in order to identify the CSFs.

The study utilised a stratified, random sampling concept, which took into account the Australia-wide populations of the sub groups, namely architects, consultants, main contractors and sub contractors. Out of a total of 2000 questionnaires posted 309 responses were received. Out of the 309 responses, 213 were considered relevant to meet the selection criteria for inclusion in the study.

4.3 *Step 3- Data screening*

The data collected was then screened to address issues arising as a result of missing values. Generally, for continuous data, it is frequently found that the procedure used to replace missing values is to add in the mean score of that variable based on all the rest of the valid responses. The rationale for using this approach is that the mean is the best single replacement value, although this method does nevertheless suffer from some disadvantages (Hair *et al*., 1997).

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4.4 *Step 4- One sample t-test*

A one sample t-test was performed on all 21 variables, with a test value of 50 (of a 0-100 scale) being indicative of respondents ambivalence. Values of less than 50 were indicative of non criticality.

4.5 *Step 5- Screening instrument validity*

The next step was to perform a reliability analysis on the survey instrument, that is, to determine that property of the measuring instrument that causes it to give similar results for similar inputs. By way of explanation, coefficient 'alpha' is an estimate of reliability and is not a sufficient measure for unidimensionality or validity. That is, alpha is designed as a measure of internal consistency. Alpha measures range between 0 to 1 and where the result is closer to 1 so the greater the internal consistency.

4.6 *Step 6- Factor Analysis*

Step 6 determines whether a factor categorisation can be derived for CSFs from the survey. Factor analysis is a technique that is often used to create new variables that summarise all the information that might be available in the original variables. Factor analysis might also be used to examine the relationships between the measured variables in a data set. Factor analysis provides an indication of the degree of relationship and the patterns of linkages between variables. The principal component extraction, along with Varimax rotation were employed to assess the factor structure in this study. Factors with high loading should have excellent face (construct) validity. The assessment of factor analysis outputs requires considerable understanding of the data and it is rare for the arithmetic of factor alone to produce entirely clear results (Gorge *et al*. 1997). The analysis was performed on the statements with varimax rotation. The factor loadings that were less than 0.3 were suppressed and factors were identified based on loadings that were greater than 0.4 (Nunnally, 1978).

5 RESULTS AND ANALYSIS

5.1 *Descriptive analysis*

Table 2 gives the profile of the 231 respondents, excluding the missing data. The majority of the organisations have been in business for 10-25 years, while the sample contains organisations that have been in business for up to 90 years. Employee numbers in the sample organisations range from 4 to 2000 and average organisational turnover ranges from \$0.45m to \$1bn. Table 3 gives the respondent group characteristics. Around 20 % of the respondents have overseas operations while majority of the firms operate in one or two Australian states. The sample profile indicates a good representation of the population in question.

Table 2: Summary of the sample organisation characteristics.

Profile	Frequency	Percentiles			
		25	50	75	99
Years in business	229	10	16	25	89.8
No. of employees	231	4	7	22	2072
Average turnover (\$)	215	0.45m	1m	6m	1.0bn
Biggest project (\$)	198	1m	3.1m	22.5m	4.01bn

Table 3: Summary of the sample respondent profile.

	Frequency	%
Participants groups		
Client	17	7.4
Principal Contractor	19	8.3
Sub-contractor	88	38.3
Architect	58	25.2
Engineer	19	8.3
Quantity Surveyor	29	12.6
Total	230	100%
Number of States Active in Australia		
1	142	63.1
2	40	17.8
3 or more	49	19.1
Total	225	100%
Overseas Operations		
No	205	88.7
Yes	26	11.3
Total	231	100%

5.2 *One Sample T test*

The one sample t-test performed on the variables with a test value of 50, identified that four of the candidate success factors were not considered critical for ICT mediated supply chains in the Australian context (refer to Table 4 for results). The non-critical factors are:

Q22. Customer demand is the driver for the adoption of new technology.

Q26. An open minded attitude to sharing project information is required.

Q31. The introduction of government regulations to stipulate minimum technology requirements is desirable.

Q32 Stipulation of one industry wide technology standard is desirable

Qs 22, 26, 32 produced ambivalent responses and Q 31 indicated a non-critical response. Therefore

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these four variables were disregarded in the further analysis.

Table 4- One sample t-test results

One-Sample Test Test Value = 50			
	t	Significance (2-tailed)	Mean Difference
(Q19)	35.332	0	27.8
(Q20)	6.29	0	8.84
(Q21)	9.716	0	11.61
(Q22)	1.196	0.233	1.72
(Q23)	5.014	0	6.56
(Q24)	9.767	0	13.55
(Q25)	21.725	0	23.63
(Q26)	0.159	0.874	0.23
(Q27)	6.117	0	8.41
(Q28)	42.256	0	30.38
(Q29)	36.229	0	27.9
(Q30)	10.779	0	12.55
(Q31)	-3.086	0.002	-5.13
(Q32)	0.748	0.455	1.14
(Q33)	24.307	0	22.77
(Q34)	5.839	0	8.32
(Q35)	16.319	0	15.85
(Q36)	16.664	0	16.98
(Q37)	25.967	0	24.23
(Q38)	5.509	0	7.38
(Q39)	15.353	0	17.34

5.3 *Reliability of the scale*

The reliability of the original scale with 21 items was 0.7325, and its reliability was not improved by deleting any further items. However, due to the elimination of 4 items (non CSFs) from the original scale, reliability analysis was performed again on the 17 remaining items with the result that reliability marginally improved to 0.7374 and again would not improve by deleting any more items.

5.4 *Factor Analysis*

In this study factor analysis was first applied to determine the underlying structure of the factors, and to create a meaningful factor framework to provide structure for the 17 critical variables.

The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) was performed to check for the sampling validity, and Bartlett's Test of Sphericity was used for testing the presence of correlation. The KMO was 0.739 (>0.05 minimum acceptance value) and the Bartlett's test of sphericity for was found to be 633.174 with significance beyond the 0.000 level. These results satisfied the criteria for performing factor analysis on the identified statements.

The factor rotation solution identified 5 factors with eigenvalues of above 1, and the proportion of the variance explained 53.37. Table 5 summarises the results of the factor analysis. Refer to Table 7 for detailed candidate success factor statements.

Table 5: Factor analysis results

Rotated Component Matrix					
	Component				
	1	2	3	4	5
(Q28)	**0.732**				
(Q29)	**0.69**				
(Q33)	**0.635**				
(Q19)	**0.606**			-0.319	
(Q30)		**0.708**			
Q27)		**0.576**		0.318	
(Q24)		**0.573**		0.39	
(Q38)		**0.477**	0.332		
(Q36)			**0.708**		
(Q39)			**0.669**		
(Q37)			**0.611**		
(Q34)				**0.719**	
(Q23)				**0.649**	
(Q35)			0.318	**0.402**	
(Q21)					**0.805**
(Q20)		0.471			**0.537**
(Q25)	0.372	0.405			**-0.488**
Extraction Method: Principal Component Analysis.					
Rotation Method: Varimax with Kaiser Normalization.					

Following factors were named from the rotated matrix factor.

Table 6. Critical success factors framework

Factor 1	Organisational commitment
Factor 2	Organisational attitude to communication
Factor 3	Rights and duties
Factor 4	Investment drive
Factor 5	Guarantee/protection/ assurance

6 DISCUSSION

This study has identified the critical success factors for ICT mediated supply chains (table 6) and their sub-dimensions are described in the following sections:

6.1 *Organisational Commitment*

Commitment of the organisation is a crucial prerequisite for its successful uptake of ICT and its subsequent integration with the project supply chains that

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it does business with. In particular the commitment of senior management is important for successful management of both its relationships with trading partners and human resource development through training. Also the commitment of the organisation's employees is essential for the success of new technology initiatives. Finally, ICT driven project communications require a culture of transparency/trust during information transactions with trading partners.

Table 7. CSF statements for ICT mediated supply chains

Statements
19. Senior management commitment is necessary for strategic relationships.
20. ICT adoption across a project team is usually imposed by a powerful organisation within the team.
21. Supply chain adoption of ICT must be supported by a 'champion' within the project team
22. Customer demand is the driver for the adoption of new technology.
23. Competitors trigger an organisation's adoption of new technology.
24. The fragmented nature of construction projects hinders the effective operation of ICT.
25. The guarantee of information security is crucial
26. An open minded attitude to sharing project information is required.
27. ICT works best for firms that engage in long-term collaborative relationships (e.g. partnering)
28. The commitment of the organisation's employees is essential for the success of ICT.
29. Successful deployment of ICT requires continuous investment in human resource development and training.
30. Currently there is inadequate provision for usage of ICT in the standard conditions of contracts
31. The introduction of government regulations to stipulate minimum technology requirements is desirable.
32. Stipulation of one industry wide technology standard is desirable.
33. Transparency/trust in information transactions is essential for the optimal use of ICT.
34. Organisations commit to new technology investment as a project-based, tactical decision.
35. Organisations commit to investment in ICT as a long-term, strategic decision.
36. Organisations should acknowledge the sensitivity of other team member's information.
37. It is important to identify and respect the intellectual property of project information.
38. It is desirable to avoid multiple online systems led by different participants.
39. The powerful ICT promoter should support technologically weak or small organisations in the project team.

6.2 *Organisational attitude to communication*

It is recognised that the culture of the construction industry negatively impacts on organisations attitude to communicating with trading partners. The fragmented nature of some construction projects is recognised as inhibiting the free flow of information and therefore more collaborative procurement approaches, which foster the development of more open communication channels, need to be encouraged. Therefore, a move from the purely competitive towards the collaborative and long term (e.g. partnering) is desirable. However, this engagement must be supported with proper agreements, tailored to an ICT enabled environment. Moreover, communications need to be based on a single, compatible structure rather than on multiple online systems led by different participants which tend to work negatively in the project environment.

6.3 *Rights and duties of organisations*

Organisations in the supply chain should be aware of their rights and duties, both formal and informal. Organisation in the supply chain should acknowledge that not all information (especially the commercially sensitive information of a trading partner) will be available to project team participants. Clear identification of ownership of the intellectual property of project information is important. Furthermore, for sustainable relationships, champions of ICT adoption across the supply chain (e.g. main contractor) must be prepared to support the weaker and less technologically able organisations (e.g. subcontractor) in order to maximise their own benefit from the technology.

6.4 *Investment drive*

Before embarking on ICT investment any organisation should make a clear investment decision, understanding the real motives and consequences of its decision. It may result in a short-term, project based, tactical decision, such as to invest in a particular type of new technology, the use of which is anticipated to be limited to a single project, in order to win a large contract that calls for its use. The return on investment would need to be recovered at the end of the project in order for it to be considered successful. This contrasts with an organisation taking a strategic decision to integrate ICT into its business processes across the firm, and even into adjacent trading partners. In such, although benefits might be apparent over a short period, the true ROI (which could include non-cost benefits such as effectiveness and performance gains) would require a longer-term perspective, possibly extending over several projects and strategic engagement with multiple project team partners.

6.5 *Guarantee/Protection/Assurance related ICT usage*

When new technology and protocols are introduced into project supply chains, their deployment is best supported by a 'champion' from within that chain,

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whose position and contractual power is such that they can moderate its use. Of particular concern to the rest of the project team, the guarantee of information security is crucial for the success of ICT in a project supply chain situation – this is only likely to be successfully moderated by a powerful team participant. Implicit in the foregoing is the recognition that the most appropriate organisation in the supply chain must exert leadership in terms of ICT protocols for project communication/management.

6.6 *Best practice guides*

This CRC CI project generated four sets of Best Practice Guides, currently in press, which utilise the factors described in sections 6.1 – 6.5. These are targeted at the needs of clients, main contractors, consultants and subcontractors, and include an interactive CD tool used to self-assess the readiness of these organisations to engage in ICT mediated supply chains.

7 CONCLUSIONS

In order to remain competitive in the construction industry, supply chain participants should be ready to face the challenges, be willing to innovate and change. It is believed that this will prove to be the sustainable path for the future. This paper identified the issues that need to be addressed to allow an organisation to venture onto the path successfully, nothing that the critical success factors that underpin the integration ICT in supply chains are, Organisational commitment, Organisational attitude to communication, Rights and duties, Investment drive, Guarantee/protection/assurance. It is noted that the critical success factors framework surfaced by this study will prove all the more persuasive as and when its findings are validated by some method of triangulation

It is highly significant that both implicit and explicit in each of the CSFs identified is the issue of an organisation's relationships with its trading partners, an area that is both complex and multi-dimensional. Whist the survey has identified its importance, it is recognised that it is not the appropriate tool with which to explore such a complex issue, nor illuminate the sub-dimensions that contribute to this complexity.

It is thus held that a series of detailed case studies of ICT mediated project supply chains will allow both the validation of the CSF framework and facilitate exploration of the relationships, both strategic and non-strategic, which exist within them.

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The use of ICT in the construction industry: critical success factors and strategic relationships in temporary project organisations

G .J. Brewer, T. Gajendran & S. E. Chen
University of Newcastle, Callaghan, NSW, Australia

ABSTRACT: This paper describes the application of a previously developed model of critical success factors for ICT-mediated chains to three construction project supply chains. These cases drew on the experiences of key stakeholder organisations within each in order to firstly, identify the extent to which features of a previously developed, generalised model of ICT success factors were present in each case, and secondly to extend the model in respect of those aspects relating to pre-existing relationships, strategic relationship formation, and the expectation of a continuing business relationship into the future. The paper is structured to describe the protocols and analysis used, and to report a summary of the findings across the three cases.

1 PROBLEM CONTEXT

It is axiomatic to suggest that despite early optimism about the use of ICT to improve the productivity and profitability of the construction industry, anything other than localised benefit has yet to accrue. Many industry practitioners and observers have suggested reasons for this, and research has been accordingly conducted. This has been predominantly in the area of technology and technological standards, with somewhat less being conducted in the sociological aspects of the problem. This paper reports on the third and final part of a major research project commissioned and funded by the Co-operative Research Centre for Construction Innovation (CRC CI) in Australia that addresses the problem of ICT adoption and integration at the socio-technological interface. It draws upon the model of critical success factors for organisations in ICT mediated supply chains, that was developed through an international online Delphi study of ICT 'experts', and a nationwide survey of Australian industry participants. In particular it focuses upon the way in which the presence of ICT as a tool for project communication/collaboration affects the structure and operation of a temporary project organisation.

The aim of the research project was to identify those aspects of ICT uptake and integration considered critical to supply chain success in the Australian building industry and to produce a guide for the different participants in the Australian industry. The case studies served three purposes, namely, to verify the success factors uncovered by the nationwide survey, to observe their effects upon real supply chains associated with project-specific temporary project organisations, and to augment understanding of strategic relationship formation and maintenance.

It was expected that the findings would indicate that in practice there are certain factors that are more important in achieving success and/or reducing the likelihood of failure in the operation of an ICT mediated supply chain, and these were subsequently identified. Armed with this information, it was possible to generate a short series of Best Practice Guides (currently under production by the CRC CI) that would guide industry participants who wished to maximise the benefit from involvement with such supply chains whilst concurrently minimising the risks.

The Guides are based on the patterns of common experience identified by the project and form a stratified list of critical success factors (Table 1) that vary according to the participant type: these were validated by application to three project case studies, described in this paper.

Table 1. Critical Success Factors/participant type matrix

Critical Success Factors (CSFs)		Participant type
1. Organisational commitment	Hierarchy and sub-dimension mix determined by participant type	Client
2. Organisational attitude		Head contractor
3. Industry regulation		
4. Investment drive		Consultant
5. Rights and duties		
6. Guarantee/ protection/ assurance		Subcontractor

N.B. Each factor is comprised of sub-dimensions, the mix of which is specific to each participant type: these are not detailed in this paper.

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2 CASE STUDY PROTOCOL AND ANALYSIS

A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident. Therefore it is neither a data collection tactic, nor merely a design feature alone, rather a comprehensive research strategy (Yin, 1994) that yields deep but narrow findings (Fellows and Lui, 1997).The case study allows an investigation to retain the meaningful and real life characteristics of real-life events, such as business life cycles, organisational and managerial processes, but they provide limited basis for scientific generalisation. Given the confirmatory nature of the case study within this research project it was felt that the previous stages compensated for any perceived limitations of the study findings. Further, given the triangulated research paradigm adopted for the larger part of this study, its findings were not based on the case studies in isolation. A multiple case study design was adopted; however each case was approached from a single case perspective since, within the construction industry few projects, if any, are identical in the way they are procured and completed. Consequently, post-hoc analysis was employed to compare and contrast the individual case study findings to determine if there were similarities between the projects, and between the cases and the CSF model.

The case studies were carried out during the second and third quarters of 2004 using a combination of face-to-face and telephone interviews. Key ICT decision makers in each of the main stakeholder organisations were interviewed in order to reveal the factors that affected their use of ICT, and also to discover the extent to which their previous and current use of ICT influenced both their selection for inclusion in the project team, and the business processes that they employed with their trading partners.

The cases varied considerably in their value, contractual complexity, technical challenges and geographical location. All the stakeholders interviewed were asked to map the project supply chain as viewed from their perspective, indicating the nature of the links with all of their trading partners.

Given that the qualitative themes were already dictated by the CSF themes, the data coding that was undertaken by members of the research team was purely axial in nature, identifying those passages that related to each CSF and then using them to develop it. Only in the case of relationship formation and maintenance were themes identified by open coding, then further developed by axial coding.

The supply chain maps performed three functions: firstly to establish the formal links between the various project supply chain participants; secondly to ascertain the individual participants' attitudes to informal/non-contractual links with the rest of the project supply chain; and thirdly to further illuminate the interview data, especially when dealing with matters concerning communications and business relationships.

Broadly, consolidation of all case study findings was achieved at research team meetings where anomalies between individual coding exercises was resolved by discussion and further analysis.

3 CASE STUDY FINDINGS

The following sections detail each of the three cases covered by the project. They open with a brief description of the project and its background, the relationships between the participants (both pre-existing and created as a result of the project), and contractual arrangements. They continue with an exploration of the motivations of the various participants to engage with the project supply chain, seeking to find reasons (beyond those directly associated with a desire to win work) for the project supply chain's composition. The third section tries to identify the barriers to ICT adoption as perceived from within the project supply chain, whilst the last section again asks the participants to look to the future and describe the influence that their experiences (both prior, and on the current project) might have on their future business decisions.

3.1 *Case study 1*

3.1.1 *Project background, relationships and contractual arrangements*

This case study describes an iconic city centre development in a state capital, and initiated by a city council decision to leave their current premises. The winning proposal in a design competition, initiated by a developer who then on-sold development rights to a second developer, is now being driven to fruition by them. They also will become co-tenants of the completed building, together with the city council. Along the way, various members of the design and construction teams have been engaged, replaced, or have withdrawn. Further, some of the consultants who had been appointed by the client were novated to the head contractor. The project manager was also novated, but in a different manner to other consultants and was placed in a supervisory role to liaise with the developer, contractor and clients. Concurrently, the procurement mechanism was changed from a fixed maximum price contract to a design and construct contract.

The base building architect was appointed as the outcome of a design competition, but each of the tenants has appointed their own architect for the internal fit-out of their areas of the building. A similar approach has pervaded the issue of specialist sub-

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contractors associated with each tenant. However, the head contractor has been engaged to do the fit out as part of the construction management agreement.

Part of the project involves the creation of a large civic square for which the government organisation is contributing capital. It therefore holds the dual role of tenant and financial stakeholder in the final outcome of the building.

The contractual relationships on this project were complex and prone to change. Only one pre-existing strategic relationship was identified, that being between the city council and an in-house design group that has resulted in a contract for the public access areas of the development (library and customer service building). That said, several members of the design team mentioned working in informal alliances with each other in order to maximise their likelihood of being selected for inclusion in the project.

It was often mentioned that with non-contractual relationships, some communication had to be conducted with be caution so that contractual channels were not contradicted, but nevertheless, informally there was communication.

3.1.2 *Motivation to engage with this supply chain*

Most parties involved in the project had worked with some of the other parties on previous projects. However there were few references to pre-existing strategic relationships. In some cases participants did not believe that they would have the authority to decide which other parties would be selected for future projects, but that their opinion, when given informally, was important.

This attitude that was consistent among participants - that maintaining positive relationships with the project participants was good business sense especially for the specialist sub-contractors. In this project, the formation of alliances have not been an intentional strategic move, rather they appear to be the product of positive experiences.

Overall the influence of ICT on the formation of this project teams was not considered to be high, but it was a consideration. Issues of pricing, design and expertise were considered more important, however some basic ICT capabilities were considered relevant. Several organisations stated that they had taken steps to equip themselves with ICT infrastructure that was used by other project partners such as CAD. However, for all contractual purposes, hardcopies for documents were still required and email communications not recognised by any party as a contractually-valid form of information exchange and communication. The head contractor however was insistent that their organisation had taken steps to reduce paper usage and that email was an accepted form of internal communication. Further, in an effort to reduce the paper trail a project platform was established where participants had varying degrees of access to project information. Costing and accounting had also moved to electronic format within the developer's organisation. These changes appeared to have some reduction on the use of paper in the project.

3.1.3 *Barriers to ICT adoption in the supply chain*

Major issues identified in this case study were the legal ramifications of electronic communications, misunderstanding of security capabilities, ownership of intellectual property, and the capture/management of the knowledge generated during the project; issues of trust and the organisation.

Many participants stated that they did not think (but were not certain) that electronic communications were considered a valid form of formal communications, especially with document exchanges. Copyright issues for design plans were also mentioned as an inhibitor of electronic communications. PDF format documents were exchanged so changes could not be made without contacting the relevant party. This issue of protection of intellectual property and of risk was fundamental to the uptake of electronic communications. Parties were conscious that electronic communications opened the way for changes to be made to plans without their approval or sign off. Thus the issues of trust and control were major factors in the support for retaining paper communications. Knowledge management issues were also raised. With the continuous flow of documentation participants reported that it was difficult to keep up to date with project details, especially if they were working on more than one project concurrently. Storage of electronic files was therefore a priority and a coding system for documents was seen as a necessity if communicating electronically.

Another barrier to ICT uptake was that some participants did not think that electronic communications were not treated with the same urgency - that email communication was equivalent to the *"note under the door"* approach. Interestingly, one participant strongly held the view that email communication could be used subversively in such a way as to deliberately slow down supply chain activity by introducing spurious noise and unnecessary communication traffic, when it suited some parties.

The technological capacity of organisations was another consideration. Although parties were engaged in electronic communications, their bandwidth and server size were not always capable of handling the degree of usage that their employees were capable of achieving. When dealing with other organisations within the project supply chain the problem was accentuated. Across the supply chain the size of drawing/plans files is a considerable issue when aligning technology practices.

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3.1.4 *The future*

All participants saw ICT as the way of the future, seeing a completely ICT mediated supply chain as an ultimately realistic and advantageous state for construction projects to reach, especially in the exchange of documentation. The exact nature of the role of ICT was unclear, but those that had been in the industry for over ten years noted the rapid change in the way projects were completed and the speed and efficiency that ICT facilitated. They could only see this situation improving. Investment in ICT was considered highly worthwhile, especially software that could model whole of life attributes. Investment was seen not only as a wise decision, but a necessity to maintain a position in the market.

Most participants had been associated with web-based projects and saw them as an entirely feasible method of communications. Alignment of technologies was considered much more relevant in these situations, but from experience it was not found to be a principal requirement in the tendering process.

3.2 *Case study 2*

3.2.1 *Project background, relationships and contractual arrangements*

Two years ago, the client, an educational institution in regional Australia, initiated a design competition to secure new teaching accommodation. The winning architect (based in the State capital city) proposed the addition of an extra floor constructed on top of a multi-storey car park that had been completed less than two years earlier. The client appointed the regional office of a major quantity surveyor, who had previously assisted in the cost planning and bid evaluation processes to act as Superintendent. The head contractor, also locally based, had also been involved in a similar capacity during construction of the base building. The rest of the design consultants were also based in the state capital. With the exceptions of fire systems and security systems, all of the sub-contractors were domestic, contracted to the head contractor. The nominated sub-contractors had a pre-existing relationship with the client, being responsible for campus-wide provision of services.

3.2.2 *Motivation to engage with this supply chain*

The client had previous experience of working with the quantity surveyor on a number of projects and expressed high regard and confidence in their abilities to forecast costs accurately. They were initially employed to perform feasibility and project cost planning, and evaluate competition entries from a cost perspective, later extending to include their appointment as the superintendent. The head contractor had also previously worked on several projects with the client, the most recent of which had been the construction of the base building. The client described the contractor as *"good to work with......and adopted a cooperative approach"*, a fact that was taken into consideration during Tender Evaluation. Fee-bidding was not used during the appointment of the rest of the consultants, however a range of indicators such as design team quality, track record/references as well as fees was used. None of the base building's design team was involved in the design of the new extension, a fact that led to *"some niggles"* with the structural engineer on the job. In terms of Nominated Suppliers/Subcontractors, the head contractor had a pre-existing relationship with the fire systems specialist and expressed confidence in their abilities. However they had never worked with the security systems specialist before. Both were appointed by the client to ensure that any systems installed would be compatible with those existing campus-wide.

The issue of ICT compatibility was not a consideration in the selection or appointment of any project participant. However, the architect unilaterally distributed all project drawings via a project-specific extranet, located on their company web server. This ensured that all of the drawings thus accessed were the latest revisions and should have ensured that all project participants were working from the most current information. For their part, all of the consultants appeared to be happy to use the extranet, not only for accessing the architectural drawings but also third party data (such as the client's briefing document and room data sheets) and for the upload and exchange of their own data, a facility that the architect was willing to provide.

3.2.3 *Barriers to ICT adoption in the supply chain*

There were a number of contrasting attitudes and experiences in this regard. Some organisations (mostly concentrated in the design team) were very comfortable with the use of ICT both within their organisations and as the preferred medium for data and information exchange. Others (mostly concentrated in the construction team) were far less capable (though not necessarily unwilling) of interacting in a similar vein.

Amongst those interviewed the use of email for project team communications ranged from 10% up to 70% by volume– the rest would be conducted by phone, fax or hard copy.

The issue of the legality of an email remained a grey area for some. Yet for others, notably the client, this was not an issue, possibly reflecting the embedded culture of the organisation. In this case, email had been used not only for informal, internal communication related to the development of the brief, but as the contractual document to appoint all of the design team, in accordance with the client organisation's purchasing policy. They also regarded PDF drawing files in a similar vein, though the client's

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representative expressed the desire to obtain signed hardcopies of all "milestone" documents e.g. those that concluded internal consultation processes or represented "as tendered" or "as built" structures.

All of the case study participants expressed the view that email distribution of workshop drawings and revisions sped up the approval process, but several of the construction team still required printouts.

Because of the size of the project there was no permanent on-site presence from the head contractor and their site office did not have a computer or email/internet access.

3.2.4 *The future*

ICT was not viewed by any participant as a major competitive advantage. Alignment of supply chain practices was welcomed but not regarded as a pre-qualification requirement. The exception to this position was found in the architect who *did* regard ICT-enabled presentations as a *marketing* advantage in design competitions – a view borne out by the client. However most of the interviewees did regard ICT as an increasingly useful tool to facilitate accelerated supply chain responses, for instance, to speed up drawing exchange. It was noted that subcontractors were beginning to match the top supply chain tiers in their ICT capability.

A move towards a paperless office was a common theme, in one way or another, amongst all of the participants in the study. Passing printing costs onto others seemed to be the prime motivation for this. The client questioned whether cost savings actually worked their way down from the architect (who was generally regarded as being the major beneficiary) to the client. To a greater or lesser extent all of the stakeholders used email to replace faxes. But equally, all email recipients tended, to some degree, to want to have hard copies of them.

The head contractor reported that PDF files of workshop assembly drawings were formatted to print out on A4 paper – bigger drawings would be reformatted as TIFF files and plotted out at head office. For subcontractors this continues to be a limiting factor, requiring a third party to print out the files. Several interviews revealed the irritation of users at having to zoom in and out of drawings being viewed on screen, commenting that, in a number of cases, on-site problems were only resolved after a round table discussion over large-scale paper prints of relevant drawings.

However, electronically updated latest versions of the design drawings would be used at the end of the project as indicative of the "as built" state of the building, for inclusion into the building manual.

In regard to remote activity (project interaction at a distance) conflicting views and experiences were expressed, often from the same participants. On the positive side, the exchange of e-photos of site work to augment teleconferences, laptops for site supervisors, bar coding for materials and electronic drawing exchange were all mentioned. On the negative side the difference between sending an email and resolving an issue was described thus; *"I can't help feeling that it can be a bit like slipping a note under someone's office door... I've delivered the message so now it's his problem!"*

3.3 *Case study 3*

3.3.1 *Project background, relationships and contractual arrangements*

This case study describes a part of the project supply chain that formed around the construction of a landmark art gallery in a major overseas city. centred on the activities of an export award-winning Australian facade engineering company that utilised a highly geographically dispersed supply chain, which would not have been feasible without the use of ICT.

After a design competition the winning architect prepared sketch plans that were approved by the client (city council). The documentation was prepared and cost planning undertaken. The key feature of the project was the technically challenging front facade, known as the 'Sculpture Wall'. An overseas facade engineer was appointed as consultant to the client and highly detailed documentation developed in order to brief specialist subcontractors. The consultant engineer referred the client to a number of projects in Sydney and arranged an introduction to the firm responsible for their design and construction, who then assisted in the development of the Sculpture Wall. After a round of advisory discussions fully detailed documentation was prepared by the architects, specified by the consultant engineer, and put out to tender ahead of the main contract for the building. The successful head contractor was apprised of the client's preferred subcontractor and proved happy to employ them as a domestic subcontractor.

3.3.2 *Motivation to engage with this supply chain*

Clearly the facade supply chain has accreted around the specialist subcontractor, who had pre-existing business links with most of their supply chain partners. These were variously described as "of mutual benefit", "strategic and valued", and "important to our company". Alignment of business interests was the predominant sentiment, with alignment of business processes, including the use of ICT, being of secondary importance. There was vigorous competition for the award of contracts to supply the various components with all supply contracts put up for tender, albeit from within a limited pool of suppliers whose quality and reliability were already established.

The focal company expressed the view that ICT was a pretty-much indispensable tool for modern

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businesses on an international stage, noting that the early design processes were exclusively electronically mediated, by email attachment or by CD. Ironically, the only part of the project that was detailed by hand was the Sculpture Wall, where an early CAD wire frame diagram was subsequently developed manually. The geometric complexity and a lack of suitable CAD operators were cited to explain this anomaly. Interestingly, this allowed the designers of both the wall and the building to check the geometry and interface between them by overlaying them by hand, by mathematical calculation and by reference to the CAD wire frame. However, this has left the architect with the headache of scanning a mass of B1 sized drawings for digital inclusion in the building manual.

Outside of the Facade subcontractor's supply chain the motivations to engage became far more conventional, and although the use of ICT was a conspicuous feature of the project communications, the notion of making it a prerequisite for involvement with projects was not considered viable by anyone interviewed.

3.3.3 *Barriers to ICT adoption in the supply chain*

Very few barriers to ICT adoption were evident within this supply chain. All of the consultants used in the facade subcontract and on the main contract had broadly compatible ICT capabilities. There was little apparent tension in regard to the sharing of commercially sensitive information within the facade subcontract, although there was initial reticence from the head contractor when faced with such an open communication structure. This was initially overcome by client/architect persuasion and presumably subsequently, by favourable experience.

Interestingly, during the early stages of the project it was felt that email was the predominant form of communication (together with email attachments). However once the Facade engineer had established an on-site presence this was supplanted by telephone and face-to-face meetings. This transition broadly coincided with an increase in the size and complexity of the drawings associated with the Sculpture Wall, leading to a move away from email attachments for drawing distribution to be replaced firstly by CDs and later on, paper copies.

3.3.4 *The future*

The lack of a project web site for the sharing of documents/concurrent working on a common 3D building model was noted and flagged for future rectification on other projects, as was the use of manual drafting for parts of the sculptural wall. This was attributed to a lack of availability of skilled personnel in the country, the result of a number of downturns in the industry over the last three decades, leading to a brain-drain.

Possibly the most interesting innovation on the project was the use of rudimentary virtual prototyping prior to the construction of a full-size mock up of the cladding. Both the architect and the facade sub contractor undertook aspects of testing prior to finalising the unitary design. This included dimensional control, earthquake and wind load simulations, aspects that were later confirmed during tests conducted on the mock up. Many design defects were picked up during testing – a goal of zero defects was thought to be realistic.

4 DISCUSSION, VALIDATION AND CONCLUSIONS

The specific motives for conducting the case studies were twofold:

- To validate the survey findings represented by the CSFs (see table 1) within project supply chain settings.
- To investigate the role of ICT in the formation and maintenance of strategic business relationships.

Generally the case studies revealed patchy ICT integration into supply chain activities, where small groups of participants worked well together, but often encountered problems when dealing with others at a larger, pan-project level. Furthermore the extent to which many of the participants interviewed understood their own organisations position relative to the rest of the project team was sometimes unclear, hinting at structural ambiguity within the project. It was possible to find examples of best practice, as defined by the CSF model, to identify a group of project stakeholders that displayed interlinked, ICT-mediated strategic business relationships.

4.1 *Validation of CSFs*

Content and thematic analysis of the full transcripts of all the case study interviews was conducted, allowing the frequency and context of excerpts to be established. Examples were found across all three supply chains of the factors previously identified in the national survey. Although it would not be valid to generalise the specifics of these examples up to an industry level it is instructive to note that the most frequent references were to these topics:

- Limited or scarce resources (including time) for ICT investment
- Alignment difficulties when working with trading partners
- Lack of leadership in determining/championing common project communications protocols and mechanisms, which themselves were unavailable.
- The impracticality of a fully paperless project, especially in terms of drawings

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- The potential for ICT to improve the flow of information during the design and construction phases
- The potential for ICT to improve the efficiency and accuracy of data captured for post-completion purposes

4.2 *Correlation with CSF framework*

The salient issues identified with each CSF are presented below in point form.

4.2.1 *Organisational commitment*

- Widespread commitment to the use of ICT.
- Similar level of satisfaction reported with ICT investments.
- Respondents broadly split into two groups when considering the degree to which ICT was essential to their organisations business activities, with the majority having a strategic vision of where they saw their firms ICT enabled future. A minority regarded ICT as useful but not vital to the effective operation of either their firm or the project.
- Two organisations reported providing pan-project ICT enabled communication for all participants at no cost, viewing this as making good business sense.
- Almost total acceptance of e-enabled project communication, reflecting their acceptance that this was the way of the future.
- Widest variation in attitude to ICT enabled communication found among clients, or more correctly, their representatives. In some cases this reflected the culture of the client organisation, whilst in others it appeared to be at variance with them.
- Commitment to ICT was stronger in design team members than in the construction team.
- Strong commitment to CAD amongst consultants, with architects having a strong expectation of a move towards 3D CAD in the short to medium-term.

4.2.2 *Organisational attitudes*

- Wide variation in attitudes was found across the cases. The attitudes of individual firms within a particular project seemed to reflect the overall culture of the project.
- One project was widely reported as having "something special about it". Although no special efforts had been made, or protocols put in place to reduce conflict or facilitate the use of ICT, members of both the design and construction teams reported openness and trust in communication and sharing of intellectual property. Potential risks and actual disadvantage arising from the use of ICT was shared without recourse to formal dispute resolution processes, seemingly to preserve good working relationships.
- Sensitivity regarding access to, and the sharing of intellectual property stemmed from a number of factors, including potential disadvantage in the future, IP leakage, and potential legal liability in the event that IP was misused by an unauthorised third party. Restricted access to project web sites and extranets, issue of contract documents in PDF format, and a insistence on hardcopy confirmation were all approaches taken to limit the effect of this problem.
- Informal collaboration between various parties at a very early stage in a project, often prior to project team creation, was evident in two of the three projects. ICT compatibility was a secondary issue in this process.
- Established strategic relationships were apparent in one project. ICT compatibility, though not the cause, was a highly significant factor in their existence.

4.2.3 *Industry regulation*

- Almost every respondent reported the compatibility of technologies and data exchange standards as a serious concern.
- Some respondents reported aligning their ICT with that of their trading partners in an attempt to appear a more attractive proposition by reducing interoperability conflicts for prospective customers.
- Many respondents tempered their enthusiasm for universal standards with the observation that they would not be accepted unless they catered for the needs of all users.
- Issues associated with document identification, and conflicting document numbering systems across a project team raised important concerns for those charged with overseeing quality assurance.
- Version control, whilst aided by the use of ICT, was reported as being problematic at the interface between users and non-users of ICT, commonly at the contractor/subcontractor level. There is no guarantee that the existence of the latest version of drawing on an extranet will mean that it is being used by small subcontractors on-site. Equally it was noted that there was a big difference between posting current information electronically and ensuring that it was read, a matter that could have contractual significance.

4.2.4 *Investment drive*

- All participants recognised the veracity of their organisations ICT investments as essential to the conduct of their business.
- General agreement that for all firms, generating a return on their ICT investment, and determining the payback period were the overriding concerns.

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– Agreement that ICT facilitated business improvement, not revolutionary advance.
– General agreement that the threat of work drying up if firms fail to engage enthusiastically with ICT is a myth.
– Architects alone felt that certain types of ICT were, if not essential, then the highly desirable in order to win work. Specifically the 3D modeling capability of certain CAD systems was believed to be essential in order to win high-end design competitions.
– None of the other respondents reported losing work as a result of the level of their ICT capability.

4.2.5 *Rights and duties*
– Obviously driven by contractual considerations.
– Less obviously driven, but nevertheless influenced by project team culture.
– Clients/client representatives have a strong role to play in determining the effectiveness of ICT use across the project supply chain.
– General recognition that the legal community has been very slow to react to the advent of ICT in construction projects, and that current contractual tools are inadequate for the current environment.
– It was observed that Australia was amongst the most litigious operating environments in the world.
– It was also observed that trust and good faith could, and had overcome project specific problems triggered by ICT, to the detriment of no party.

4.2.6 *Guarantee/protection/assurance*
– Security of communication channels is a major issue, restricting the extent to which many firms are prepared to engage with an ICT mediated supply chain.
– One respondent was concerned that e-mail traffic could be accessed and records manipulated to obtain contract all advantage by sewing seeds of misinformation.

4.3 *Role of ICT in the Formation and Maintenance of Strategic Business Relationships*

Several participants reported strategic relationships with others both within the cases under investigation and in other supply chains. Some were clearly formal whilst others tended toward the expedient and short-lived. This indicated that the term ‘strategic relationship’ held different meaning for different people. On one project it meant close, informal cooperation between consultants prior to their appointment to the project team, unpaid work that was intended to increase the likelihood of their appointment. Their ICT was known to align and its use would have been intense. Winning the work would have had strategic implications for both firms. However it was unclear whether their relationship was really strategic in intent, holding long-term implications.

Formally acknowledged strategic business relationships existed in two of the three of the three cases described above and that a potential for informal strategic relationships to form existed in the third. The presence of ICT to facilitate project communications was noted in all three instances but was not recorded as being instrumental in the formation of any of them. To be precise, none of the business relationships identified had come into existence because of either party’s ICT capability. In one case, a number of suppliers had formed enduring business relationships with a specialist contractor on the basis that they had proven to be consistently reliable in terms of cost, quality and time certainty. Their ability to add value to the contractor’s business was the trigger to relationship formation, but their ability and willingness to align their business processes with those of the contractor enabled relationship maintenance, an attribute made all the more urgent given the geographical dispersal of the suppliers and projects on which they would subsequently work. Central to these business processes was the use of ICT mediated design, communication and quality assurance tools that meshed with those of the contractor. Strategic relationships, in the truest sense, require a two-way commitment indicative of the expectation of mutual benefit. In each of the relationships explicitly described within the case study project supply chain, and others alluded to in the interview (in other project supply chains), the contractor had invested energy in the supply chain alignment process by embedding staff in the partner firms to thus assist in their compliance with the contractor’s quality assurance procedures. This had been matched by the partner firms’ energy in the form of time and resources. Thus the various ICT tools were the means by which business would subsequently be facilitated.

From this study it may be posited that true strategic relationships must deliver two-way streams of value, commitment and benefit, along an aligned supply chain, and that whilst the mere presence of ICT is unlikely to trigger relationship formation, it is becoming increasingly likely to facilitate relationship maintenance over time, for as long as those streams continue. Further, parallel energy investments in ICT by supply chain participants, whether strategic in intent or not, are increasingly likely to result in strategic outcomes.

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Economic Expediency of Building Waste Recycling

T.D. Dakovsky & R.A. Zaharieva
University of Architecture, Civil Engineering and Geodesy, Sofia, Bulgaria

ABSTRACT: The economic aspect of recycled building waste use is observed. Technical and economic conditions providing the economic profitability of the recycling facilities, as an investment project realisation, are formulated. The condition, which provides the market competitiveness of the recycled aggregates against the natural ones, is drawn up. The production costs of aggregates recycled from building waste as well as of natural aggregates are grouped. They reflect also the costs of building waste transport to landfills and the disposal fees. Relations between prices of recycled aggregates and of natural ones in some European Union countries are indicated. Accent is put on some of the reasons, causing skepticism in the potential users about recycled building waste and recommendations are given for their better market presentation.

1 INTRODUCTION

The existence of large quantities of building waste in the industrialised countries is a fact which is dictated by a number of circumstances – dynamic new construction or restructuring of urban areas, whereby old buildings are being demolished; building of new infrastructure facilities, whereby old ones are being demolished too; availability of produced and not implemented quantities of various reinforced concrete elements, like sleepers, panels, etc.

Another source of building waste are buildings and structures demolished by earthquakes and other natural disasters as well as during war operations. In parallel to this, the demand of construction materials and particularly, aggregates for concrete mixes and various mortars is constantly growing. Very often, the natural aggregates used in the construction process are extracted at growing costs and transported to a great distance, which complicates the new construction and raises the unit price of construction works.

The availability of large quantities of building waste has a negative effect on the environment, since they lead to dust pollution, troubles in sewer systems when raining, and risk of contamination of people being around. Besides, they occupy a lot of space and impede the rational use of the respective sites.

The proximity of building waste to real estates lowers their market price and worsens the quality of life in the respective habitat. In the course of time, the existence of building waste from the civil, industrial and infrastructural construction turns out into a serious technological, economic, social and ecological problem.

Technologically, the problem of building waste recycling is already solved. In EU countries, U.S.A., Japan, Canada and Australia the recycling of building waste obtained from demolished buildings and old road pavements is a profitable business.

The heavy machine-building industry in these countries produces stationary and mobile equipment for recycling and it is easily marketable. This offers two possibilities – to erect plants for building waste treatment or to drive the mobile equipment to the places of heavy concentration of such waste.

The first option needs a higher initial investment, while the second one benefits from the more efficient use of the equipment and lower transportation costs. The stationary facility provides a higher productivity and respectively, a lower unit cost per ton of recycled aggregates. However, the decision for its location depends not only on building waste transport analysis but also on a number of other limitations of administrative, planning or ecological nature.

Within the economic environment in the Balkans it is difficult to prove the economic efficiency of a stationary option from purely financial point of view (Radeva at all, 2003). This is due to both the relatively small concentration of building waste and financial sources availability for such an investment project. At the same time, the building waste quality is hard to be predicted and consequently, the quality of the obtained recycled aggregates.

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It is difficult to predict also the market response of the potential users because there are no traditions in this business and only more attractive prices would have made it more attractive. There are still no problems so far with the natural aggregates supply and their prices are lower than the average ones in Europe. Nevertheless, the building waste recycling is an up-to-date problem, its importance will grow in the course of time, and the conditions here will become closer to the ones in the industrialized countries. All this requires proofs for the expediency of the recycled building waste use under the local economic conditions

2 ECONOMIC PROFITABILITY OF THE RECYCLING FACILITIES

First of all, the conditions providing the economic profitability of the recycling facilities should be formulated. They depend, to a great extent, on the local conditions but could be limited to:

– availability of a vast amount of building waste with a tendency of increasing;
– building waste sources of the same kind (demolished reinforced concrete buildings, damaged road pavements, damaged panels, etc.);
– possibility of separation of the building waste components – concrete, steel, glass, etc.
– convenient access of heavy vehicles for loading and transport;
– availability of a collection site for building waste – preferably in the immediate vicinity of an existing landfill for industrial and/or municipal waste;
– existing high fees for the disposal of the existing building waste;
– shortage of high-quality natural aggregates for the needs of the building production;
– relatively high prices of natural aggregates at the market – sand, gravel and crushed stone (rubble);
– the users at the aggregates' market should have the adjustment to implement recycled aggregates.

Taking into account the above factors, it is not surprising that the biggest stationary facilities for building waste recycling are located in heavily populated areas in the industrialized countries where a large-scale construction is realized, usually on the place of old buildings being demolished. A typical example of this is Berlin, which has been transformed into an enormous construction site where high-productivity recycling facilities are disposed. The industrial recycling of building waste is also well developed in the Netherlands, Belgium, Japan and around the big urban agglomerations in the U.S.A. – New York, Chicago and other cities. A specific peculiarity exist in the U.S.A. – due to the large number of buildings with steel structures, including the ones erected in the 1920s and 1930s, their recycling is performed after the disassembly of the structure in steel plants.

From macroeconomic point of view it is very difficult to determine the quantity of the building waste per capita in the respective country. In U.S.A., per example, this amount is estimated to be 270 kg per capita. A number of economic and natural factors may influence this value. It is closely connected with the investment activity, its growing and the subsequent building in areas where buildings-subject-to-demolition exist. The types of structures of the demolished buildings also have an effect on the building waste volume. If the source of waste is road pavements, their type is of importance for the waste composition. Sometimes, the source of building waste is an earthquake that has caused demolitions.

All this outlines the scope of the problem of the economic efficiency of the recycled building waste use. One more technological condition has to be taken into account here – the physical and mechanical properties of building waste (estimated in lab tests) should conform to the norms being in force. Particular attention should be paid to the separation of the building waste components and possible unwanted chemical reactions stemming from this process.

If the physical and mechanical properties of natural aggregates and recycled aggregates become close to each other, it is necessary to investigate the competitiveness of recycled aggregates. This is of great importance before initiating investments in stationary or mobile facilities for recycling, which should be preceded by a number of technological, economic and market studies. Besides, the market adjustment of the future users of such recycled construction materials should be carefully studied and even stimulated. This can be realized in an appropriate way – through an advertisement campaign, demonstration of individual construction products or buildings, in the erection of which recycled aggregates have been used. Assistance in research works in this field is also a useful form of stimulation. This is important, since the physical amortization of buildings and structures could be forecasted, which could lead to an estimation of the building waste volume that is subjected to recycling.

The condition, which provides the market competitiveness of recycled aggregates against natural aggregates, is that the sum of all costs for recycled aggregates production should not exceed the cost of natural aggregates extraction. This condition is given in (1).

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$$\sum_{i=1}^{7} S_i \leq \sum_{i=1}^{4} N_i \qquad (1)$$

where: S_i – costs for recycled aggregates and Ni - costs for natural aggregates.

In Table 1 and Table 2 are shown the individual costs for recycled aggregates and costs for natural aggregates respectively.

Table 1. Individual costs for recycled aggregates production

	Recycled aggregates production
S_1	Additional activities for treatment of waste from demolition
S_2	Waste disposal (with reverse sign)
S_3	Transport to a landfill for building waste (with reverse sign)
S_4	Transport of waste to a recycling site
S_5	Processing
S_6	Transport of aggregates to a construction site
S_7	Additional costs for control, storage and sale

Table 2. Individual costs for natural aggregates extraction

	Recycled aggregates production
N_1	Extraction of aggregates from a quarry
N_2	Processing
N_3	Internal transport
N_4	Transport of aggregates to a construction site

3 DETERMINING OF COSTS FOR RECYCLED AGGREGATES PRODUCTION AND NATURAL AGGREGATES EXTRACTION

Four groups of costs can be distinguished in the process of extraction of natural aggregates – for their extraction from a quarry, for processing, for the internal transport and for the transport of aggregates to a construction site. These groups of costs are comparatively easy determinable because the extraction of aggregates and their processing are made in a mechanized way.

The machines used for this purpose have a fixed delivery price, which is supplemented with all costs related to putting them into operation, the current operational costs and the profit. Then, the unit price can be fixed on this basis, taking into account the productivity of the extracting facility. If natural aggregates need processing, similar steps are undertaken. The processing is performed by appropriate machinery.

The internal transport within the site for natural aggregates extracting raises additionally their production price. In order to correctly compare the natural aggregates costs with the recycled aggregates ones it is necessary to add the transport costs of natural aggregates to the respective construction site. It is necessary to note, that the quarries for natural aggregates become increasingly far off the construction sites and this are one more argument in favor of recycled aggregates.

The group of costs fixing the unit price of recycled aggregates is larger. It includes, first of all the costs of the additional operations for treatment of waste, which are a product of demolition. The way of demolition and the respective associated costs are not taken into account because we consider the building waste as an available one. This group includes also the costs for separation of the demolition site but an additional separation is also possible to be carried out at the recycling site.

Table 1 and Table 2 indicate two items, which are with a reverse sign – these are the costs for transport to the building waste landfill and the costs for the disposal itself. In case of starting the waste treatment, the cost of transport to the recycling site should be taken into consideration, which is mainly true for a stationary facility. Following are the real costs of building waste treatment and they are fixed for the facility as a whole.

The cost of recycled construction materials transport to the construction site is added, as well as one more group of specific costs. It includes the additional costs for control, storage and sale, the control being realized in licensed laboratories.

There exists very big difficulty to reach an identity of values from (1) in practice. Therefore, it is important, in case of inequality, to establish to what extent we can deem that the use of recycled aggregates is economically justified. Beforehand, however, it should be estimated which group of costs dominates, although this is a very difficult task.

The object of demolition should be carefully evaluated and especially, in terms of possible selective demolition. In the West European countries the selective demolition costs have reached 25%. Besides, the building waste disposal fees depend significantly on the local conditions – they can vary up to 10 times in different locations, ranging from 1.35 EUR to 14 EUR for a cubic meter of building waste.

In the EU countries the additional costs for preparation, production, testing and control, storage and sale of recycled aggregates are around 5.5 EUR per ton. If the fee for building waste disposal is neglected, recycled aggregates can not be competitive to natural aggregates. Practically, this is not possible in the EU countries, since the legislation related to environmental protection is to a great extent compatible and includes very severe sanctions if such waste is not disposed by a fixed term.

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In the construction materials market, natural aggregates are still preferable for concrete mixes, but if the price differs with 25% in favor of recycled aggregates, European users will prefer them. In the U.S.A. the market realization of the recycled construction materials is even more difficult – with equal technical parameters they have to be at least 50% cheaper in order to be preferred by the users.

One serious obstacle to the wider distribution of the recycled construction materials is the skepticism about their building qualities. This skepticism is due to a lack of enough experience in their use while lab tests show that their physical and mechanical properties are not worse than those of natural aggregates. The construction companies do not have proofs so far that, in a long term, the erected structures that have used recycled aggregates are durable enough. At the same time, there are some troubles and additional costs involved when recycled aggregates are used in concrete mixes. They are connected with the use of chemical additives and possible increase of the amount of cement, the complicated treatment of the concrete mix, the steps undertaken against shrinkage and taking care of concrete in its early age. Nevertheless, the use of recycled aggregates in most countries is profitable.

The relationships between prices of recycled aggregates and natural aggregates in some European countries are shown in Table 3, where are indicated the average sale prices.

Table 3. Price relations between recycled aggregates and natural aggregates in some EU countries

Country	1	2	3
France	4.4 – 9.0	3.6 – 6.5	1.2 – 1.4
Spain	3.0	6.0 – 14.4	0.5 – 0.2
Belgium	2.4 – 7.2	2.4 – 10.8	11.0 – 0.7
United Kingdom	3.3 – 8.4	4.4 – 15.2	0.5 – 0.6
Germany	4.8 – 8.4	6.5 – 8.8	0.7 – 0.95
The Netherlands	8.7	11.4	0.76

where 1 - Average sale price for recycled aggregates;

2 - Average sale price for natural aggregates;

3 - Price relation between recycled aggregates and natural aggregates;

After the analysis of the production costs of natural aggregates and recycled aggregate and the relations between them, the economic efficiency of their use can be determined. It should be, however, preceded by forecasts for the existing volume of building waste, review of prices and investigation of operational costs of stationary and mobile recycling facilities as well as the provisions of the local ecological legislation with respect to waste disposal. The increase of building waste volume in the future, taking into account the ever expanding scale of building activities, will lead to more extensive use of them and certainly will raise the trade interest to them in parallel to the reduction of their market prices.

4 CONCLUSIONS

An approach for economic expediency of building waste recycling is concerned. Technical and economic conditions providing the economic profitability of the recycling facilities, as an investment project realization, are formulated. The condition, which provides the market competitiveness of the recycled aggregates against the natural ones, is drawn up. The production costs of aggregates recycled from building waste as well as of natural aggregates are grouped. Relations between prices of recycled aggregates and of natural ones in some European Union countries are indicated.

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Professional and Educational Implications of Innovations in Building and Construction

(Demonstrated by the Robert L. Preger Intelligent Workplace (IW) and Expected from the Building as Power Plant (BAPP) / Invention Works Projects at Carnegie Mellon University)

V. Hartkopf, V. Loftness, A. Aziz & Y. Hua
Center for Building Performance and Diagnostics, Carnegie Mellon University, Pittsburgh, USA

ABSTRACT: The Center for Building Performance and Diagnostics (CBPD) at Carnegie Mellon University (CMU) in Pittsburgh with the support of the Advanced Building Systems Integration Consortium (ABSIC) has realized the Robert L. Preger Intelligent Workplace (IW), a living (always adapted) and lived-in laboratory occupied by faculty, staff and students. The IW represents a major breakthrough realizing advanced requirements for occupant's comfort and productivity, organizational flexibility and effectiveness, technological adaptability, and energy and environmental effectiveness, throughout the lifecycles of all materials, components and systems.

Building on the experience and success of the Robert L. Preger Intelligent Workplace, CMU, CBPD and the ABSIC are committed to realize the Building as Power Plant (BAPP)/Invention Works project on the CMU campus. In addition to advanced energy-effective enclosure, heating, ventilation, and air-conditioning and lighting technologies, the BAPP will integrate innovative distributed energy generation systems. This will enable that all of the building's energy needs for heating, cooling, ventilating, lighting and equipment are met on-site, maximizing the use of renewable energies. Thereby the BAPP addresses significant international needs in terms of energy effectiveness, energy quality, reliability and security, as well as environmental performances. Consequently, the U.S. Congress has designated the BAPP as the National Test-bed for Energy Efficient Building Technology.

The IW is being visited by about 1000 visitors from all over the world annually, many of them governmental representatives, clients, architects and engineers. Consequently, CBPD faculty and staff were asked to apply major concepts of the IW in buildings in Korea, China, France, Germany and North America. The School of Architecture at CMU has introduced a new course and design-studio sequence in building performance and systems integration. The Graduate Program in Building Performance and Diagnostics currently has 13 doctoral and 6 master students.

1 INTRODUCTION

KEY QUESTION: Taken as a whole, the built environment represents neither any company's core business, nor does it fall under the purview of a single governmental agency's core mission. It is instead the result of many actions, and influenced by numerous actors, while no one takes final responsibility. Should the universities assume this duty to set examples?

CHALLENGES:

- Worldwide growth of nonrenewable resource consumption and waste
- Finite reserves of nonrenewable resources (2009 world-wide peak of oil production)
- Finite carrying capacity of Earth
- 50% of world population living on less than $2/day and mostly on solar income
- The United States of America – the leader in fashion; instant gratification

When focusing on the built environment in the US, we realize that it:

- creates 40% of land-fill waste by weight, and 30% by volume
- consumes almost 40% of the US's primary energy for operation and an additional 10%-20% (estimated) for building materials production

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– contributes in the US, over 500 million tons of CO_2 into the atmosphere per year from the generation of the electricity that is used for building operations (67% of total electricity - source: Energy Information Administration, Annual Energy Review 2001)
– produces 18% of the US's total annual CO_2 emissions by cement production

also offers potential for health and productivity savings in the range of $20-200 billion annually through improved practices and systems integration.

2 THE ROBERT L. PREGER INTELLIGENT WORKPLACE:THE LIVING AND LIVED-IN LABORATORY

The Robert L. Preger Intelligent Workplace™ (IW) (*Figure 1*) is the result of an unprecedented collaboration between the Center for Building Performance and Diagnostics, the first National Science Foundation Industry/University Cooperative Research Center in the building industry, and its supporting industry and governmental members, organized in the Advanced Building Systems Integration Consortium (ABSIC). The 7000 square foot IW is a living laboratory of office environments and innovations.

Occupied in December 1997 and continuously being adapted, the IW is a rooftop extension of Margaret Morrison Carnegie Hall on the Carnegie Mellon campus. The project provides a test-bed for:
– organizational innovations for the advanced workplace;
– innovations in information technology;
– innovative enclosure, HVAC, power, voice, data networking, and interior systems;
– products for thermal, air, visual, acoustic, connectivity, and spatial quality;
– demonstrations of products' performance in an integrated setting;
– training in material, component, and systems choices and their integration for performance; and hands-on learning in instrumentation and metrics for evaluating performance and occupancy comfort, and in development of CAD packages for design, simulation and management.

The IW enables the interchangeability and side-by-side demonstrations of innovations in HVAC, enclosure, interior, and telecommunication components and assemblies. Most importantly, as a "lived-in" occupied office, research, and educational environment, the IW provides a testing ground to assess the performance of new products in an integrated, occupied setting (*see Figure 2*).

Figure 1. The Intelligent Workplace™, a rooftop extension of Margaret Morrison Hall at Carnegie Mellon University

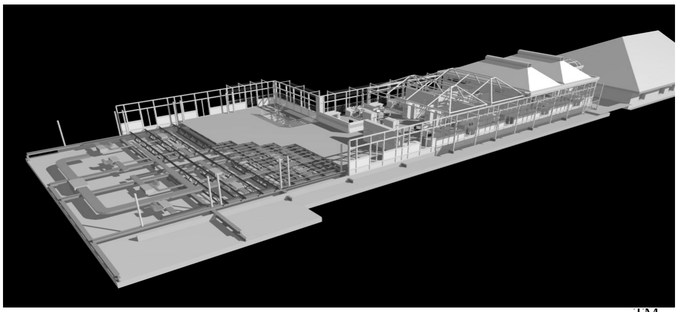

Figure 2. Peel -away view of the Intelligent Workplace™ illustrating the floor-based integration

2.1 *Goals of the Robert L. Preger Intelligent Workplace™*

– *Individual Productivity and Comfort:* The demonstration of advances in individual comfort and productivity requires that both interior system and engineering infrastructures are "plug and play" to ensure that furniture and space reconfigurations for individual productivity and creativity are immediately matched by technology and environment reconfigurations for comfort, health, and corresponding productivity.
– *Organizational Flexibility:* The demonstration of advances in organizational flexibility requires that the community of workplaces be reconfigurable on both annual and daily levels to ensure "organizational re-engineering" for collaboration supporting regrouping and sharing for organizational productivity, creativity and innovation.
– *Technological Adaptability:* The demonstration of advances in technological adaptability requires that vertical and horizontal pathways for connectivity are accessible and open and that both interior systems and engineering infrastructures support changing technological demands for horizontal and vertical work surface, lighting, acoustics, thermal conditioning, and ergonomics.
– *Environmental Sustainability:* The demonstration of advances in environmental sustainability requires that both energy and materials are used effectively over a building's and its components' life cycles. Concepts, such as system efficacy, user controls, micro-zoning for flex-time, just-in-time delivery of infrastructures, environmentally sustainable and healthy materials, natural condi-

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tioning, should all be demonstrated and comparably measured to standard practice.

2.2 Systems Integration for Performance

The IW is not envisioned as a onetime "show-and-tell" demonstration project, but rather as a dynamic environment for the teaching and evaluation of how integrated building components, systems, and assemblies affect building performance. In-house post-occupancy research is critical to validating predicted performance through simulation and to assessing the performance in the integrated setting. The IW also provides the platform to explore broad environmental and ecological issues such as recycleability of building products and assemblies, and long -term resource management. As a test-bed of new ideas, and a demonstration center for successful innovations, combined with innovative office concepts and portable diagnostics, the IW is a unique living laboratory of office environments.

The IW is conceived as a modular system, the units of which can be stacked or reconfigured to adapt to the needs of multiple office settings, allowing the organization and the employees to decide and constructively adjust the location and density of people and equipment, as well as their enclosures for physical, visual and acoustic privacy.

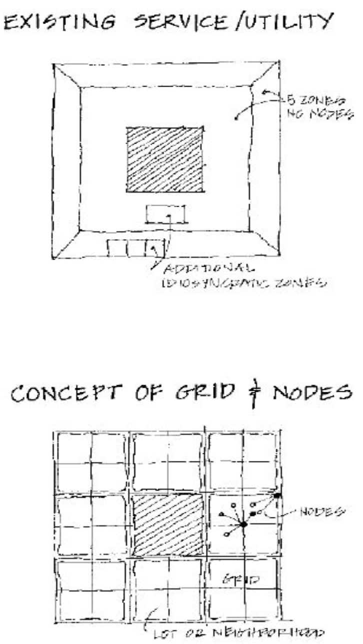
2.3 New Design Approaches to Absorb Change and Avoid Obsolescence: Flexible Grid - Flexible Density – Flexible Closure Systems

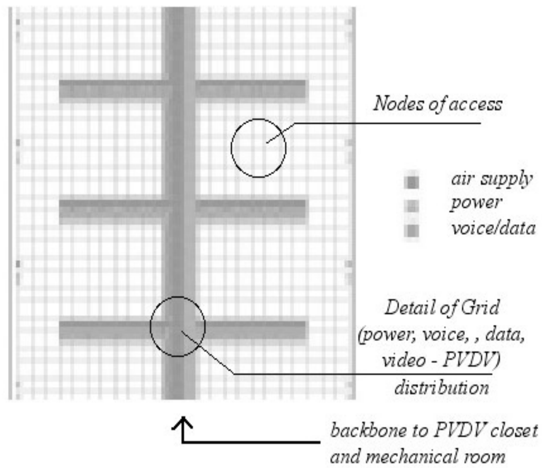
To avoid frequent environmental quality failures, or median and long term obsolescence, it is critical to invest in user-based infrastructures that are modular, reconfigurable, and expandable for all key services - ventilation air, thermal conditioning, lighting, data/voice and power networks. The dynamic reconfigurations of space and technology typical in buildings today cannot be accommodated through the existing service infrastructures - either the "blanket systems" for uniform open-plan configurations or the idiosyncratic systems for unique configurations. Instead, flexible infrastructures are required, capable of changing both location and density of services:

> *Flexible Grid - Flexible Density - Flexible Closure Systems are a constellation of building subsystems that permit each individual to set the location and density of HVAC, lighting, telecommunications, and furniture, and the level of workspace enclosure.*

These services can be provided by separate ambient and task systems, where users set task requirements and the central system responds with the appropriate ambient conditions, or fully re-locatable, expandable task/ ambient systems.

Advanced buildings today demonstrate that floor-based servicing may more effectively support the dynamic workplace (*Figure 3*). Since networking, ventilation and thermal conditioning need to be delivered to each workstation, services at floor level or at desktop offer a greater ease of reconfiguration than ceiling-based systems. In addition, floor-based systems such as electrical and telecommunication cabling and outlet terminal units can be continuously updated to meet changing needs. Today, a number of industry partnerships are forming to offer collabora-





Nodes of access in the IW

Detail of Grid (power, voice, data, video) distribution in the IW

Figure 3. Conventional large zone approaches to thermal conditioning and lighting are incapable of delivering adequate environmental quality to accommodate the dynamics of technology, workstation density and teaming concepts

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tive solutions to flexible infrastructures - floors, data/ voice, power, thermal conditioning and ventilation. With these modular, floor-based services, the ceiling can become more playful and elegant - as a light and acoustic diffuser - defining working groups, work neighborhoods as well as recreating the ceilings of landmark buildings (Loftness et al, ARTI21-CR, 2003)

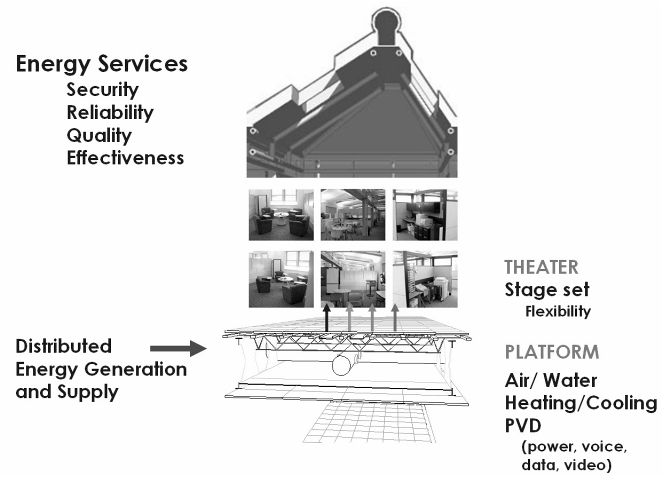

Figure 4. The IW central system integration concept for flexibility, plug and play systems, distributed energy generation and supply, as well as advanced energy services

Interactive multimedia and web-based technologies create the possibility to work within ever changing teams, both locally and globally. This requires that built environments must be responsive to ever changing organizational and rapidly evolving technological circumstances.

2.4 Reduced Waste in Construction of the Intelligent Workplace

The IW project exemplifies how the design and engineering, as well as material selection, can result in 70-90% reduction of emissions and waste during production of the materials used for the exterior wall, floor and roof, compared to a conventional building. This includes the reduction of NOx by 90%, SO_2 by 70%, and CO_2 by 80%. An analysis of the project also showed dramatic savings potentials when selecting recycled aluminum and steel rather than virgin materials. Here the avoided emissions ranges were similarly pronounced.

In addition, there was no on-site waste during most of the construction phase (steel structure and facade erection as well as interior fit-out), because of the IW's modular design and its off-site fabrication with complete recycling capacity of all by-products. This also resulted in a reduced potential for injury and significant time-savings during construction, which ultimately leads to capital savings by shortening delivery time.

2.5 Reduced Waste in Operation

The IW is conditioned for six or more months through "natural" energies alone during daylight hours (passive and active solar heating, cooling, daylighting and ventilation).

In addition to the resource savings of operating a building, there is significant potential to reduce material waste through the management of material and subsystem obsolescence. The reconfigurable/ relocatable interior systems, with modular interfaces to the envelope, HVAC, lighting, communication, structure, power systems, enable organizational change on demand, as well as technological change on demand, as demonstrated in the IW.

This dual concept of just-in-time organizational change and technological change assures that the building is meeting flexibility and adaptability requirements without redundancy or waste. Access in the "open" system and plug-and-play technologies allow for the complete component-by-component, or system-by-system change-out of technology with complete recycleability when and where necessary. These concepts also insure that the building is a renewable asset for its investors and will not become a straightjacket that eventually has to be discarded in whole or in part. These concepts also insure that all changed-out components or systems are fully recyclable, since composite materials are avoided and systems are demountable. For instance, the IW enclosure and structural elements are pinned or bolted and made from recycled aluminum and steel.

Consequently, the integrated, modular and demountable systems reflect the fact that buildings are made from components that have different life cycles. The envelope as a system should have a life of 50-100 years, with a possibility of exchanging glazing materials, photovoltaic elements and other components, when superior performance becomes economically feasible. The structural system should have a life of 100 years, and when becoming obsolete at a particular site should become re-deployable elsewhere (a column is a column, a truss is a truss). Whereas interior systems have considerably less "life expectancy", down to computing systems that might have a useful life of 2-3 years. When all fails, at least, the demountable system can be up-cycled completely as either biological or technical nutrient (Michael Braungart, 2002).

In summary, the four waste-management and environmental benefits of the IW are:

– The materials, components and systems during their production and assembly require a fraction of the energies and produce a fraction of the emissions of comparable systems.
– During the construction phase, due to prefabrication and modular design, waste is eliminated.
– During the operational phase, the management of obsolescence supports organizational and tech-

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nological changes-on-demand. This is enabled through re-locatable infrastructure: HVAC, lighting, power, communication and interior systems. In addition, the fact that major building components and systems have different life cycles is accounted for through the use of the modular, plug and play systems. This allows for easy change-out and advancement of technology as the need or opportunity arises.

– The design anticipates a complete decommissioning of the building and its constituent parts. The “long life systems”, such as structure and envelope, can be redeployed elsewhere. Or, as in all other cases, the materials of non-unified components of subsystems can be completely up-cycled.

2.6 *Intelligent Workplace Energy Systems Analysis*

The energy usage and performance of the Intelligent Workplace and its building control systems are being analyzed. The lessons learned during this study are being used in the design and engineering of integrative demonstration and “laboratory” project, the Building as Power Plant/Invention Works (BAPP) on CMU’s campus (see below).

The analysis focuses on: 1) data acquisition system, 2) building control systems, and 3) the next BAPP design.

The IW uses several energy systems to provide heating, cooling, ventilation, dehumidification, and lighting. Heating is provided by the warm water mullions of the façade. The cooling is provided through multi-modal strategies consisting of radiant panels, COOLWAVES by LTG, Johnson Control Personal Environment Modules (PEMs), a make-up air unit to supply the PEMs and floor vents, and a SEMCO air-handling unit. The SEMCO unit, which is controlled by an Automated Logic system, is a 100% outdoor air system with enthalpy wheel for dehumidification. A JCI Metasys system controls most of the HVAC system. The lighting system is controlled by a Zumtobel-Staff LUXMATE system.

The IW uses three different systems to record energy data. Energy Sentry (72 data points) records electrical energy consumption, Metasys (160 data points) is used for HVAC related data and Weather-Station (8 data points) records outdoor environmental data. These three systems record data in different formats in different locations and within the systems, each sensor records data in a different file. To expedite and facilitate the analysis process, it is necessary to bring the data into the same format. As a result a tool, IW Energy Sentinel (IWES), was developed to: (a) actively capture continuous streams of data from different sources, process and aggregate them into a common format, and provide useful information; (b) create a central repository for storing building system information and sensor information, such as specification and maintenance history, throughout the life cycle of the building; (c) provide visual data displays, reports and alarms that work with multiple building systems; and (d) function successfully without changing the operation of the installed sensor systems. This tool also has several features that allow easy analysis of the building data.

The data collected from sensors in the building was analyzed to determine energy usage and trends. It was found that the data contained had missing values. Reasons for this were incomplete documentation of the file storage structure, IP address problems and the system going offline for various reasons. Statistical techniques and simulation were used to fill in missing data to make the calculations more accurate. The existing DOE 2.1E simulation model of the IW was calibrated to match the current measured conditions in the IW. This model was then used to predict energy consumption under different scenarios when data were missing.

It was found that although energy usage was considerably less in the IW when compared to standard US office buildings (*Figure 7)* there were still areas where the energy consumption could be reduced further. This will be accomplished by the BAPP.

– Several hypotheses were suggested to explain the results obtained from the analysis. These were based on the design of the building and its mechanical systems.

– The high air infiltration, due to leakages in the interfaces between the façade and the roof, as well as the floor below.
– The heating set point in the IW was higher than that of a standard office building, which further increased the load.
– The higher then typical amount of glass and exposed surface area caused an increase in cooling energy.
– This cooling load was sometimes increased by inappropriate operations of windows.
– The unconditioned under-floor plenum above several floors below, all of which are not cooled during summers, was measured to have an average temperature of 31C during the summer. Since it is not insulated from the IW living space, it also increased the cooling load.

Fluorescent fixtures with dimmable ballasts provide artificial lighting. At the time of construction these were available only for 220V, therefore, transformers were used. It was found that of the total annual lighting load of 18.92 kWh/m^2 (about 1/5th of best US practices), 10.12 kWh/m^2 was caused by transformer losses (the “parasitic” load therefore is a 50% of this reduced load).

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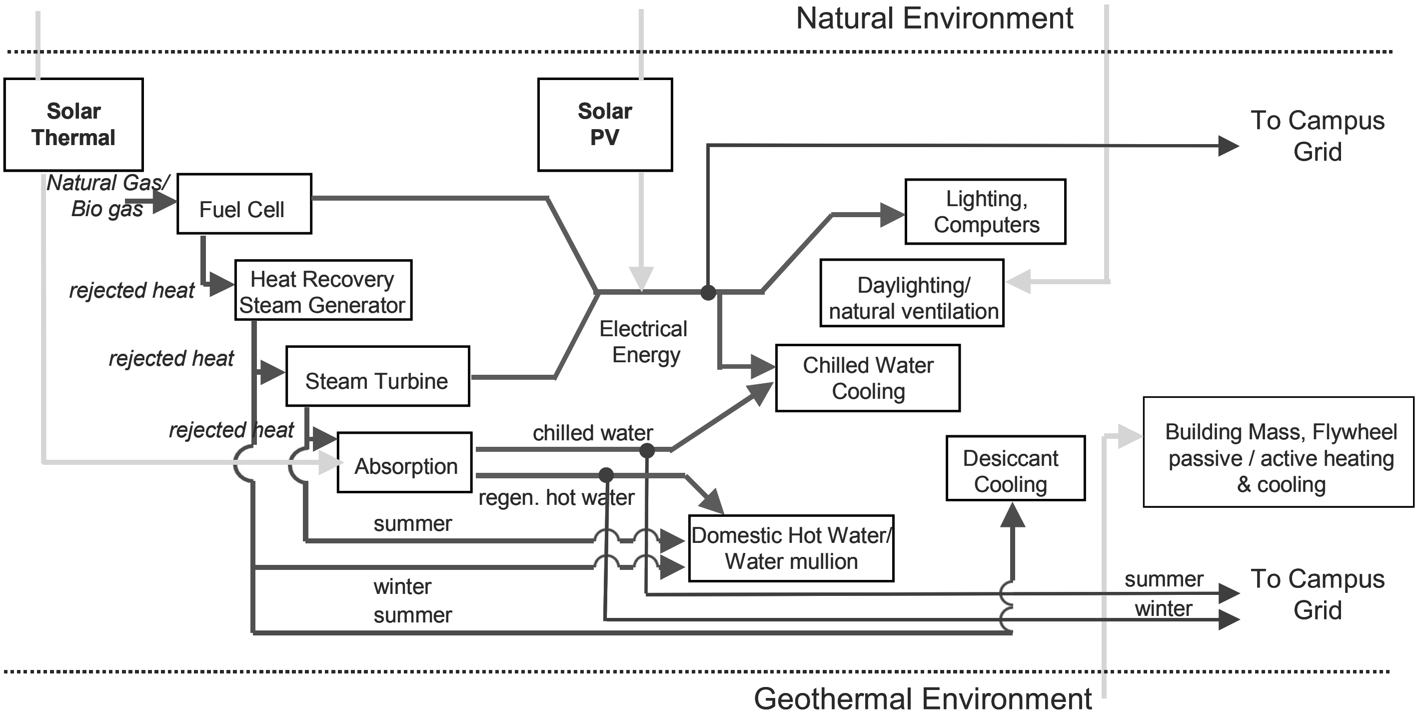

Figure 5. Building as Power Plant conceptual scheme for a building-integrated "ascending-descending" energy system

3 BUILDING AS POWER PLANT/INVENTION WORKS

Building on the concepts of and experiences with the Intelligent Workplace™, a living (always adapted and updated) and lived-in laboratory at Carnegie Mellon University (Hartkopf and Loftness 1999, Napoli 1998), a research, development and demonstration effort is directed at the "Building as Power Plant – BAPP". This project seeks to integrate advanced energy-effective enclosure, Heating, Ventilation, and Air-Conditioning (HVAC) and lighting technologies with innovative distributed energy generation systems, such that all of the building's energy needs for heating, cooling, ventilating and lighting are met on-site, maximizing the use of renewable energies. (Figure 5 schematically illustrates this idea.)

BAPP is designed as a 6-storey extension of the existing Margaret Morrison Carnegie Hall Building with total area of about 6000 m^2, which houses classrooms, studios, laboratories and administrative offices for the College of Fine Arts. TH BAPP will be equipped with a decentralized energy generation system in the form of a combined heat and power plant. This will include a 250 kW Siemens Westinghouse Solid Oxide Fuel Cell (SOFC) and absorption chiller/boiler technologies. In addition, advanced photovoltaic, solar thermal, and geo-thermal systems are being considered for integration.

An "ascending-descending energy scheme" integrates energy generation and building HVAC and lighting technologies. In an 'ascending strategy', fenestration, shading, and building mass will be configured to minimize the lighting, cooling and heating loads and maximize the number of months for which

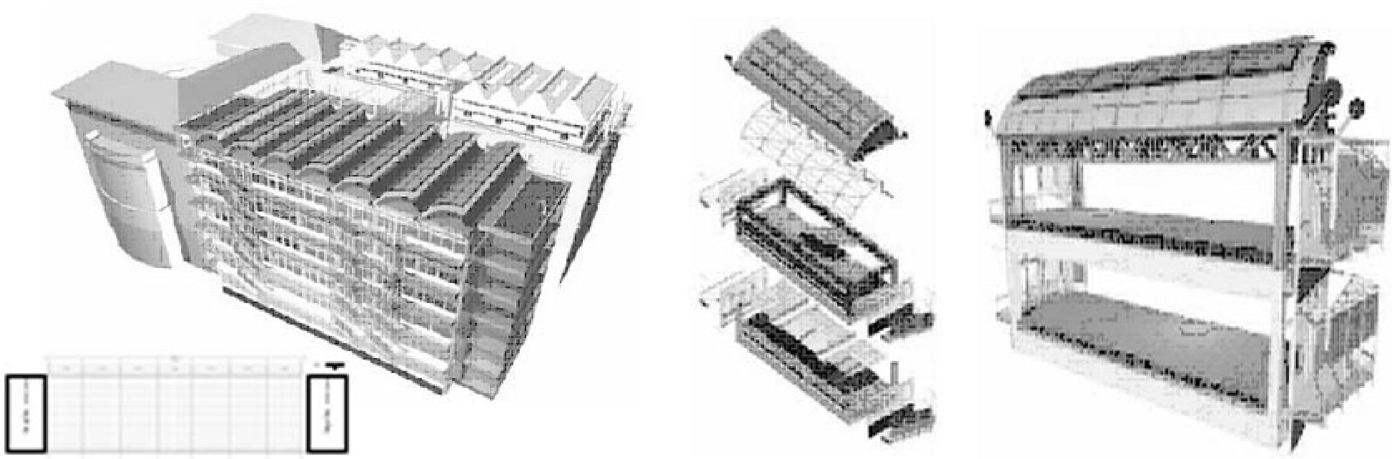

Figure 6. Column-free, flexible floor plan, perspective, modular design, stacked bays and solar-thermal collector arrangements for the new wing of the Building as Power Plant/Invention Works

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no cooling or heating will be needed. Then, passive strategies such as cross ventilation, stack ventilation, fan-assisted ventilation and night ventilation would be introduced. Passive cooling would be followed by desiccant cooling when humidity levels exceed the effective comfort zone. Geothermal energy will be used to activate the building mass for cooling and heating. As outdoor temperatures or indoor heat loads exceed the capability of these systems, then absorption and finally refrigerant cooling will be introduced, first at a task comfort level. Only the last stage of this ascending conditioning system will be a task-ambient central-system refrigerant cooling system. Complementing the 'ascending' energy strategy is a 'cascading' energy strategy, designed to make maximum use of limited non-renewable resources. In the building's power generation, reject heat from the fuel cell can be converted into steam, which can be used to drive a steam turbine, and/or in the cascading system, reject heat will be used to drive desiccant, absorption and refrigerant systems; and finally the resulting reject heat can be used for space and domestic hot water heating.

4 CONCLUSION

Figure 7 clearly delineates the vast opportunities of the BAPP project. Increased building performance and energy effectiveness hold for 40% of the primary US energy consumption and 67% of the US electricity demand. In fact, the expected performance of the Building as Power Plant/Invention Works, which will include integrated solar-thermal, ground-source heat pump, as well as fuel cell technologies is expected to function as a significant net energy exporter to the campus at large. This is in addition to providing the environment for occupant productivity, organizational effectiveness and the conservation of material resources.

The mission of the School of Architecture at Carnegie Mellon University is to educate outstanding professionals with design creativity, social responsibility, historical perspective, technical competence, and global environmental consciousness. The School has taken the position that future architects should be accountable for the measurable performance of the buildings they design. This accountability demands that architectural education must provide hands-on knowledge about thermal, air quality, visual, acoustic, and spatial performance, as well as long term building integrity in a fully integrated, occupied setting. To this end, the Intelligent Workplace (IW) serves as a proving ground for the advancement of integrated systems for superior building performance. This innovative office setting begins to establish buildings as renewable assets rather than depreciating investments with liability. At the same time, the IW plays a vital role in the education of our students to provide unprecedented hands-on learning about the performance of integrated building systems, providing settings for individual comfort and productivity, organizational flexibility, technological adaptability, as well as energy and environmental effectiveness (Streitz, et. al., 1999, GSA Office of Real Property, 2004).

The graduate program in building performance is built on the principles of sustainability. The graduate

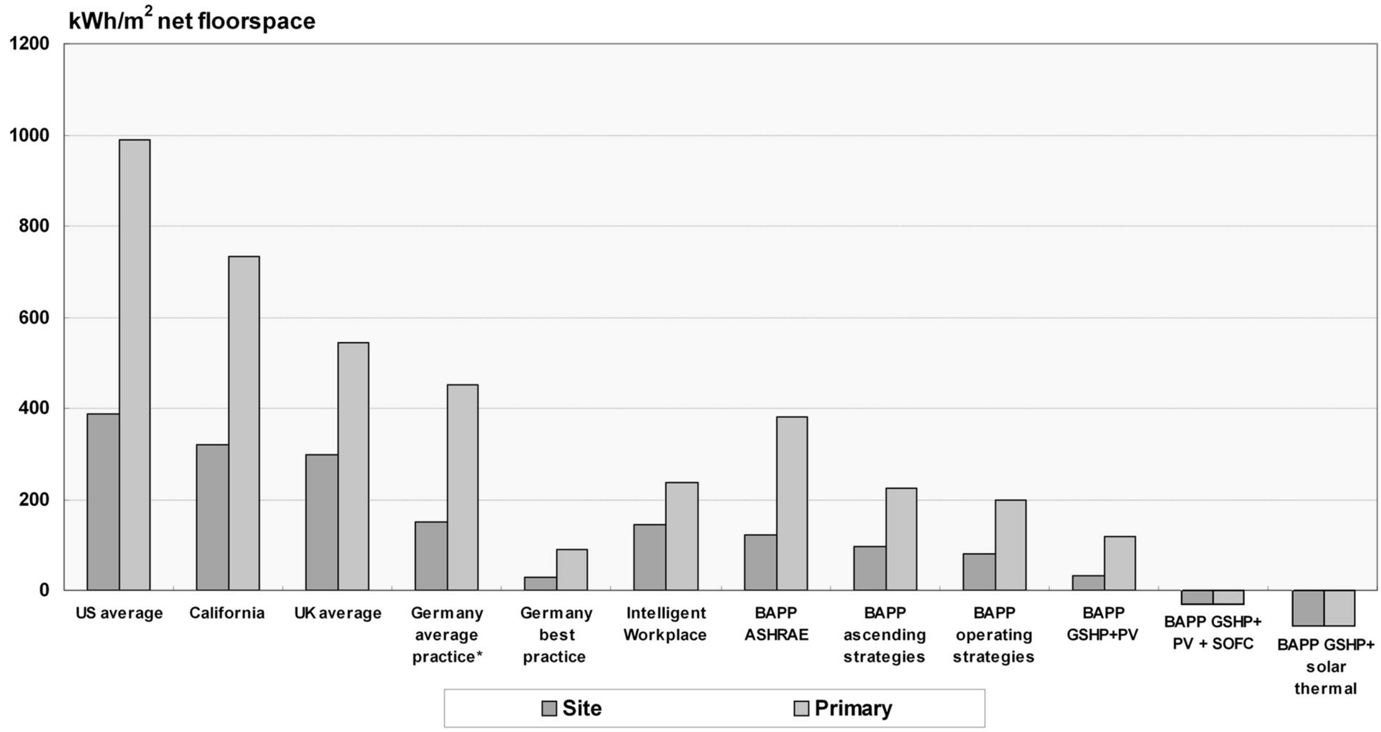

Figure 7. Source (Primary) and Site Energy Comparisons

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research focuses on both new science and new engineering developments for environmental sustainability, including simulation tools, design guidelines and decision support tools, innovations in systems and systems integration, as well as demonstration projects and POE towards a more sustainable future for the built environment.

In addition, the CBPD is actively developing strategies for influencing the building delivery process towards improving the performance of buildings. The industry is limited by an overly strong emphasis on first cost decision-making, therefore, the development of a life-cycle tool identifying the cost-benefits of advanced building technologies is central to the commercialization of higher performance building solutions. In a web-based tool called BIDS (Building Investment Decision Support™), the Center is developing life-cycle justifications for high performance building systems with user-customized recalculations of world-wide case studies. BIDS™ is a case-based cost-benefit analysis tool to support investments in advanced and innovative building systems that improve environmental quality, health and productivity in buildings. Through ABSIC support, it continues to identify laboratory and field case studies demonstrating the relationship of high performance components, flexible infrastructures and systems integration to the range of cost-benefit or productivity indices, with over 200 data sets incorporated by July 2005. The team is also expanding the data base relating quality indoor environments to major capital cost and benefit areas, including productivity, health, and operations costs, with baseline data sets to support life cycle decision-making. (http://cbpd.arc.cmu.edu/ebids)

No one discipline owns sustainability. Progressive environmental leadership must draw from ethics, economics, science, technology, and public policy. Progress depends on the sort of cross-campus collaboration – with an eye toward solving real-world problems – that is this Carnegie Mellon's signature strength. Such efforts can lead to policy development. For instance, the US Dept. of Energy (DOE) held the National Lighting Visioning Workshop in the Robert L. Preger Workplace (IW). In 1999 DOE brought 100 Chinese professionals to the IW, amongst them the Vice Minister of Construction. This resulted in the CBPD team to lead the redesign of the Ministry of Science and Technology (MOST) Headquarters for The Agenda 21 Team (Climate Change), jointly with the NRSC and the USDOE. The effort resulted in the 12,000m^2 building to consume 77% less energy than was projected by meeting ASHRAE (American Society of Heating, Refrigeration and Air-conditioning Engineers) standards. The building was recently the centerpiece of the Joint Sino-US Green Building Conference at MOST in Beijing, showing a desirable path of development.

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A vision-based sensing system for sentient building models

O. Icoglu & A. Mahdavi
Department of Building Physics and Building Ecology, Vienna University of Technology, Vienna, Austria

ABSTRACT: The quality and cost effectiveness of services in the building industry possess high potential for improvement. A possible approach to bringing out this potential is to conceive buildings as sentient entities that continuously adapt to changes in environment and occupancy. To achieve real-time building operation support and to avoid bottleneck situations resulting from manual model input and updating activities, the underlying model must possess the capability to autonomously update itself. This requires a versatile sensing mechanism that provides real-time facility state information. The research described in this paper aims to demonstrate the potential of vision-based sensing solutions to support the operations of sentient buildings. Toward this end, a system prototype has been implemented that focuses on building systems control (lighting). The resulting arrangement of required hardware and software components (tied together via internet) provides a flexible and self-adapting structure, which is highly suited to the requirements of control applications for sentient buildings.

1 INTRODUCTION

The research presented in this paper is part of a project to demonstrate the feasibility, scalability, and potential of sentient building technologies. A sentient building is one that possesses a multi-faceted internal representation of its own context, structure, components, systems, and processes. It can use this representation, amongst other things, toward the full or partial self-regulatory determination of its indoor-environmental status (Mahdavi 2004). The realization of a sentient building is, we argue, within reach. However, to achieve this goal, already acquired scientific foundations (theories, methods, and tools) must be translated into a technically mature and industrially promising level. Specifically, the representational core of sentient buildings must integrate static building component class hierarchies (product models) with process-oriented systems controller hierarchies (process models). Moreover, the complexity of buildings (multitude of components, environmental systems, occupancy patterns, contextual influences) implies that the associated representations must be continuously updated, if they are to be applied effectively in the course of building operation and maintenance activities. To avoid bottleneck situations resulting from manual input and updating activities, the underlying product-process model must possess the capability to autonomously update itself. This requires a versatile sensing mechanism that provides real-time facility state information. The research described in this paper aims to demonstrate the effectiveness of vision-based sensing solutions to support the operations of sentient buildings.

2 VISION-BASED SENSING

To deliver a proof of concept for the feasibility, the necessary sensing mechanisms are implemented focusing on the lighting control system for a sentient building (Mahdavi 2001a, 2001b). In such a control system, objects in the space must be identified, their locations must be sensed, changes in reflectance of the objects and surfaces must be monitored, and occupancy information must be obtained. Furthermore, the prospective solution must comply with the building-specific requirements where low-cost, low-maintenance, and scalability are crucial. In our efforts for realizing such a solution, a Vision-based Object and Occupancy Location Assessment System (VIOLAS) is developed that extracts context information from the built environment using vision-based methods. In a technology review performed prior to the implementation of the system (Icoglu et al. 2004), vision-based approaches were found to be preferable in terms of being software supported and system customizable.

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The “sensing core” of VIOLAS is comprised of five major blocks, whereby each block performs a distinct function for context data extraction (Fig. 1).

2.1 *Hardware Interface*

The Hardware Interface block allows data acquisition from multiple sensors. Recent developments in embedded computing led to the integration of sensors with processors. This reduced the costs, as dedicated computers were not necessary to enable data compression and communication. Thus, data could be efficiently conveyed over large-scale networks. In vision sensing domain, such developments gave rise to network cameras (netcams). Netcams have embedded computing power that enables image compression and data communication over Internet via standard protocols. They also enable the control of third-party devices like pan-tilt units (P/T) through the same communication channel.

Netcams can be easily adapted to built environments by making use of existing network installations without requiring additional infrastructure. Towards this end, we use network cameras together with pan-tilt units that effectively increase the monitoring range. However, netcams generate relatively low-quality data due to data compression. This results in low resolution and blurred images without sharp details. To enhance the performance, the system applies adaptive sharpening and zooming to the initial netcam images (see the following section).

2.2 *Object Identification and Location Sensing*

The location sensing module is adapted from TRIP system (Lopez de Ipina et al. 2002) that basically uses “pose extraction from circle” algorithm, estimating the pose of a circle in space from a single intensity image. The working of the algorithm is illustrated in Figure 2. The target plane generates an ellipse on the image plane of the camera. From the known parameters of the ellipse, it can be back-projected to the original circle, enabling the extraction of the orientation and the position of the target plane with respect to the camera origin (Trucco & Verri 1998).

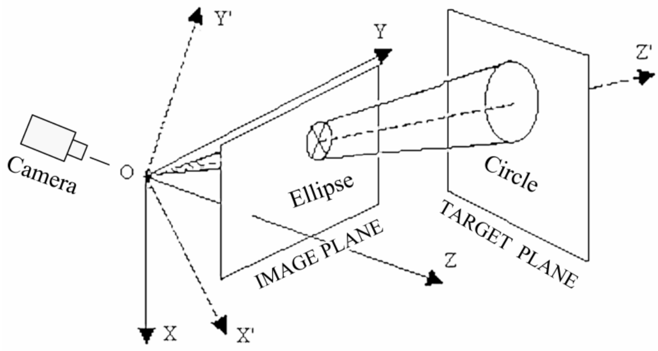

Figure 2. “Pose from circle” algorithm. (X,Y,Z) denotes the coordinate system of the image plane whereas (X',Y',Z') denotes the coordinate system of the target plane. The outcome of the algorithm is the parameters of the transformation between two coordinate systems

For the realization of the algorithm, barcode like tags with circular marks are used. These tags can be printed using regular black-and-white printers. This is one of the main benefits of the system, as the tags are low-cost and low-maintenance, and require no power input. Currently, we use 12 by 12 cm tags. The identification is accomplished by the codes printed around the circular mark (reference circle). Unlike the TRIP system that uses ternary coding, VIOLAS uses binary coding, where the tags are divided into 16 equal sectors (Fig. 3) resembling pie slices. The presence or absence of the black mark on the sector denotes the 1 or 0 coding respectively. The pattern of “0111” code sequence defines the start bits, and is never repeated elsewhere in the rest of the data string.

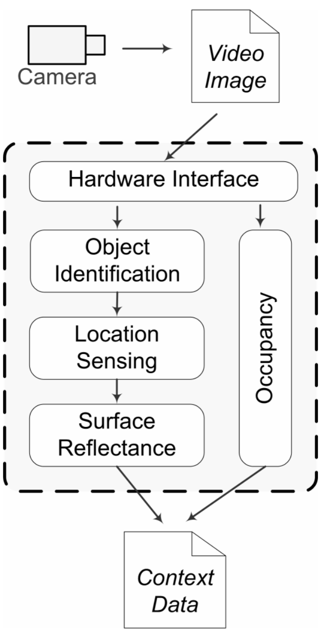

Figure 1. “Sensing core” in VIOLAS

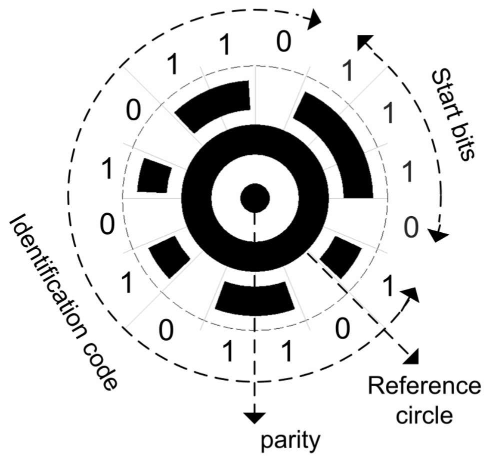

Figure 3. Tag structure is illustrated with a sample tag coded with 0111-011010101101 data string (even-parity = 1). Identification number corresponds to 1709 in decimals

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The identification number is encoded in the remaining 12 sectors. Finally, an even-parity bit is added at the center of the reference circle for the verification of the decoded data string in the end of the identification phase. This coding structure enables the definition of 2031 distinct tagged objects.

The TRIP system divides the location sensing procedure into two phases. First is the “target recognition” phase, where the tags are detected, parameters of the reference ellipse (projection of the reference circle on the camera image) are extracted, and the identification numbers are decoded. Second is the “pose extraction”, where the location of the tags are computed from the outputs of the first phase (Lopez de Ipina et al. 2002).

VIOLAS enhances the original TRIP method by integrating two additional algorithms (Fig. 4). The original system was implemented on images captured by digital cameras that provide uncompressed, high quality data. However, working on raw images is not applicable in distributed environments such as buildings. As mentioned in section 2.1, netcams are used as sensor devices for this reason, where the images can be transported in wide areas through HTTP. Like other digital video devices, netcams are designed to convey images as fast as possible and therefore apply compression to images prior to transmission. This generates smoothed input images and causes tag image regions to lose sharpness. To compensate this, VIOLAS applies an “adaptive sharpening algorithm” (Battiato et al. 2003) on the input image prior to “target recognition” (Fig. 4).

In addition to camera artifacts, an increase in the distance of tags to camera reduces the pixel resolution of the tag images and makes the identification codes harder to decipher, even though the tags are detected and reference ellipses are extracted properly. To solve the problem, “edge-adaptive zooming” (Battiato et al. 2000) is applied locally to spurious tags from which the code could not be deciphered or validated. Edge-adaptive zooming, as opposed to its counterparts such as bilinear and cubic interpolation, enhances the discontinuities and sharp luminance variations in the tag images. This procedure is repeated until the “target recognition” succeeds or the zoomed image region loses its details (Fig. 4). The latter case indicates a false alarm or an unidentified tag.

2.3 *Surface Reflectance Estimation*

In addition to location information, surface attributes of the corresponding objects are also important for the model generation. Surface Reflectance Estimation determines the reflectance of the objects that are identified and located in the previous steps.

Key information in the reflectance estimation of diffuse surfaces is the illumination data, which is obtained in the system based on the known tag reflectances. Since the tags are attached directly to the object surfaces, they possess the same illuminance. By comparing the brightness of the object with the brightness of the tag, the reflectance of the object surface can be estimated (Horn 1986).

2.4 *Occupancy Sensing*

Occupancy information is acquired from the temporal image sequences with the calculation of optical flow, i.e. a motion detection method that tracks the apparent motion of brightness patterns (Ballard & Brown 1982).

3 VIOLAS IMPLEMENTATION

The aim of the system is to collect visual data from sensors and extract context information from the environment. The results must be conveyed to the Lighting Control System. Figure 5 illustrates the process to fulfill this goal. Towards the realization of the system, context data generated by the “sensing core” must undergo some additional processes to provide unified, consistent, real-world information.

3.1 *Coordinate Transformation*

The outcome of the “sensing core” regarding the location data is the position and orientation information with respect to the coordinates of the camera from which the processed image is acquired. Coordinate Transformation converts the position and orientation data with respect to camera coordinates to the position and orientation data with respect to the real-world coordinates by using 3-D transformations. The transformations must also take into account the presence of a P/T unit and the camera’s position on it (Fig. 6).

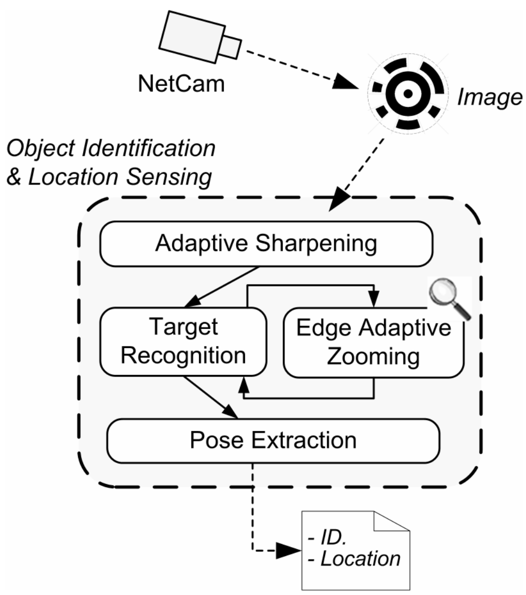

Figure 4. Algorithm flow of Object Identification and Location Sensing in the “sensing core”

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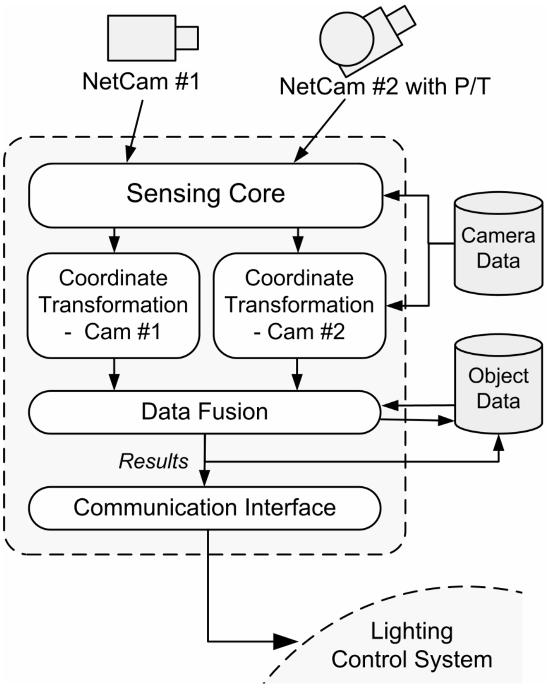

Figure 5. Process flow designed for VIOLAS implementation

3-D transformations map the coordinates of one point in 3-D space to potentially different coordinates defined in a distinct system frame in 3-D space. The camera parameters are stored in a camera database that uniquely identifies the transformations between each of the camera reference frames and the world reference frame (the same database is also used by "sensing core" for data acquisition and camera calibration). For describing the relative positions of the origins of the two reference frames, a 3-D translation vector, T, is used. An orthogonal 3×3 rotation matrix, R, aligns the corresponding axes of the two frames. The orthogonality relations reduce the number of degrees of freedom of R to three angles. In a common notation, the relation between the coordinates of a point P in world and camera frame, P_w and P_c respectively, is

$$P_w = R \cdot (P_c) + T \tag{1}$$

where rotation is defined from room to camera and translation is defined in room coordinates (Fig. 6a).

If the camera is attached on a pan-tilt unit, a sequential transformation must be applied, first from room to P/T, where P/T device is at its original position *(pan = 0°, tilt = 0°)*, and then from P/T to camera, where pan and tilt angles are involved (Fig. 6b). The rotations of these two transformations are given respectively as;

$$R_1 = room \rightarrow P/T, \qquad R_2 = P/T \rightarrow camera \tag{2}$$

If we assume that the camera is mounted on top of the pan-tilt unit, there is no additional translation other than the translation of the Pan-Tilt Unit, T. Therefore the equation becomes:

$$P_w = R_1 \cdot R_2 \cdot (P_c) + T \tag{3}$$

However, practically it is impossible to place the camera right at the top of the P/T unit: there is always a shift from the origin of the P/T coordinate system (Fig. 6c). This shift, S, is defined in the P/T unit's coordinate system, and must be transformed into the room specific values, S', in order to be added in the final equation:

$$P_w = R_1 \cdot R_2 \cdot (P_c + S) + T, \quad \text{or} \tag{4}$$

$$P_w = R_1 \cdot R_2 \cdot (P_c) + S' + T \tag{5}$$

The total rotation ($R_{total} = R_1 \cdot R_2$) and the total translation ($T_{total} = S' + T$) give the final relation between the locations of the objects in world and camera frame.

3.2 *Data Fusion*

The context data acquired from all cameras are combined in the Data Fusion phase. In addition to its fusion task, Data Fusion also constructs the graphical representations of the combined context data. By using these representations, a user interface displays images of the system results for a convenient user interaction. There are two phases of the Data Fusion, namely tag level fusion and object level fusion.

3.2.1 *Tag Level Fusion*

The same tag can be detected with more than one camera, or one camera assigned to multiple instances of the "sensing core" (to be discussed in section 4). This will eventually generate repeated tag records coming from multiple cameras (or "sensing cores") in the system. Data Fusion combines these records by taking the identification time and uncertainty data into account. Most up-to-date and certain information is selected as the final, unique tag information. Time and uncertainty are assigned by "sensing core" right after the object identification. Uncertainty is generated with respect to the pose data (particularly, the parameters of the reference tag ellipse). This provides information about the accuracy of the location sensing.

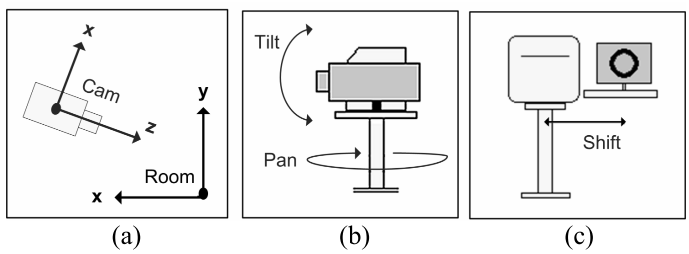

Figure 6. a) Camera parameters are important to define the transformations. b) If P/T unit is involved, pan and tilt angles must also be considered. Most P/T devices are manufactured with built-in potentiometers that provide the angle values. c) Position of the camera on the P/T unit is not negligible

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As distance and incidence angle increase (as reference ellipse gets smaller and diverges from a circle), the deviations of the location information from the real values increase as well.

3.2.2 *Object Level Fusion*

The second phase of the Data Fusion is implemented in the object-level. In this phase, the (fused) tag information is transformed to object information.

When a tag-code is created (by a user interface program), the related object information (name, description, dimensions, etc.) is also entered. Additionally, the location of the tag on the object is defined. Therefore, the system is aware of the object information with the identified tag-code and can generate the graphical representation of the object from the object dimensions and tag location.

The system also enables the attachment of multiple tags on a larger object to reduce the occlusion possibility and to increase the line-of-sight between tags and cameras. This requires the second level fusion in order to prevent redundant object records when both tags are identified. As with tag-level fusion, the most up-to-date and certain information is selected as the final, unique object information.

3.3 *Communication Interface*

Output of the Data Fusion, i.e. the final, consistent context data, is transformed into XML-like data packets for convenient data communication, and transferred to the Lighting Control System through the Communication Interface. The communication is established with a TCP/IP socket server implemented in the interface that enables the connection of not only the main system but also any other third party applications that can prospectively download and process the data packets. Communication Interface conveys the context data to the clients in the course of the first connection and afterwards, whenever a change occurs in the environment.

4 SOFTWARE PLATFORM

In order to cover the distinct activities of the location and context sensing in a common software platform and to simultaneously fulfill the requirements of a sensing technology adaptable to the building environment, the VIOLAS platform is designed in a distributed structure, with the components tied together via internet. Communication and data sharing is facilitated by the Distributed Component Object Model (DCOM) protocol that enables software components to communicate directly over a network (DCOM 2004). This design enables efficient resource utilization and permits load balancing and information sharing derived from the parallel operation and remote data access. Distributed structure provides scalability and incremental growth, in addition to enhanced performance resulting from the parallel operation.

Based on the above structure, VIOLAS resides on a distributed platform, divided into server and client tiers (Fig. 7). The server tier is comprised of an application server that achieves the resource management and data integration, a user interface server that performs web-based user interaction, and a database server that handles data management. The application server is the heart of the system. It controls the distributed components including the sensors (resources) and clients (consumers). As mentioned in section 2.1, netcams are used as visual sensors that fit in this structure by conveying video images like as distributed network devices. Clients are the Image Processing Units (IPUs). They wrap the "sensing core" described in section 2 (including Coordinate Transformation described in section 3.1) and interpret input images. IPUs are implemented on different computers scattered across a facility. Results obtained from multiple IPUs are combined in the application server and subsequently transferred to the Lighting Control System. This combination process is performed by Data Fusion and data transfer is accomplished by Communication Interface, both implemented in the application server. Result displays are also generated in the Data Fusion phase as mentioned in section 3.2, and relayed to the users through the user interface server. This server allows for web-based access from every computer on the Internet.

An additional function of the application server is to control the status of the distributed components and dynamically assign active netcams to active IPUs in such a manner that the workload is constantly balanced within the system. This arrangement provides a kind of "self-organizing" capability

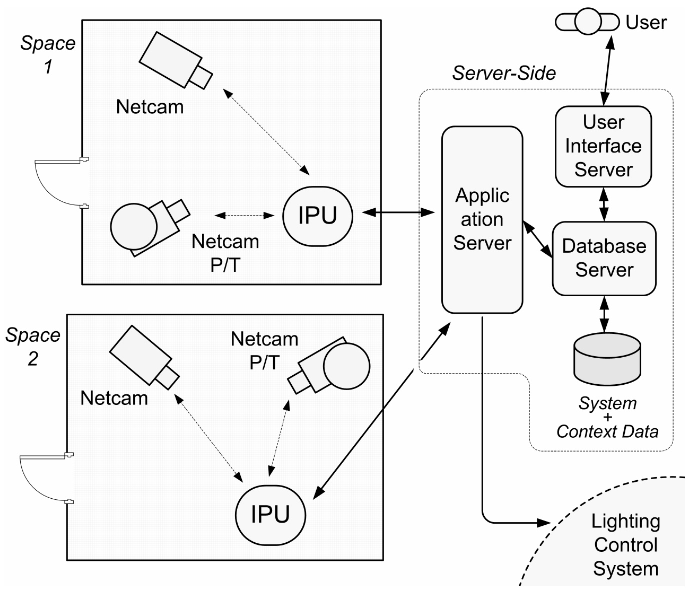

Figure 7. Distributed software platform of VIOLAS. Distinct sensing activities are collaborated under a common self-organized model

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by minimizing operator overhead. It also enables the utilization of *a)* multiple cameras by a single IPU in a resource-rich configuration, or *b)* a single camera by multiple IPUs in a customer-rich configuration. A resource-rich configuration can increase the coverage area of the system, whereas a customer-rich configuration can augment the system speed.

5 A DEMONSTRATIVE TEST SPACE

To evaluate the performance of VIOLAS, a demonstrative test was performed. Thereby, the accuracy of object identification and location sensing were observed. Towards this end, a typical office environment (test-bed) was used that involves 26 tagged objects relevant for the Lighting Control System. A 2-D sketch of the test-bed is illustrated in Figure 8. The ground-truth data (actual location information) of the objects were measured for the test (Table 1).

VIOLAS was then instantiated with a single netcam - P/T pair and the results were recorded. The system achieved a 100% identification performance, extracting all tag-codes and recognizing all objects (Table 2).

To evaluate the test results, "position error" is defined as the distance between the ground-truth position and the sensed position of the tag. "Orientation error" is defined as the angle between a plane's true surface normal and the sensed surface normal.

Table 3 includes, for our test, the resulting position and orientation errors together with the respective camera-tag distances. Table 3 includes also the position errors in relative terms (in percentage of camera-tag distance).

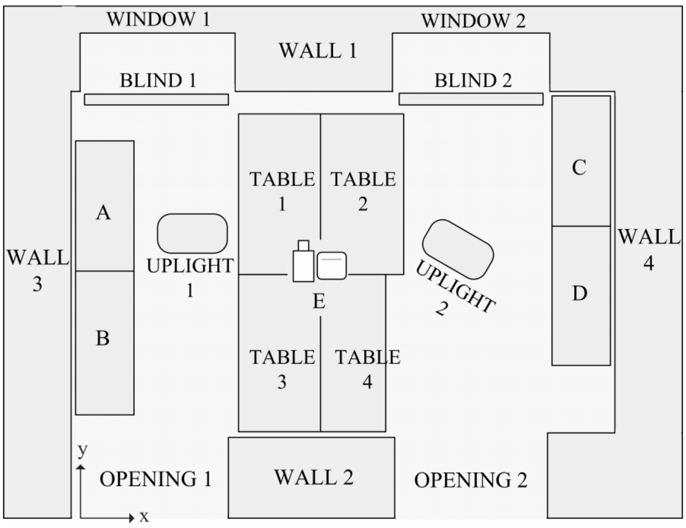

Figure 8. 2-D sketch of the test-bed. 'A' refers to Cabinet-3 and Upper-Cabinet-2, 'B' refers to Cabinet-4 and Upper-Cabinet-3, 'C' refers to Cabinet-1 and Upper-Cabinet-1, 'D' refers to Cabinet-2, 'E' refers to Camera and P/T unit

Table 1. Ground-truth data of the objects in the test-bed. Orientation is denoted with the normal vectors of the tag planes. This vector represents the orientation of the tag expressed in the room coordinate system

Object Name	Position (m)			Orientation		
	Tx	Ty	Tz	Nx	Ny	Nz
BLIND 1	1.04	4.25	3.38	0	-1	0
BLIND 2	4.03	4.25	3.38	0	-1	0
CABINET 1	5.16	3.1	1.42	-1	0	0
CABINET 2	5.16	1.9	1.42	-1	0	0
CABINET 3	0.44	3.69	1.42	1	0	0
CABINET 4	0.44	2.5	1.42	1	0	0
CEILING	4.1	1.25	4.05	0	0	-1
FLOOR	0.12	0.1	0	0	0	1
TABLE 1	1.95	2.55	0.73	0	0	1
TABLE 2	1.95	0.94	0.73	0	0	1
TABLE 3	3.35	3.94	0.73	0	0	1
TABLE 4	2.75	0.94	0.73	0	0	1
UPLIGHT 1	1.4	2.89	1.75	0	0	-1
UPLIGHT 2	4.24	2.44	1.75	0	0	-1
UPPER CABINET 1	5.16	3.1	2.16	-1	0	0
UPPER CABINET 2	0.44	3.69	2.16	1	0	0
UPPER CABINET 3	0.44	2.5	2.16	1	0	0
WALL 1	2.55	4.33	1.28	0	-1	0
WALL 2	2.55	0.8	1.28	0	1	0
WALL 3	0	1.43	3	1	0	0
WALL 4	5.6	2.8	1.89	-1	0	0
OPENING 1	0.85	0.8	3.5	0	1	0
OPENING 2	4.1	0.8	3.5	0	1	0
WINDOW 1	0.8	5.11	2.6	0	-1	0
WINDOW 2	3.95	5.11	2.6	0	-1	0

Table 2. Sensed location values of the objects in the test-bed recorded by VIOLAS

Object Name	Position (m)			Orientation		
	Tx	Ty	Tz	Nx	Ny	Nz
BLIND 1	0.94	4.13	3.32	0.03	-1	-0.01
BLIND 2	4.01	4.28	3.26	0.07	-0.99	0.08
CABINET 1	5.08	3.22	1.31	-1	0.05	0.05
CABINET 2	5.2	2.04	1.31	-0.99	-0.12	-0.02
CABINET 3	0.5	3.6	1.38	1	0.01	0.02
CABINET 4	0.53	2.43	1.36	1	0.02	0.07
CEILING	4.38	1.25	3.79	-0.21	0.12	-0.97
FLOOR	0.26	0.09	-0.07	-0.01	-0.02	1
TABLE 1	1.97	2.54	0.75	0.01	0.05	1
TABLE 2	2.04	1.02	0.72	-0.01	-0.02	1
TABLE 3	3.27	3.9	0.73	0.03	0	1
TABLE 4	2.82	1.07	0.74	-0.01	-0.02	1
UPLIGHT 1	1.51	2.82	1.67	0.04	0.05	-1
UPLIGHT 2	4.19	2.5	1.64	-0.05	-0.03	-1
UPPER CABINET 1	5.17	3.22	1.77	-0.97	0	0.25
UPPER CABINET 2	0.47	3.59	2.07	1	-0.01	0.03
UPPER CABINET 3	0.49	2.41	2.06	1	0.02	0.03
WALL 1	2.49	4.23	1.24	0.06	-1	0.05
WALL 2	2.65	0.91	1.2	0	1	0.07
WALL 3	0.04	1.22	2.91	1	0.1	0.02
WALL 4	5.6	2.97	1.75	-0.99	-0.02	0.11
OPENING 1	1.02	0.65	3.34	-0.05	1	0.06
OPENING 2	4.33	0.9	3.22	-0.03	1	0
WINDOW 1	0.82	4.96	2.47	0.08	-1	0.03
WINDOW 2	3.9	5.13	2.47	0.02	-1	0.03

As Table 3 shows, position errors increase with camera distance. Table 4 shows the average and maximum position and orientation errors for different camera-tag distance bins. The system possesses

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an average position error 0.18 m and orientation error of 4.2° on aggregate. The position error percentage has a mean value of 7.3% (Table 4).

The graphical representation of the test bed, as generated by the Data Fusion and displayed by the user interface server, is illustrated in Figure 9.

Table 3. Position and orientation errors of the objects sorted with respect to their camera distances

Object Name	Dist. to Cam (m)	Position Error (m)	Position Error (%)*	Orientation Error (°)
TABLE 1	0.70	0.03	4.3	2.9
UPLIGHT 1	1.21	0.15	12.6	3.7
TABLE 3	1.65	0.09	5.4	1.7
TABLE 4	1.69	0.15	8.8	1.3
WALL 1	1.75	0.12	7.0	4.5
TABLE 2	1.76	0.12	6.9	1.3
UPLIGHT 2	1.78	0.13	7.6	3.3
WALL 2	1.82	0.17	9.3	4
CABINET 4	2.08	0.13	6.2	4.2
UPPER CABINET 3	2.26	0.14	6.4	2.1
CABINET 3	2.32	0.12	5.0	1.3
UPPER CABINET 2	2.49	0.14	5.5	1.8
CABINET 2	2.50	0.18	7.3	7
CABINET 1	2.68	0.18	6.8	4
UPPER CABINET 1	2.83	0.41	14.4	14.5
BLIND 1	3.01	0.17	5.6	1.8
BLIND 2	3.05	0.13	4.1	6.1
WALL 4	3.18	0.22	6.9	6.4
WINDOW 2	3.23	0.14	4.4	2.1
WALL 3	3.28	0.23	7.1	5.8
WINDOW 1	3.3	0.20	6.0	4.9
OPENING 2	3.34	0.38	11.3	1.7
OPENING 1	3.35	0.28	8.3	4.5
CEILING	3.49	0.38	10.9	14
FLOOR	3.69	0.16	4.3	1.3

* Position error in percentage of camera-tag distance.

Table 4. The average and maximum position and orientation errors for different camera-tag distance bins

Error values	Camera-tag distances (m) 0..1	1..2	2..3	3..4	*All Dist.*
Position Error (m)					
AVERAGE	0.03	0.13	0.19	0.23	*0.18*
MAXIMUM	0.03	0.17	0.41	0.38	*0.41*
Position Error (%)					
AVERAGE	4.3	8.2	7.4	6.9	*7.3*
MAXIMUM	4.3	12.6	14.4	11.3	*14.4*
Orientation Error (°)					
AVERAGE	2.9	2.8	5	4.9	*4.2*
MAXIMUM	2.9	4.5	14.5	14	*14.5*

The test was performed with a 800×600 resolution IQeye™ camera possessing 10 mm (36° FOV) lens, f1.6 aperture and 6×6 μm effective pixel size. The P/T unit used in the test is a Bewator Mustang P25 that possesses 0.2° backlash. However, the total maximum error of the device is measured as 0.8° with the addition of quantization error of the digital-analog converter. 0.8° rotation error generates roughly 4.5 cm deviation in 3 meters.

6 CONCLUSION

The object identification and location sensing subsystems of VIOLAS are implanted within the previously mentioned software platform and were fully tested in an office environment as demonstrated in section 5. However, the work on the implementation and integration of reflectance and occupancy sensing subsystems is still in progress. Currently, VIOLAS with a single netcam and pan-tilt unit possesses an effective camera-tag distance range of 4 meters and an effective scanning area range of roughly 50 m^2. It achieves a 100% object identification performance under constant lighting conditions. The identification performance may drop down up to 85% under fluctuating lighting conditions that can reduce the contrast of the images acquired from netcams due to the intrinsic control mechanism of the cameras. The obtained results suggest that vision based sensing, when enhanced computationally and integrated with appropriate hardware, is a promising technology for spatial domains such as facilities and buildings.

Our future studies will focus on increasing the identification performance. Toward this end, software-based methods are being developed to selectively adjust image contrasts to compensate for changing light conditions. Moreover, prior information (and constraints) regarding the nature of the space model as well as heuristic information (and corresponding geometric reasoning) about the attributes of objects in the environment will be used to improve the location sensing performance of VIOLAS.

VIOLAS wraps the assorted sensing solutions under a common self-updating platform representing a scalable and configurable structure. We believe this provides a flexible and adaptive system that is highly suited to the requirements of indoor-environmental control applications in the built environment. The self-updating building model, as generated by VIOLAS, can provide, thus, the core of the prototypical implementation of the simulation-based control strategies in sentient buildings.

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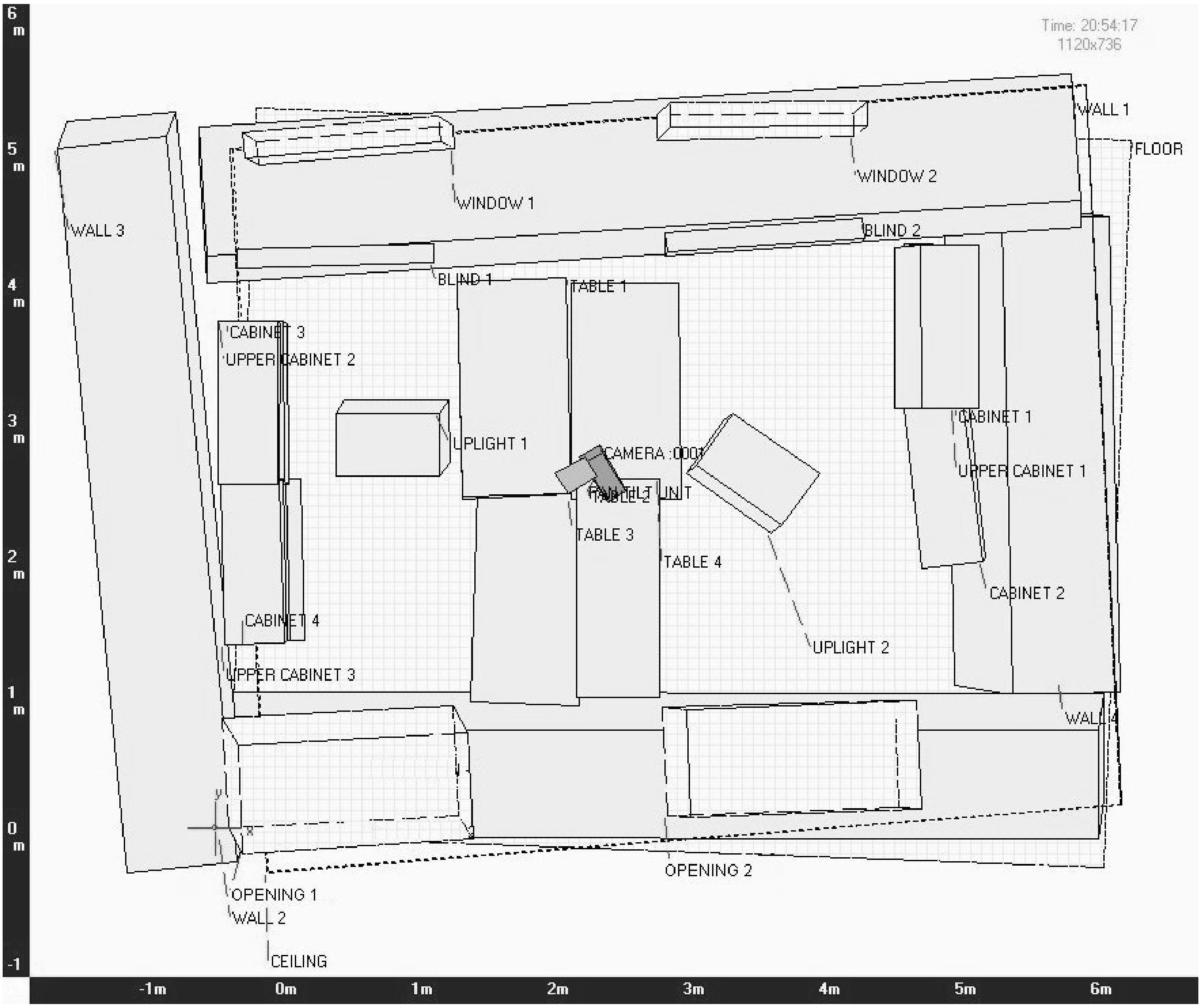

Figure 9. Graphical representation of the testbed generated by VIOLAS, after the execution of the test. The slides are caused by orientation errors that have an average value of ~5°

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The software design of a dynamic building model service

K. A. Brunner & A. Mahdavi
Department of Building Physics and Building Ecology, Vienna University of Technology, Austria

ABSTRACT: We present the software architecture and a prototypical implementation of a dynamic building model service system. The primary purpose of this model service is to support (simulation-assisted) indoor-environmental control operations in buildings. However, as a comprehensive, structured, sensor-based, and self-updating information resource, the model can support other building tasks such as those concerned with building logistics and management. At the core of our model service design, an object tree continuously updated from sensor data reflects the current state of the building, concurrently accessible to multiple clients and backed by persistent storage. The service is embedded in a distributed infrastructure based on tuple spaces for transparent object-based communication between system components. The preliminary evaluation of the model service system suggests that the proposed design is feasible and appropriate for further testing in realistic (large-scale) settings.

1 INTRODUCTION

This paper presents a software design for dynamic building model services. As such, it represents a component of ongoing work on a larger research project toward realization of sentient buildings (Mahdavi 2004). Sentient buildings possess an internal, dynamic, and self-updating representation (model) of themselves. They use this model to support various services and operations. The research project focuses on the application of such internal models toward supporting indoor-environmental control systems of buildings (e.g. heating, cooling, ventilation, and illumination systems). Specifically, we have been investigating the potential of dynamic building models to enable simulation-based building control strategies (Mahdavi 1997, 2001, Clarke et al. 2001). To identify a desirable state for a building control device, the simulation-based control method projects a number of alternative device states into the future, predicts the implications of these alternative states via simulation, compares the simulation results in view of pertinent objective functions, identifies the most preferable device state, and informs the user (or instructs a relevant actuator) toward the realization of this state. As compared with traditional control algorithms, simulation-based strategies have been shown to be highly effective in the context of built environment. This is primarily due to two circumstances: *i)* building control operation involves a large number of environmental sub-systems and a multitude of devices and networks; *ii)* buildings are subject to both dynamic contextual forces (e.g. weather conditions) and internal fluctuations (e.g. occupancy presence and actions) that are difficult to predict.

Whilst simulation-based control strategies have a number of advantages, they are not easy to implement. First, they require a fairly detailed model of the building, its systems, its context, and its occupancy. Second, given the dynamic nature of building-related processes, such a model must be continuously updated to be reliable. Advances in computer hardware and simulation algorithms have brought simulation times to a level that is useable for BEMS (Building Energy Management Systems) applications. However, creating simulation models is still, to varying extent, manual labour. The transition from initial CAD (computer-aided design) building documents to simulation models is hardly seamless and often requires additional domain-specific information and extensive post-processing. Moreover, any significant change in the building must also be reflected in the simulation models, if they are going to be of any use in the context of building systems control. Ideally, simulation-based control requires a model of the building's status that is updated without human intervention. This evidently requires an extensive sensor infrastructure in the building generating a huge amount of raw data – and consequently, software that processes these data, collating and organizing them contextually for access by other soft-

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ware. We believe that such a dynamic building model would be useful for many other purposes besides simulation-based building systems control, offering a level of abstraction and a common interface that has not been available so far.

Today, modern office buildings are often equipped with considerable networks of sensors and actuators. However, there is generally a lack of meaningful integration and open access to make full use of these available data. We therefore propose a dynamic building model service to address this need, outlining requirements and a prototype software design, and report our experiences with an actual implementation.

2 BACKGROUND

Considerable work has been done in the field of building product modelling (Eastman 1999, Mahdavi et al. 1999). Product model specifications formally describe structures and notations and thus serve as a conceptual basis for building models; however, they do not address the architecture and run-time behaviour of a building model service.

Work on communications infrastructure for sensors and actuators within buildings has resulted in many specifications and products, e.g. BACnet, LonWorks, LUXMATE and others (Bushby 1997, Sharples et al. 1999, Luxmate 2005). A building model service naturally relies on some form of communications infrastructure and should be easily adaptable to specific variants.

Recently, the integration of various control domains has become a focus of research in building energy management systems (BEMS). The EDIFICIO project (Guillemin & Morel 2001) has shown the use of soft computing techniques applied to concurrent control of heating, ventilation, and lighting. Simulation-based control has been argued for and demonstrated successfully by Mahdavi (2001) and Clarke et al. (2001). The models used in these instances were specialised to the given experimental setups and control tasks and not designed to be scalable or usable for multiple applications concurrently.

The S2 project (Mahdavi et al. 1999) demonstrated automated derivation of domain-specific models for simulation from a general building model, in a distributed environment. However, it was geared toward the design phase only and did not support simulation-based control or dynamic building model updating during its operational phase.

3 DESIGN AND IMPLEMENTATION

In this section, we outline the design of the model service and discuss its key elements. Functional and non-functional requirements for a dynamic building model service are stated in section 3.1 and previous work (Brunner & Mahdavi 2005). The most important non-functional requirements are *scalability* and *versatility*. Scalability relates to the need to handle large buildings with great numbers of spaces, sensors, actuators, and other elements efficiently. Versatility (or flexibility) means that the model service must be able to accommodate a wide range of different uses and application software: this suggests a lean core application that can be extended during run-time with additional data and behaviours as needed.

3.1 *Concepts*

An *integrated* building model comprises information on all elements of a building to a level of detail that is sufficient to support a wide range of applications, such as photorealistic rendering, occupancy monitoring, and thermal simulation. Contrary to domain-specific, parametric models such as those used in model-based control (Pargfrieder and Jörgl 2002), it must be designed to hold multi-aspect, multi-purpose data and to be openly accessible for any application through a well-defined interface.

Unlike a simple database of raw values, data are organized in the form of a well-defined *object-oriented product model* providing context and semantics.

A *dynamic building model service* is updated regularly, e.g. through sensor readings, to reflect the current state of the building as accurately as possible at all times. As it does not merely store the received data, but can also apply some processing to them or reconfigure itself if necessary, it can be seen as "self-updating". Thus, the model is not merely a description used for reference and off-line analysis; it is a live object tree to be used by any number of applications during the building's operation, processing data updates and application requests concurrently. Input data may come from a range of different sources and must be correctly placed in model context. Such data updates can happen continuously (e.g. a stream of measurement values from an illuminance sensor) and must be processed within a short timeframe to meet the requirements of control applications. Additionally, it is desirable that not just the current, but all historic states of the model are stored persistently to be easily retrieved.

3.2 *Centralised vs. decentralised architecture*

Some types of applications (e.g. thermal simulation) span the entire building, while others (e.g. lighting control for a windowless room) may be focused on just a small portion. This determines their usage patterns for building data and suggests different designs: an all-encompassing central model service allowing random access to any portion of the building,

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or multiple, loosely connected or even independent sub-model services focused on different parts of the building (Sharples et al. 1999).

The burden of model-keeping for a centralised model in terms of memory and CPU usage may be huge. A central model has to receive data from all sources in the building, essentially forming a bottleneck in the data flow. Decentralised model services could be distributed to different computers for workload distribution and shorter data paths.

Decentralisation means that it must be decided from the outset how the entire model is broken into parts. However, it is hard to find an optimal division scheme for all possible applications. While many applications lend themselves easily to a division along units such as “floor”, “apartment”, “room”, some building systems work across these lines, such as elevators or HVAC piping. Applications monitoring these systems would have to be in constant communication with multiple sub-models, increasing network traffic and CPU loads.

As versatility is a key requirement of our specification, we have opted for a centralised model design. The full current state of the model is kept in working memory of a single process on one computer. However, it is possible to extract copies of parts or the entire object tree for off-line analysis. This way, an application working repeatedly on a relatively static portion of the model can be fully decoupled from the model service.

The Java language system was chosen as our implementation platform mainly for reasons of operating system independence, good availability of third-party class libraries and mature facilities for distributed computing.

3.3 *Interconnection of system components*

In our project, the model service is part of a distributed infrastructure that comprises a number of other services that depend on or assist the model’s operation (Brunner & Mahdavi 2005). As a design guideline, we identify two types of runtime behaviour in terms of model access patterns:

a) *Batch* behaviour: a module collects some input data, performs intensive processing on it, and returns some output data. One example is model-based lighting simulation (by ray tracing or radiosity), another is spatial reasoning (e.g. to generate space boundaries from tag locations). Modules of this kind are essentially services operating on a request-response basis.

b) *Interactive* behaviour: a module keeps accessing a number of objects repeatedly, possibly reacting to events and changing the objects. It requires little processing power, but low-latency object access. One example is a lighting controller task that monitors workplaces and registers any relevant events that may occur, e.g. changes in occupancy or daylight.

Modules with *batch* behaviour benefit from distribution to keep high CPU workloads off the computer hosting the model service. To achieve this distribution, we are using a tuple spaces system based on JavaSpaces (Freeman et al. 1999). For instance, a client’s request for lighting simulation can be posted to the *service* space and subsequently picked up and processed by any connected machine running an instance of such a service. Once completed, the results are placed back into the space to be picked up by the client. This allows a simple and transparent load distribution that decouples modules in time and space as much as desirable. Neither clients nor servers need to know anything about each other except how to access the common space and the signature of the relevant request and response objects. Clients can choose a synchronous or asynchronous mode of operation: either posting requests and waiting for responses sequentially, or posting a batch of requests at once and coming back later to pick up the results. The latter scenario is particularly suited for simulation-based control programs, which frequently need to commission a set of simulations to select the best control decision.

The characteristics of modules with *interactive* behaviour suggest a different approach. It is desirable to keep these modules’ code close to the data during runtime without losing the flexibility and loose coupling of the system by hard-wiring their code into the model service. One way to achieve this goal is to design an elaborate query language for the model: the main advantage of this approach is that modules are not bound to any specific programming language, as long as they can submit well-formed query strings to the model service and process the results. However, the developer effort of translating query or program logic into an intermediary is considerable, and there would be significant communications overhead incurred by repeated queries and responses. Ideally, modules should be able to access the model just like any other Java object.

This is achieved by implementing them as *agents*, which might also be called “mobile plug-ins”. Agents are thread objects that may be submitted to the model service over the JavaSpace, where they are started inside the service process. They can directly access the object tree and use all public operations on the objects as well as a number of utility methods for traversing the object tree, retrieving historic versions, and communicating with other modules via the JavaSpace. Moreover, agents can register for events on specific objects to be notified of data updates.

As an example, the core of a heating control application can be sent to the JavaSpace, where it can examine the relevant objects, derive a number of possible control decisions and send a batch of simu-

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lation requests (containing relevant model data) to the JavaSpace. Using the results provided by one or more simulation services connected to the JavaSpace, the controller can take appropriate action (e.g. opening a valve). Further control cycles can either be triggered in time intervals or based on update events (e.g. when a temperature sensor reading rises above a threshold).

For both batch and interactive access patterns, the proposed design ensures modularity and flexibility while the specific runtime characteristics are taken into account.

3.4 *SOM objects*

We have chosen the Shared Object Model SOM (Mahdavi et al. 1999) as basis for our model. SOM defines only a core set of general attributes (mainly geometry and surface properties, and a few others depending on the object type) for the various elements of a building, as it was not designed to be a model for all conceivable building applications. Domain-specific data (e.g. the photometric characteristics of a light fixture) can be associated as separate objects if necessary.

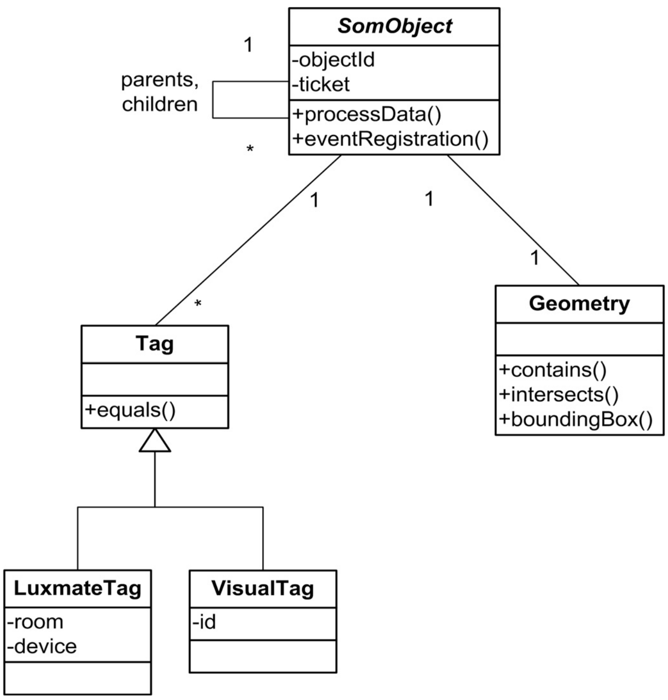

Figure 1. A generic SOM object and some of its most important associations, methods, and attributes (simplified).

Each SOM object can be associated at run-time with a number of *tags*. Tag objects represent keys for the given object: for instance, a light fixture's address in the LUXMATE device control network is one kind of tag; the ID of a physical location sensing tag attached to the same light fixture is another. In both cases, the tag object serves as a key for the model service to route incoming sensor data to the proper object. SOM objects may have child and parent objects (Figure 1).

Note that, while we use SOM as the underlying building model, the proposed software design does not preclude the use of other models (such as IFC). As our past research has shown, SOM classes can be effectively mapped to IFC classes, thus ensuring the interoperability of our developments with IFC-compliant applications (Lam et al. 2003).

3.5 *Sensor and actuator communications*

As input data may come from a variety of source at the same time, multiple threads can be working on reading data and routing it to the proper objects, based on their tags. For our experimental setup, we use a separate JavaSpace that holds data from different sources, such as illuminance sensors and an indoor location sensing system (Icoglu et al. 2004, Brunner & Mahdavi 2005). Distributed sensors push data objects to the space which are picked up by the model service.

The primary task of the input worker threads is to find the relevant SOM objects (based on their associated Tags) and call their *processData()* method. This method decides if and how incoming data is processed, which may result in updates on the object's data or the creation and deletion of new child objects. With the help of location sensing data, new objects can, to some extent, be automatically included in the building model: a temperature sensor that is marked with a location sensing tag will be represented by a new SOM object and attached to the proper space as soon as both location sensing and sensor reading data are available. We plan to reach a further degree of automation through spatial reasoning to automatically discover the boundaries of spaces (Suter et al. 2005).

To handle new sensor data types, data handler objects can be dynamically registered with the model service at runtime. These are used if a SOM object signals that it is unable to process the received data.

For actuators, SOM objects also serve as interfaces to initiate physical change. For instance, an agent can change the dimming level of a light fixture by calling the *commandDimmingLevel()* method on the appropriate *LightFixture* object. This method sends the appropriate commands to an output worker thread, which in turn passes them on to the physical device.

3.6 *Persistent storage and retrieval*

The model service is backed by a relational database for persistent storage, handled by an *ObjectStorageManager* component. Each SOM object carries a unique object ID and a *ticket* obtained from a global, strictly monotonously increasing counter.

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3.6.1 *Storing and retrieving single objects*

When an object's data are modified through a *set()* operation, a new ticket value *v* is obtained from the counter and set in the object. A new table row is then inserted into the database, containing a copy of the object as a byte array created by the Java object serialization mechanism, and the object ID and ticket value as key attributes for later retrieval. Associations to parent and child objects (which are normal Java references) are converted to object IDs before storage. To reduce delays, database storage is executed by a separate background thread. A mapping of tickets to clock time is kept for later queries.

If the state of an object at a given clock time *t* is requested, first the corresponding ticket value *v* is retrieved. Due to the limited resolution of clock timekeeping (milliseconds), multiple ticket values may exist for each point in time – in this case, the highest value will be chosen. The database is then queried for the row with the given ID and the highest ticket value that is less than or equal *v*, and the object version is retrieved from the database und unserialized. As opposed to the latest, in-memory version of an object, older versions are immutable and cannot be changed or used to send actuator commands.

This storage scheme is based on the principles of multiversion databases (Easton 1986).

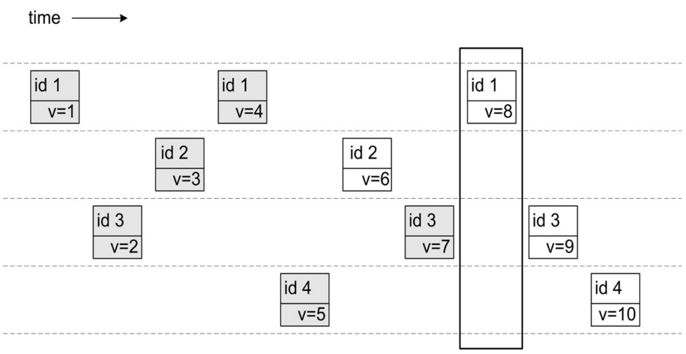

Figure 2. Four objects changing over time. At the time instant corresponding to ticket value 8, object 1 is changed. At the same point in time, the most recent versions of objects 2, 3, and 4 had the tickets 6, 7, and 5, respectively.

3.6.2 *Storing and retrieving multiple objects*

Certain operations must be grouped atomically to avoid inconsistent tree states. E.g. if a SOM object is moved from one space to another, it must be detached from the original parent object and attached to the new one, creating an intermediate step when the object is either not attached to any space, or attached to both spaces at the same time. To avoid this situation, a sequence of operations can be grouped in one ticket.

Obtaining a consistent view of a sub-tree from an object tree that is concurrently changed by other tasks (updating object data or adding or removing new objects) usually requires special measures. One way of ensuring that the object tree does not change while a client operation is traversing it is *locking*: entire parts of the tree are temporarily blocked from changes until the reading task has finished, resulting in frequent delays when many tasks are accessing regularly changed subtrees.

The storage and retrieval method outlined above offers an alternative approach that follows naturally from the single-object retrieval procedure, in the pattern of an overlapping tree (Burton et al. 1990). Assume that an application wants to traverse a subtree beginning with the root object O_1, iterating through its child objects recursively. To obtain the state of the subtree at a given time instant, it must select a ticket value v_{max} that serves as the upper bound of all ticket values in the subtree. To obtain the most recent version of the subtree (at the time of beginning the traversal), it can query the ticket counter for its current value. From then on, it recursively queries O_1 and its child objects based on the condition that the ticket value of each object must not be greater than v_{max}. If an in-memory object does not fulfil this condition (because it has changed in the meantime, resulting in a new version), the latest version with a ticket value less than or equal v_{max} is restored from the database. An example is illustrated in Figure 2.

4 EVALUATION

The aim is to test *i)* whether the chosen design and implementation work correctly so that the general requirements for a dynamic building model are fulfilled and *ii)* to test the performance of the system in a small-scale setup to estimate its scalability potential to larger setups. An overview of the system and some of the main modules used in our project is given in Figure 3.

4.1 *Experimental setup*

We are monitoring and controlling lighting in an office space with two workspaces, equipped with two dimmable uplights and two motorised Venetian blinds.

Indoor and outdoor sensor data are collected by LabView applications; actuator commands and status information pertaining to light fixtures and the motorised shading are communicated via the LUXMATE bus. A location sensing system tracks the positions of furniture and light fixtures with attached optical markers (Icoglu et al. 2004) and supplies its data over a TCP/IP connection. Additionally, the sky luminance distribution is measured through the use of a digital camera (Mahdavi and Spasojević 2004). All these data are collected and communicated as objects through a *data space* that decouples data producers and consumers.

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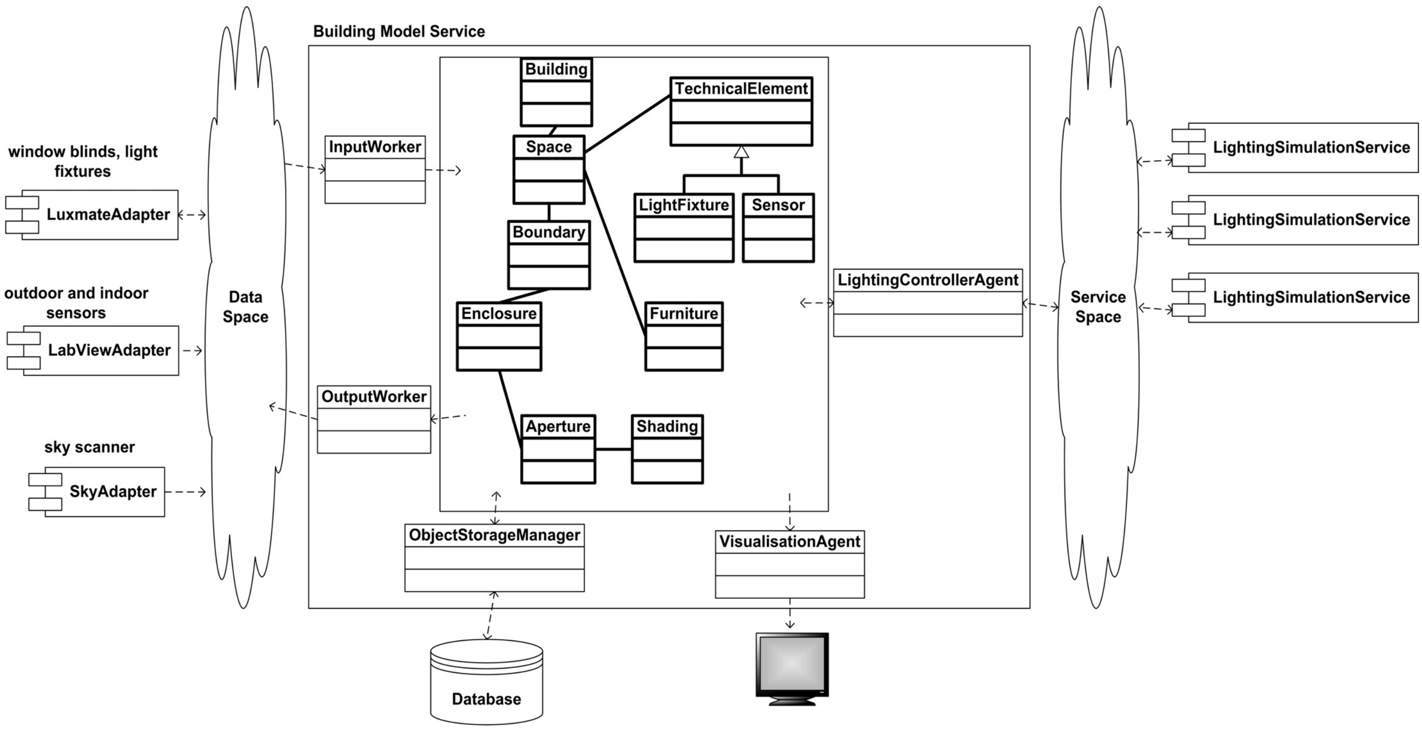

Figure 3. Overview of the building model service and its context within the experimental setup (simplified).

A commercial JavaSpaces implementation (GigaSpaces) is used for the data space and service space. The runtime locations of modules communicating over the spaces are fully transparent: any module can be run on any connected computer without configuration or code changes.

The lighting simulation package RADIANCE (Ward 1994) is used to evaluate the effects of control decisions regarding shading devices and light fixtures through a thin service "wrapper" that handles JavaSpace communications. Multiple instances of this service are started to achieve transparent processing load distribution. However, the granularity of this scheme is limited to one full simulation run: distributing the load of one simulation over multiple computers is only possible if the simulation package itself supports this.

A visualisation module based on Java3D is used to show the model's current geometric configuration as a three-dimensional rendering. It is implemented as an agent that uses the event registration facility to update itself as soon as geometry changes in the monitored objects are registered.

The model service, the relational database (PostgreSQL 8.0) and the JavaSpaces (GigaSpaces) are executed on a dedicated server equipped with an AMD Athlon MP 2000 processor and 1 GB of RAM.

The lighting controller is implemented as an agent that periodically evaluates the current lighting situation, selects a fixed number of possible control scenarios (i.e. changes of shading and electric lights) and commissions one simulation for each scenario. Simulation results are then ranked according to a utility function to select and execute the control decision. The lighting control algorithm is outlined in more detail in (Mahdavi et al. 2005).

4.2 *Results*

The full model of our experimental space is represented by about 80 objects during runtime. On average, about 30 sensor readings are arriving per second (with occasional peaks of up to 100), resulting in the same number of changes to various object attributes and database write operations.

Latency (the interval between the instant of reading a measurement from the sensor by e.g. LabView and the instant it becomes available in the model service for client applications) has been consistently below 500 milliseconds, including network communication overheads. CPU load on the model service host (defined as the percentage of processor time available to an idle priority process) remained below 15 percent on average. The model service has cumulated sensor data over the course of months reliably, resulting in close to 8 Gigabytes of database records. History queries on single objects (retrieving the state of an object at a given point in the past) take about 1 second on this database.

On our available hardware, lighting simulations take between 10 to 20 seconds each, depending on the level of input detail and simulation parameters. Batch lighting simulation requests of 16 simulations each were processed by up to 4 connected machines with RADIANCE installations. The load distribution has worked well, cutting total simulation times in di-

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rect proportion with the number of participating machines.

5 FURTHER WORK

Our building model service and applications are still a work in progress. While small-scale tests have been successful, performance and reliability tests using an actual or simulated large building are desirable to further evaluate and refine the chosen design. We are planning to build a framework for profiling and simulating varying loads in order to derive a formal performance model of the system and its key components.

The model service currently lacks a spatial indexing mechanism and offers only rudimentary spatial queries on the model. We are investigating suitable spatial indexing methods and the use of a spatial function library to add these important features. Work on the reconstruction of space boundaries from location information supplied as "tag" locations is to be integrated into the model service (Suter et al. 2005).

Retrieving snapshots of model subtrees with many frequently changing objects (according to the procedure outlined in 3.6.2) can be inefficient, as many database accesses to retrieve just recently changed objects may be necessary. We are working on a cache layer between the current model and the database that keeps recently changed object versions in memory for fast access.

The current design does not address any security aspects, relying on existing network infrastructure for access control: any system able to connect to the JavaSpace can submit an agent to the model service and change model data. In a real-world scenario, various access restrictions on the model service (such as object ownership and capabilities) would be necessary.

6 CONCLUSION

We have outlined the requirements for a dynamic building model service, and have described a prototype design and implementation. An experimental application running simulation-based lighting control for an office space has been implemented. Our preliminary evaluation has shown that the chosen design is feasible and has the potential for being tested in larger-scale configurations.

While originally driven by the requirements for simulation-based control, we expect dynamic building model services to be a valuable foundation for a wide range of different applications in building operation and management.

ACKNOWLEDGEMENT

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Merging Building Automation Network Design and IFC 2x Construction Projects

A. Karavan
Institute for Applied Computer Science, Dresden University of Technology, Dresden, Germany

M. Neugebauer
*Institute for Applied Computer Science, Dresden University of Technology, Dresden &
SAP Research Group Dresden, Dresden, Germany*

K. Kabitzsch
Institute for Applied Computer Science, Dresden University of Technology, Dresden, Germany

ABSTRACT: Currently, different design tools and databases are used for building automation networks and construction projects. Effort (design time, tools) can be reduced if these two design spaces can be merged. In this paper an approach for the integration of building automation network design in IFC 2x is introduced. Based on the resulting model, existing tools are to enhance in order to accomplish a holistic design approach for construction projects.

1 INTRODUCTION

Today, building automation networks are designed using standardized tools and data bases. The model structure of a building automation network with all required components (i.e. sensors, controllers, actuators) is created with graphically supported tools (i.e. LonMaker, see Figure 1). All necessary connections between the components on different layers (application and physical layer) are carried out within these tools. Even deployment (configuration of real components according to model structure) and maintenance (network monitoring, deployment of additional functionalities and devices, etc.) are facilitated by these tools.

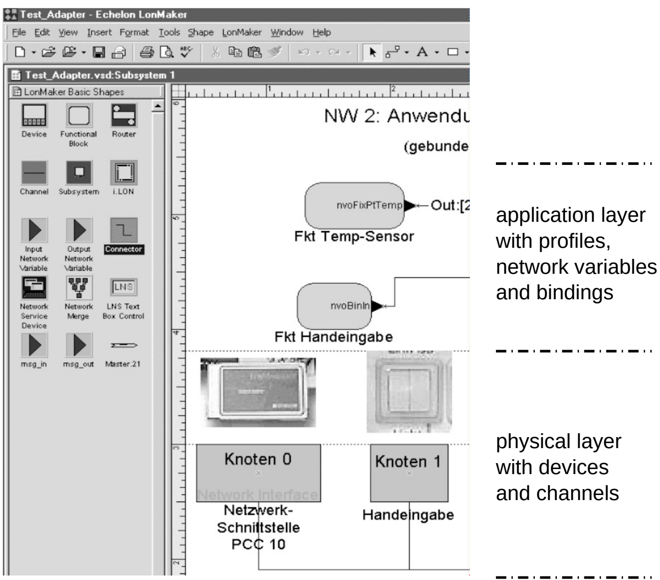

Figure 1. LonMaker for graphically supported design of building automation networks.

There are certain similarities between the approaches used for designing building automation networks and construction projects. The LNS Network Operating System (Echelon 1999) is the quasi standard data base for design and deployment of building automation networks used by different parties involved. Therein, the complete information about the structure of the network on different layers is contained. The aim of IAI's IFC 2x (IAI 2005) is about the same in a different application area: a common standard to exchange information among various parties involved in a construction projects (i.e. spatial structure, walls, building services elements).

So far, the two design approaches for building automation networks and construction projects are carried out in two different tool worlds. According to the data on which the structures rely on there is no connection, except a drawing delivered from the architect to the building automation network designer. There are no basic approaches for interoperability guidelines that could enable seamless integration of building automation network structures in construction projects.

In this article we show an approach for future design methodologies and tools to integrate building automation network design and therewith to enable a comprehensive building model including the automation facilities (Schach et al. 2002). Especially, the similarities in current tool domains (building automation networks and construction projects) are elaborated in order to enable merging of different design approaches. Hence, the existing model structures in building automation networks have to be reused and integrated in IAIs IFC 2x.

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In Section 2 and 3 LonWorks technology and IAIs IFC 2x are introduced. Concepts for merging the two design methodologies are discussed in Section 4 and explained in more detail with an example in Section 5.

2 LONWORKS AS A BUILDING AUTOMATION NETWORK

Building automation is a fast growing market. It proposes now open and interoperable solutions (Dietrich at al. 2001). One of the leading networking standards in this shift is the LonMark standard, based on LonWorks control network technology.

A LonWorks network consists of intelligent devices that communicate with each other using a common protocol over one or more communication channels (Fig. 2). Each device includes one or more processors that provide its intelligence and implement the protocol. Each device also includes a component called a transceiver to provide its electrical interface to the communication channel. Transceivers are available for a variety of communication media including single twisted-pair cable, power line, radio frequency (RF), infrared, fiber optics, and coax cable (Echelon 1999).

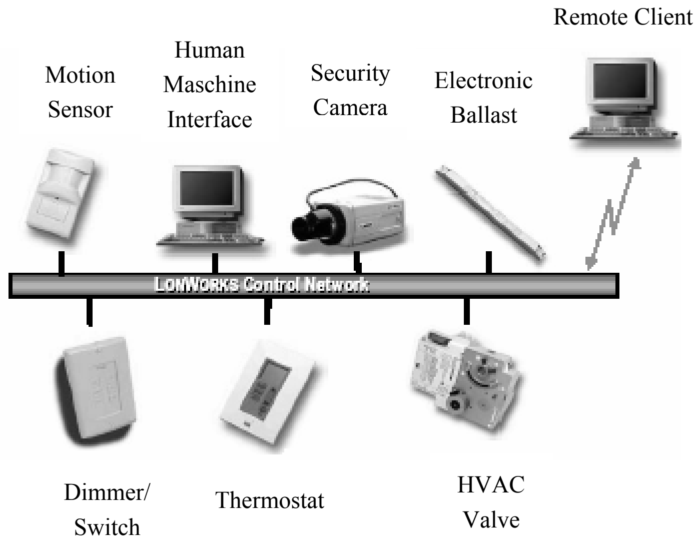

Figure 2. LonWorks network.

The LonWorks protocol, also known as the LonTalk protocol and the *ANSI/EIA 709.1 Control Networking Standard*, is the heart of the LonWorks system. The LonWorks protocol is a layered, packet-based, peer-to-peer communication protocol. The seven layers along with the corresponding services are provided by the LonWorks protocol.

The LonWorks protocol implements the concept of network variables**.** Network variables simplify the tasks of designing LonWorks application programs for interoperability with multivendor products and facilitate the design of information-based, rather than command-based, control systems.

Via a process that takes place during network design and installation called binding, the device firmware is configured to know logical addresses of the other devices or groups of devices in the network. The binding process creates logical connections between an output network variable in one device and an input network variable in another device or group of devices. Connections may be thought of as "virtual wires" (Fig. 10).

Every network variable has a type that defines the units, scaling and structure of the data contained within the network variable. A set of standard network variable types (SNVTs) is defined for commonly used types.

LonWorks Network Services (LNS) architecture is important for the LonWorks protocol. LNS provides an object-oriented programming model and brings the power of client-server architecture and component-based software design into control networks (Fig. 3). LNS enables to install, maintain, monitor and control LonWorks networks (Echelon 2004).

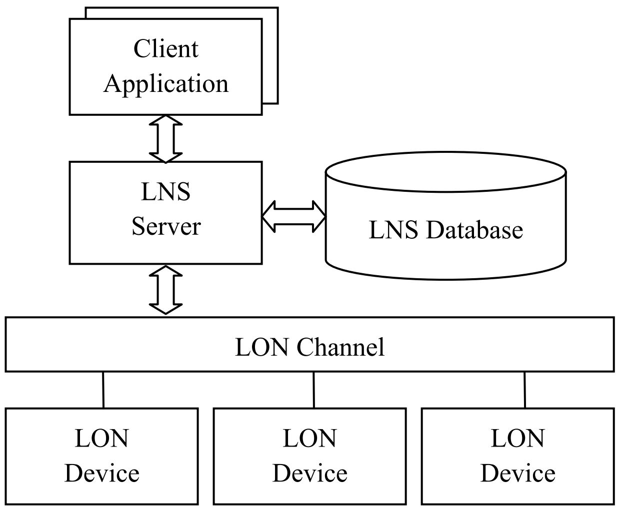

Figure 3. LNS architecture.

The LNS Object Server defines a set of objects, properties, methods and events that represent the physical attributes of networks and their configurations. LNS Object Server is a COM server that provides an interface, independent of any programming language, to the LNS Server and the LNS database.

The objects are grouped together in a hierarchical fashion (Fig. 4), such that the *ObjectServer* object is at the top of the hierarchy. The *ObjectServer* object contains a collection of *Network* objects, each of which represents a network defined in the database. Each *Network* object contains a *System* object representing the network's system, and each *System* object contains a set of *Subsystem* objects that represent logical or physical partitions of that particular network. Each *Subsystem* object contains a collection of *AppDevice* objects which represent the application devices defined in that subsystem.

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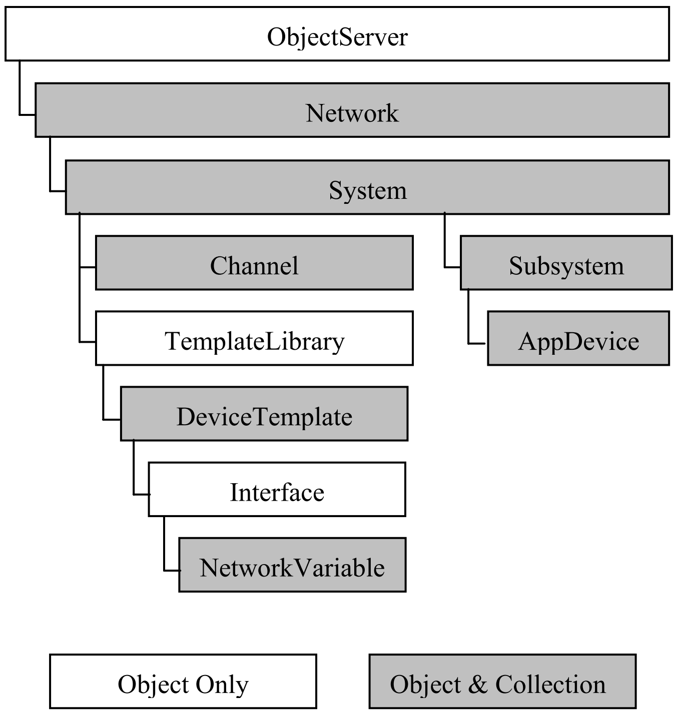

Figure 4. LNS Object Server hierarchy.

For example, the user must set up a network to control a building with three floors. The user can define three subsystems within the network, so that the user can logically group the devices on each floor separately. The user can also set up additional subsystems representing different rooms on each floor of the building.

As the subsystems are logical divisions of a network, and devices can belong to multiple logical divisions, the user can create multiple subsystems that cross-reference a network, and add individual devices to each of them. In this manner, devices can appear in multiple subsystems. For example, the user can create one subsystem to represent the physical layout of network, and another one to represent the functional layout (i.e. HVAC, lighting, etc.).

Table 1. Properties and methods of LNS objects.

AppDevice	**Subsystem**
- AttachmentStatus - Channel - Handle - Name - NeuronId - SubnetId - Subnets - Subsystems	- AppDevices - ClassId - Description - Extension - Handle - Name - RouterDevices - Subsystem
+ Load + Reboot + Replace + Reset + Test	

Each one of the object types defined in the LNS Object Server includes its own set of properties and methods (Table 1). Properties contain information defining the current configuration and operational behaviour of an object. Methods provide a mechanism to perform various operations on each object.

3 IFC AS A SHARED PROJECT MODEL

IFC (Industry Foundation Classes) is the set of internationally standardized object definitions (ISO 2005) for use in the building industry developed by the International Alliance for Interoperability (IAI 2005).

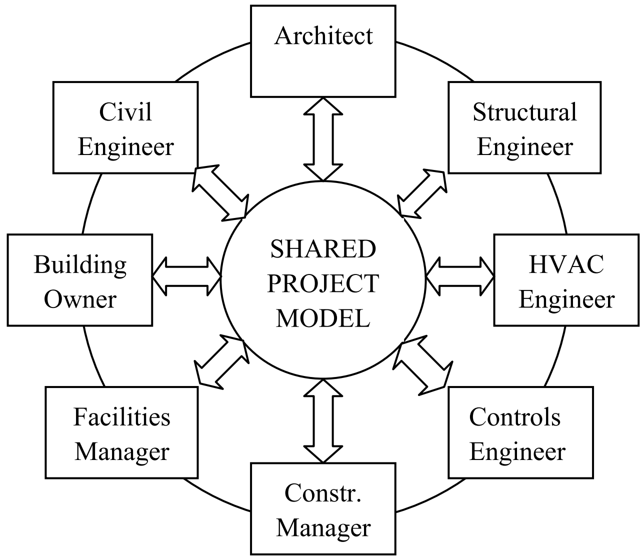

Figure 5. Shared project model for building.

IFC is an universal language to improve the communication throughout the design, construction, operation and maintenance life cycle. The IFC concept is based on the idea of objects brought together in an integrated model. These objects are defined to support the whole lifecycle of facility development from inception through design, then facility management and finally demolition (Fig. 5).

Objects in IFC in addition to the full geometric description in 3D have also location and relationships, as well as all the properties of each object.

IFC contains not only physical properties, but also spatial concepts such as floors and rooms (Liebich 2004).

The following three different concepts are subsumed under the *IfcSpatialStructureElement* (Fig. 6):

- Building
- Building Storey
- Space

These different entities contain each other such as they provide a clear hierarchical structure for the building project. The three subtypes *IfcBuilding*, *IfcBuildingStorey*, *IfcSpace* are used to represent the levels of the spatial structure. The spatial structure is created by using the fundamental decomposition relationship. The subtype *IfcRelAggregates* is used

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to link the instances and establishes a hierarchical structure.

IfcBuilding is used to provide additional information about a building itself. The building includes the references to the building storeys belonging to that building or it can have building sections.

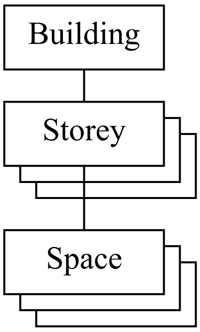

Figure 6. Spatial structure of a building.

IfcBuildingStorey is used to provide information about a building storey itself, a vertical structure normally used with building and construction. The building storey includes the references to the spaces belonging to it.

IfcSpace is used to provide information about the space as a functional area or volume with a spatial structure. Spaces normally contain all building services or interior design elements (such as distribution elements, electrical elements, furniture). The space boundaries define the relationship between the space and its bounding elements.

4 INTEGRATION PLATFORM CONCEPT

As it has been mentioned in Section 4, the LNS model represents the structure of the LonWorks automation network, and IFC model - the structure of the building. These models are created by means of different tools saved in various databases and have different interfaces to data.

By creation of a new project of the building automation network, the user repeats operations which have already been done by the user of the CAD system and results are kept in IFC model (definition of subsystems: floors, rooms and systems of lighting, ventilation, heating). For the process acceleration of the building automation network design, it is expedient to integrate LNS model in IFC model, as more general and universal one. The holistic model also can be used for more detailed modelling of various processes in the building.

For the planning architecture of the building and its life-support systems various CAD systems are used. These systems support import and export of the IFC data model. These systems have also their own API with which it is possible to expand functionalities at the program level. Some CAD systems, such as ArchiCAD and ADT (Geiger 2001), support import and export of IfcXML format that is necessary for integration.

For the integration of two models we propose the following approach:

1. integration on the basis of an existing automation network model;
2. integration on the basis of the creation of a new automation network model.

4.1 *Integration on the basis of an existing automation network model*

This kind of the integration implies that the model is created by other tools (e.g. LonMaker) and stored in the LNS database. As mentioned above, CAD systems (e.g. ArchiCAD) support the import of IFC data. There are two basic methods for such data exchange: the IFC (STEP) file and the IfcXML file. For the construction of the IFC model on the basis of the LNS database, it is possible to use XML (Fig. 7).

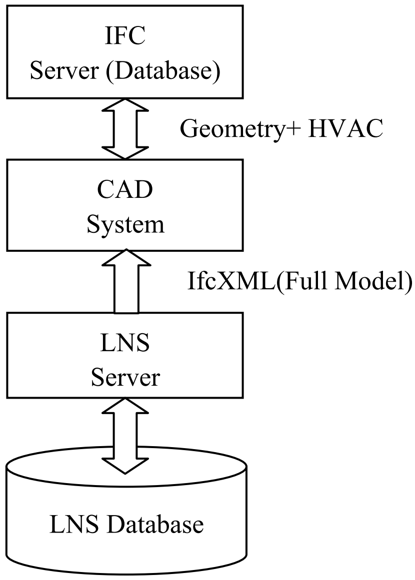

Figure 7. Integration on the basis of existing model.

Integration process proceeds as follows. Necessary data are read out from the LNS database, an ifcXML file is created dynamically and then it is imported in ArchiCAD. By means of a special tool, a user of ArchiCAD links physical objects (sensors, controller) with objects of the automation network model.

4.2 *Integration on the basis of the creation of a new automation network model*

That kind of integration implies that the model is created in a CAD system. On the basis of an already existing building model (geometrical model, HVAC, lighting, etc.) the user of CAD system creates the generalized automation network model (creates such objects as sensors, actuators, controllers and makes their logic connections). The final generalized automation network model is exported into the

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ifcXML file. This model is a template for the full automation network model. A user of LonMaker imports the ifcXML file and uses the template as the basis for the construction of full model adding the data peculiar for LonWorks technology (Fig. 8).

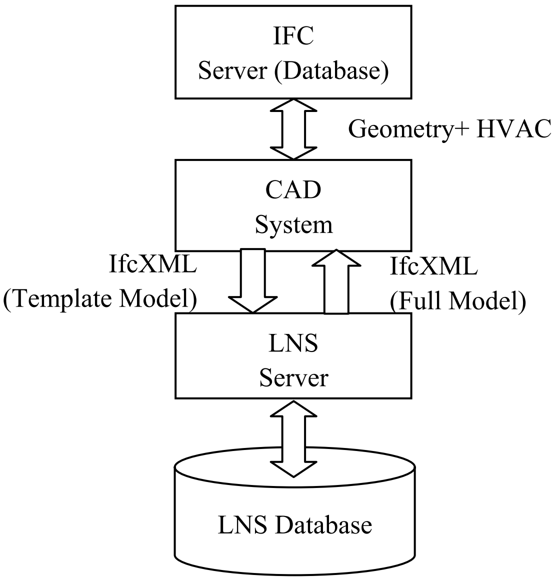

Figure 8. Integration on the basis of the creation of new model.

The template helps to create subsystems of the automation network (i.e. heating, lighting, ventilation, etc.) with territorial division (i.e. floor, room, etc.). By means of the template, logical connections between network variables can be automatically created.

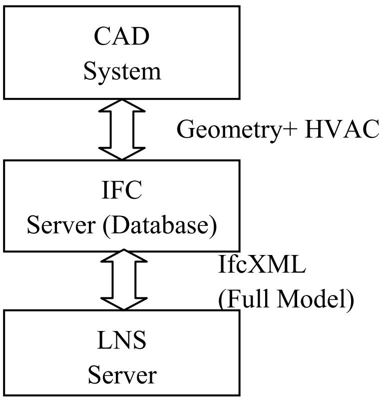

Figure 9. Integration on the basis of the creation of new model without LNS Database.

The technology described above can be used on the basis of already existing program systems (ArchiCAD and LNS Server). A variant when instead of LNS Database will be used IFC Database, could be of interest. Thus the full process of development of the automation network will be carried out in one place, and its results will be stored as IFC model. It means that LNS Server will use directly the information from the IFC model (Fig. 9). Thus it is possible to avoid a duplication of the data and to concentrate the building information in one place.

4.3 *IfcXML in the integration*

In the basis of the mechanism for definition of object properties lies EXPRESS definition. With the help of XML specification, EXPRESS schema can be transformed into the XML Document Type Definition (DTD) or XML Schema Definition (XSD). This process can be valid both for all IFC models and for their certain parts (Nisbet & Liebich 2004).

Table 2 shows a XML Schema Definition of the class *IfcDistributionControlElement* as an output from the general definition in IFC2x2.

Table 2. EXPRESS and ifcXML specifications of *IfcDistributionControlElement.*

EXPRESS specification

```
ENTITY IfcDistributionControlElement
  SUBTYPE OF (IfcDistributionElement);
    ControlElementId : OPTIONAL IfcIdentifer;
  INVERSE
    AssignedToFlowElement : SET [0:1] OF
      IfcRelFlowControlElements FOR
      RelatedControlElements;
END_ENTITY;
```

IfcXML specification

```
<xs:element name="IfcDistributionControlElement"
type="ifc:IfcDistributionControlElement" substitution-
Group="ifc:IfcDistributionElement" nillable="true"/>
   <xs:complexType
name="IfcDistributionControlElement">
      <xs:complexContent>
         <xs:extension base="ifc:IfcDistributionElement">
            <xs:sequence>
               <xs:element name="ControlElementId"
type="ifc:IfcIdentifier" nillable="true" minOccurs="0"/>
            </xs:sequence>
         </xs:extension>
      </xs:complexContent>
   </xs:complexType>
```

5 MERGING BUILDING AUTOMATION NETWORK IN IFC MODEL

In the previous section, CAD system has been chosen as an integration platform for LNS and IFC models. The general integration scenarios also have been described. For the realization of these scripts, it is necessary to select IFC subtypes and relationships which would represent an essence of objects and their communications in LNS model.

Communications between objects of the automation network model are presented by two levels: physical and logical (Fig. 10). The IFC2x2 provides the mechanism of connectivity management between objects (Liebich 2004).

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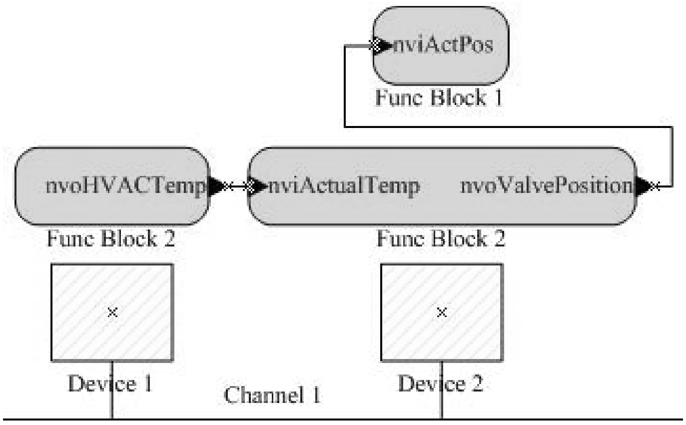

Figure 10. Objects communications in the automation network.

5.1 *Physical layer of connections in the network*

In LonWorks networks a physical connection exists between network nodes and data channels (i.e. cable, powerline, radio channel), and between network nodes and elements of control systems (sensors, actuators).

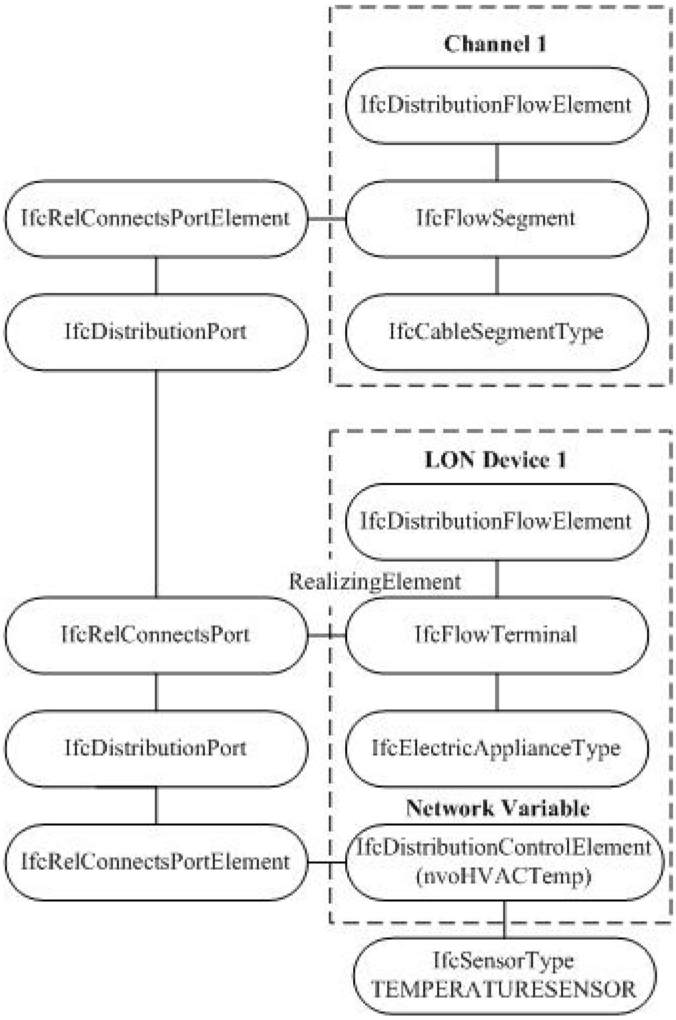

Figure 11. Definition of physical connections with ports.

Class *IfcDistributionFlowElement* (with subclasses *IfcFlowTerminal* and *IfcElectricApplianceType*) corresponds to the physical network node, class *IfcDistributionFlowElement* (with subclasses *IfcFlowSegment* and *IfcCableSegmentType*) - to the data channel, class *IfcDistributionControlElement* (with subclasses *IfcSensorType*, *IfcControllerType* and *IfcActuatorType*) – to the network variable and the element of control systems.

In the IFC2x2 it is possible to operate physical connectivity through ports which are presented by classes *IfcDistributionPort*, *IfcConnectsPort* and *IfcRelConnectsPortToElement*. Here the port has no physical representation and is a virtual object for other object communications (Fig. 11).

All physical objects of the model can be connected with *IfcDistributionPort* by means of the relationship *IfcConnectsPort*. *IfcDistributionPort*'s can be connected among themselves through *IfcRelConnectsPortToElement*. Presence of the attribute *IfcConnectsPort.RealizingElement* means that connection is realized by means of some other element. Thus elements of control systems are physically connected to the data channel through LonWorks network nodes.

5.2 *Logical layer of connections in the network*

In LonWorks networks a logical connection is present at the level of communications between network variables (*IfcDistributionControlElement*). At the logical connection it is possible to do without use of ports that can be reached by introduction of the relationship *IfcRelConnectsElements* which will connect directly *IfcDistributionControlElement* objects (Fig. 12).

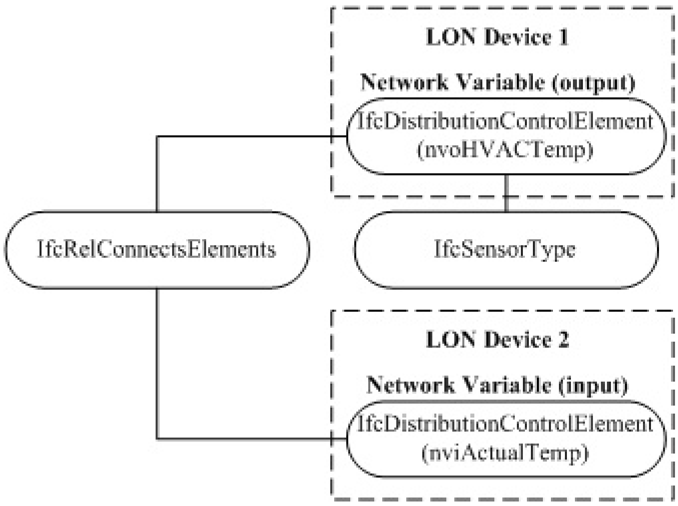

Figure 12. Definition of logical connections.

5.3 *Measurement of network variables*

Network variables are used for the measurement of process conditions in a building and for the control of these processes. For this purpose, the object *IfcMesureWithUnit* can be attached to a network variable (object *IfcDistributionControlElement*) with the help of relationship *IfcRelAssignsToProcess*. Object *IfcMesureWithUnit* has connectivity with

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object *IfcValue* which contains the numerical value of a network variable (Fig. 13).

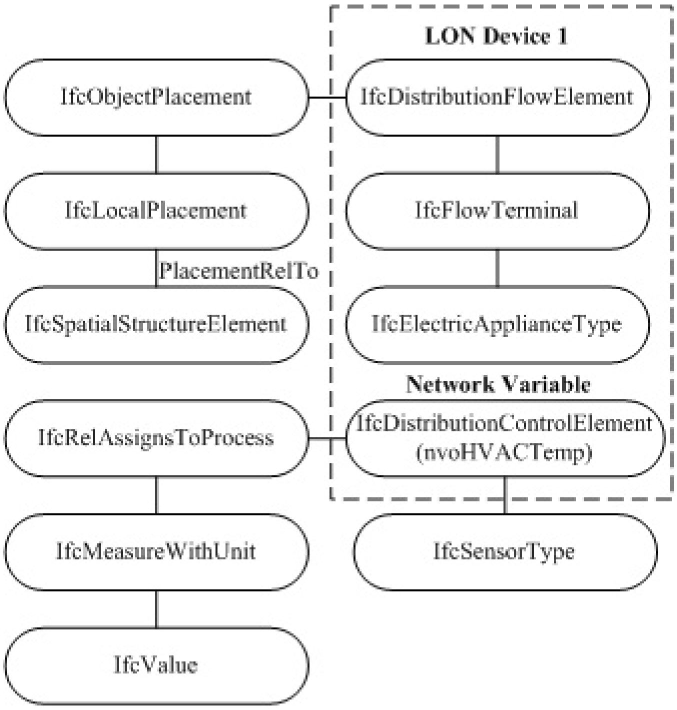

Figure 13. Definition of network variable value and device placement.

5.4 *LonWorks objects placement*

All physical objects of an automation network (i.e. nodes, cable, sensor) have their certain placement in the building. They are defined by *IfcLocalPlacement* (a subtype of *IfcObjectPlacement*) which can determine an absolute placement, relative placement, or grid reference, with each defining the local coordinate system referenced by all geometric representations. The attribute *PlacementRelTo* of *IfcLocalPlacement* points to the *IfcSpatialStructureElement* (Storey, Space) (Fig. 13).

6 CONCLUSION

This paper has presented an approach for the integration of building automation network structures in construction projects. The integration concept is to merge the LNS model into the IFC model on the basis of the software environment of the CAD system. Two integration scenarios were discussed: the integration on the basis of an existing automation network model and the integration on the basis of the creation of a new automation network model. IFC subtypes and relationships are selected which represent an essence of objects and their communications in the LNS model. That opens up new possibilities for the interoperability through the building shared object model.

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Where does CAFM really help?
Current fields of application and future trends according to system users

J. Abe1 & K. Lennerts

University Karlsruhe (TH), Facility Management (TMB), 76128 Karlsruhe, Germany

ABSTRACT: The possibilities of CAFM systems are multifarious and the system manufacturers are constantly drawing attention to these. The question is, however, what do customers actually need and which functions are being used. Karlsruhe University (TH) has therefore conducted a survey in order to determine the current situation regarding CAFM installations and the future needs of users. A mail survey was chosen as the means of data acquisition. A sample group of more than 100 CAFM users were asked to complete a standardized questionnaire. This questionnaire comprises approximately 50 questions, including questions of a factual nature, questions relating to specific knowledge and appraisal questions. The results of the survey give an overview of the current fields of application for CAFM systems and a trend for future fields of application in terms of user needs. It also shows whether CAFM is primarily used by building owners, occupants or operators. The reasons for introducing CAFM systems become evident, as well as the extent to which these needs have been fulfilled. An overall evaluation of the systems draws attention to the deficits and strengths of CAFM systems.

1 INTRODUCTION

1.1 *What CAFM does*

The main purpose of a CAFM system is to support operational and strategic facility management, i.e. all of the activities associated with administrative, technical and infrastructural FM that arise when a building is in use, as well as the strategic processes. This support for areas of a business that are relevant to FM takes the form of documentation, provision and filtration of information and monitoring. The optimization of FM processes constitutes another purpose of CAFM. This support offers a means of reducing costs and making profits and is achieved against a background of operating expenses accounting for around 80 % of the overall costs of a building throughout its life cycle (design, planning, construction, use and realization). "Many building owners in Germany are still not sufficiently aware of the fact that 85 % of a building's life-cycle costs are incurred during the utility phase as a result of mortgage interest, rent, insurance, tax, energy, maintenance, repairs, running costs, cleaning or security services" GEFMA (2001).

1.2 *Fields of application for CAFM systems*

Nävy (2000) defines three fields of application. These were formed in order to enable better differentiation between the various applications. The first of these is the management-oriented field of application. "Management-oriented applications are the instruments for the organization, management and provision of information" [Nävy00 page 78]. As far as the management-oriented field of application is concerned, priority is given to the provision of information, which therefore constitutes the basis for the other fields of application.

The planning-oriented application supports planning activities by producing data and subsequently editing it specifically for the planning process that is relevant to CAFM. The editing function offers a means of evaluating planning alternatives. Priority is given to the performance of tasks for the procedure-oriented application which supports sequences of operations, procedures and processes.

1.3 *Benefits and objectives of CAFM systems*

The benefits and objectives can be divided into several main areas. One of these pursues functional objectives, i.e. using CAFM to achieve transparency of information, direct access to data and an improvement in planning performance and quality.

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Another aims to fulfill economic objectives, i.e. reducing costs on a one-off and long-term basis, e.g. savings achieved as a result of user-specific accounting and maintaining the fabric of the building and its market value. A further area is concerned with legal objectives or, more specifically, adherence to statutory requirements, such as environmental legislation and the necessary documentation of compliance with these. There are also targets and objectives which cannot be clearly assigned to any of the aforementioned areas or are of a more general nature.

2 POSED PROBLEM

The documents provided by the manufacturers are very specifically tailored to their own systems and draw attention to the benefits that they offer. Manufacturers frequently boast a wide range of applications for their software, but there is as yet no overview of the actually used fields of application for CAFM systems. Neither is there any detailed information available concerning the scope of use of the systems in practice. This study examined existing CAFM installations in order to draw a comparison between claim and reality.

3 METHODS

The study was carried out with the help of a questionnaire. This method was chosen in order to be able to examine the largest possible number of installations.

3.1 *Questionnaire construction*

3.1.1 *Requirements and objectives*

The purpose of the questionnaire was to examine the installations in terms of range of application, scope and benefits for the user. It should supply results which can be analyzed and compared. The same questionnaire was therefore sent out to all companies.

The main criteria for the formulation of the questionnaire were that the wording should be simple and concise and that the questions are easy to understand.

As no survey leader was available as a contact person to interview the respondents, the questions had to be formulated in clear terms and enable unambiguous interpretation. Misunderstandings could otherwise falsify the results under certain circumstances. Furthermore, there is a brief introduction at the beginning of the questionnaire, containing instructions on how to complete it.

3.1.2 *Scope*

The scope of the questionnaire was restricted to five pages so that the respondents did not need to spend too much time completing it and would therefore be more willing to do so. Five pages make a good compromise between obtaining information and reasonable amount of effort.

The questionnaire was accompanied by a document that included information on the background and the scope of the study. This made it possible to restrict the cover letter to just one page, again reducing the time required by the target person. Although the respondent could read the accompanying document, it was not essential in order to complete the questionnaire.

3.1.3 *Making contact*

As the manufacturers were unable to give us the names of contacts for certain reference customers, difficulties were encountered in locating the responsible members of staff within the companies concerned. A single-stage contacting procedure was planned for the survey, i.e. a letter was sent to each reference company directly and the questionnaire was enclosed with the letter. The disadvantage of this course of action is that there is no way of knowing exactly who has completed the questionnaire. A two-stage contacting procedure was out of the question because of the limited time available.

3.1.4 *Pilot study*

A pilot study offers a means of identifying errors in the questionnaire before it is sent out. These may take the form of systematic errors of reasoning, formulation errors or simple spelling mistakes. As far as this study is concerned, a pilot study was carried out within the bounds of possibility, i.e. the questionnaire was discussed and subsequently proofread by two people from the IT and FM sectors who were known to the author.

3.1.5 *Formulation of the questions*

The questionnaire comprises questions of a factual nature, questions relating to specific knowledge and appraisal questions. Questions required both open and closed answers, as well as a combination of both. The open questions required an answer formulated by the respondent himself, whereas the closed questions offered the respondent a choice of alternative, pre-formulated replies (multiple choice).

3.1.6 *Anonymity*

The reference customers were assured that the data would be analyzed anonymously and in confidence to ensure compliance with data protection requirements and to dispel any doubts that they may have had. Anonymity had already been assured in

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the cover letter. We deliberately avoided repeating this assurance too often, however, as an exaggeration may possibly have given rise to reservations.

3.1.7 *Layout*

Attempts were made to achieve a plain, uniform layout for the documents. The logos of Karlsruhe University and the Institute for Technology and Management in Construction (TMB) were used on the cover letter to reinforce the impression of "respectability" and underline the origin and academic purpose of the questionnaire.

The questionnaire, the cover letter and the attachment were printed on white paper of DIN A4 format. The chosen font was 10-point Arial with 1.5 line spacing and center justification.

3.2 *Topics covered by the questions*

3.2.1 *Working environment for the CAFM systems*

The aim was to acquire data that would permit an analysis of the installed software systems, with the system itself and associated boundary conditions in the foreground. The questions asked for details of the software used and the pertinent line of business, as well as data concerning the company itself.

3.2.2 *Range of application for the CAFM software*

Many different users and departments give rise to a very broad diversity of data and utilization. It is therefore important to know the working environment and the way in which the software is used in order to be able to make an assessment. Furthermore, under certain circumstances, the same performance is demanded of a system by different companies in the same line of business. This also offered a means of assessing the systems from several manufacturers. As facility management provides for a holistic examination, the life-cycle phase in which the CAFM systems were used was taken into consideration here as well.

3.2.3 *Fields of application for the CAFM software*

Although almost all systems offer the complete range of functions required for technical, infrastructural and administrative facility management, the functions actually used in practice constitute an unknown factor. An attempt was made to determine which of the various functions are actually used and in which fields of application.

3.2.4 *Installation characterization*

The questions asked for details of the point-in-time managed area with proportions in percent and the number of individual buildings to be managed to enable an assessment of the size and characteristics of an installation. They also asked about the number of employees and budgets, whereby it was assumed that these questions would not be answered in full, if at all.

A knowledge of whether a company has an integrated building services management system, an interfaced business administration system or intranet integration makes it possible to determine the extent to which the system is being used within the company.

3.2.5 *Pursued objectives and effects*

The intention was to reach a conclusion regarding the achievement of pursued objectives. It is difficult to gain information on individual objectives with a single questionnaire that is identical for all respondents, which means that some very interesting answers were given in the "Other" section. The pursued objectives and effects were divided into the following sections: "General objectives and effects", "Functional objectives and effects", "Economic objectives and effects" and "Legal objectives and effects".

3.2.6 *Study of the costs*

Statements concerning actual costs incurred, their apportionment in percent and cost savings proved to be interesting here. This data can be used to calculate characteristic values, which may prove useful when planning a new installation.

3.2.7 *Assessment of the installation*

Questions related to user satisfaction and the quality of the installation were in the foreground. This part of the questionnaire asks the user for a purely subjective appraisal in an effort to discover improvement potential for the software.

3.3 *Sample group*

Letters were sent out to the selected 106 users of CAFM software for data sampling. These users were selected on the basis of research conducted with CAFM suppliers, who give details of reference installations on their web sites and on the basis of research in various FM journals, looking for progress reports relating to the operation or installation of CAFM.

Of the 106 companies who were asked to participate, 22 completed and returned the questionnaire. This corresponds to a response rate of 21 %.

4 RESULTS

4.1 *Working environment*

As far as the lines of business were concerned, the companies were distributed over a very wide range (refer to Table 1), which ensures that the results

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were not affected by predominantly sector-specific influences.

Table 1: Lines of business for the responses

Line of business	Percentage
Financial services	18.2 %
Real estate service providers / FM	18.2 %
Industry	13.6 %
Municipal and local authorities	13.6 %
Trade fair companies	4.5 %
Energy suppliers	4.5 %
Clinics	9.1 %
Federal states' authorities and organizations	9.1 %
Media and communications	4.5 %
Education	4.5 %

4.1.1 *Databases*

Of the databases used, Oracle proved to be the most dominant. Nävy (2000) ascribes a market share to the various database systems on the basis of the number of systems available on the market. This way of looking at the situation does not make any allowance for the frequency of each type of installation. A comparison with the results of the survey (refer to Table 2) shows that the dominance of the market leader database systems is even more pronounced when the number of installations is taken into consideration.

Table 2: Used database systems

Database	Percentage – Nävy	Percentage – survey
Oracle	47.1 %	63.6 %
Access	14.7 %	18.2 %
Fox Pro	5.9 %	9.1 %
ObjectStore	5.9 %	0.0 %
Sybase	5.9 %	0.0 %
Other	20.6 %	9.1 %

4.1.2 *CAD system*

There was no clearly defined trend noticeable among the CAD systems used. Apart from AutoCAD and Microstation which are the dominant systems for pure CAD applications, the products of smaller businesses are also used in the CAFM sector (refer to Table 3). This is probably due to the fact that these products are more reasonably priced and are primarily used during the utility phase. Considerably fewer CAD drawings are produced during the utility phase of a building and, as a result, the software products of smaller, less well-known manufacturers also provide solutions which are technically adequate and are therefore suitable for use.

A comparison between the results of the survey and the reference literature confirms the results of the survey in this respect. AutoCAD has adopted a leading position in the market of CAD systems for CAFM.

Table 3: Used CAD system

Line of business	Percentage
AutoCAD	45.5 %
Condor	13.6 %
Atlantis	9.1 %
Microstation	4.5 %
Spirit	4.5 %
Nemetscheck	4.5 %
Other	18.2 %

4.2 *Range of application*

In an effort to obtain an overview of the main applications, an index was developed which allows for 0.75 weighting for applications already in use and 0.25 weighting for applications that are currently in the planning stage. The index is standardized to a value of 1, whereby 1 indicates maximum utilization of the function. Table 5 shows the results for this index. Table 4 shows the distribution of applications already being supported by the CAFM system and those for which the implementation of support is planned.

As far as the reference installations are concerned, the main fields of CAFM application relate to infra-structural facility management. This is made evident by the two individual areas of "room book" and "strategic room planning". These applications are in use at virtually all of the examined installations.

The main fields of application that have emerged with respect to the examined installations can be clearly correlated with Nävy's definitions of the fields of application. These were formed by Nävy (2000) in order to enable better differentiation and typification of the various applications.

This is a predominantly management-oriented field of application, which constitutes the basis for the other fields of application. The reference customers' main fields of application correspond exactly to the core of the management-oriented field of application, which means that CAFM is primarily used as an instrument for the organization, management and provision of information.

4.3 *Pursued objectives and effects*

On the whole, it is true to say that the objectives and effects reflect the main fields of application, i.e. functional aspects are in the foreground.

More than 70 % (refer to Table 6) of the respondents are of the opinion that FM processes have been improved by means of CAFM. This is frequently due to the fact that processes are not defined properly until they are documented. This alone brings about a considerable improvement, but the success can only be attributed to CAFM secondarily. However, most respondents did not believe that they had been able to conserve resources as a result of im-

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plementing CAFM, but this had not been a primary objective for many reference customers, anyway.

Table 4: Range of CAFM application

Range of application	in use	use planned	total
Area and room management	86 %	14 %	100 %
Room book, strategic room planning	68 %	9 %	77 %
Cleaning management	50 %	23 %	73 %
Contract management	50 %	9 %	59 %
Fault management	45 %	23 %	68 %
Relocation management	45 %	23 %	68 %
Preventive maintenance management	41 %	27 %	68 %
Services on outside installations	36 %	9 %	45 %
Caretaker services / help desk	36 %	23 %	59 %
Cost accounting / controlling	36 %	23 %	59 %
Safety and security management	32 %	9 %	41 %
Cost management	32 %	27 %	59 %
Fire protection	27 %	9 %	36 %
House and apartment management (incidental charges etc.)	27 %	27 %	55 %
Order management / tender, order placement, accounting	27 %	23 %	50 %
Building services management system / building automation	23 %	23 %	45 %
Disposal	23 %	14 %	36 %
Energy management	18 %	18 %	36 %
Safety and security technology	18 %	9 %	27 %
Personnel management	14 %	5 %	18 %
Network / cable management	5 %	27 %	32 %
Canteen / catering	0 %	0 %	0 %

A large number of the functional objectives and effects had been achieved. This agrees with the main fields of application because the infrastructural functions offering functional benefits are most in demand. A deviation is evident with respect to the issue of "planning quality", however. A large number of reference customers stated that they had not been able to meet this objective. That means that the reference customers found that an improvement in planning quality was less easy to achieve with CAFM than the other objectives.

Economic objectives and effects were pursued and achieved to a lesser extent than functional objectives and effects. Only 13,6% of the reference customers had been able to reduce investment costs as a result of using CAFM and this would therefore appear to be generally difficult to achieve. Around 50 % of the respondents had been able to improve cost transparency.

A large number of the installations did not pursue legal objectives or effects and very little importance was attached to this aspect as far as the installations were concerned.

Table 5: Index of the ranges of application

Range of application	Index
Area and room management	0.68
Room book, strategic room planning	0.53
Cleaning management	0.43
Relocation management	0.40
Fault management	0.40
Contract management	0.40
Preventive maintenance management	0.38
Caretaker services / help desk	0.33
Cost accounting / controlling	0.33
Cost management	0.31
Services on outside installations	0.30
House and apartment management (incidental charges etc.)	0.27
Safety and security management	0.26
Order management / tender, order placement, accounting	0.26
Fire protection	0.23
Building services management system / building automation	0.23
Disposal	0.20
Energy management	0.18
Safety and security technology	0.16
Personnel management	0.11
Network / cable management	0.10
Canteen / catering	0.00

Table 6: Objectives and effects

Objective / Effect	Was not pursued	Was pursued	Was achieved
More transparent information	0.0%	18.2%	81.8%
Improvement of FM processes	4.5%	18.2%	77.3%
More effective information management	0.0%	27.3%	72.7%
No redundant data entries	0.0%	22.7%	72.7%
No redundant data storage	0.0%	31.8%	68.2%
Clearly defined areas of responsibility	22.7%	9.1%	50.0%
Faster planning	18.2%	22.7%	50.0%
Better cost transparency	9.1%	36.4%	45.5%
Better planning quality	22.7%	31.8%	45.5%
Cost reduction through process optimization and its consequences	9.1%	45.5%	40.9%
Customer-oriented accounting	40.9%	13.6%	31.8%
Conservation of resources	9.1%	54.5%	31.8%
Adherence to statutory requirements	36.4%	36.4%	27.3%
Reduction of planning costs	36.4%	31.8%	22.7%
Economical optimization of planning decisions	27.3%	45.5%	22.7%
Reduction of investment costs	40.9%	31.8%	13.6%

In an effort to evaluate the success rate for the achievement of pursued objectives and effects, quotients were calculated which reflect the respective

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probability (refer to Table 7). The quotient is calculated from the values for the objectives that were achieved and not achieved. The pursued objectives and effects with the highest success rates are those relating to the provision and management of data. This, however, is due to the nature of the system.

Table 7: Success rate for the pursued objectives

Objective	Success rate
Clearly defined areas of responsibility	84.6 %
More transparent information	81.8 %
Improvement of FM processes	81.0 %
No redundant data entries	76.2 %
More effective information management	72.7 %
Customer-oriented accounting	70.0 %
Faster planning	68.8 %
No redundant data storage	68.2 %
Better planning quality	58.8 %
Better cost transparency	55.6 %
Cost reduction through process optimization and its consequences	47.4 %
Adherence to statutory requirements	42.9 %
Reduction of planning costs	41.7 %
Conservation of resources	36.8 %
Economical optimization of planning decisions	33.3 %
Reduction of investment costs	30.0 %
Mean value	59.4 %

4.4 *Study of the costs*

The costs of implementation are determined to a great extent by the scope of functions, existing data, the number of workplaces and the fields of application (e.g. other, more detailed data is required for technical applications). The absolute implementation costs for a complete system amount to € 170,000 on average. Nine of the questionnaires were excluded from the assessment of implementation costs as the operators did not enter any information in response to the question. This means that the database is different. The scatter band varies between € 35,000 and € 500,000 and the range of the results amounts to € 465,000.

The average implementation costs for one CAFM workplace therefore amount to around € 4,300. It must be stated at this point that there is no linear characteristic for the implementation costs as a function of the number of workplaces. Disproportionately high costs are incurred by the first workplace, e.g. for data acquisition and the EDP structures.

As the informative content of a global statement regarding implementation costs is limited, the implementation costs were put in relation to the managed area. In addition to this, the number of fields of application used within the framework of each installation was also taken into consideration. In this context, it makes sense to allow for the number of fields of application, as an increase in the number of applications necessitates a greater volume of data, possibly with a greater degree of detail, thereby incurring higher costs.

It did not appear expedient to break the fields of application down into any greater detail so this was not done. Examples of individual fields of application include cleaning management, room book and maintenance management.

The implementation costs for a CAFM system can be estimated on the basis of the calculated characteristic values. This can be done by simply basing the calculation on the gross area in m², allowing for a mean value of 8,375 fields of application used. In this case, the costs of implementation amount to € 1.70 per m². Alternatively, the implementation costs can be estimated on the basis of the gross area in m² and the number of fields of application used. In this case, the costs amount to € 0.28 per function and m².

The implementation costs for CAFM solutions are made up of various parts. Nävy (2000) and Warner (1999) break the costs down in a virtually identical manner. Both sources state that the largest proportion of the costs are incurred by data acquisition (42 % and 37 %). According to Warner (2001), data acquisition accounts for 41 % of the costs. Warner's compilation [Warner01] is based on information gathered from 16 projects, whereby the statement from 1999 was taken from information supplied by the manufacturers. As far as Nävy (2000) is concerned, no details are given regarding the sources of the published results.

The results of the survey indicate a pronounced deviation from the values quoted by Nävy (2000) with respect to the costs of software and data acquisition (refer to Table 8). It appears as though the percentages for "data acquisition" and "software" have been swapped over. Attention must be given to the fact that the costs of data acquisition are affected by several parameters. The existing volume of data and its quality is one decisive factor; another critical criterion for the costs of data acquisition is the degree of detail of the requisite data.

Table 8: Costs proportionate to implementation costs

Cost segment	Percentage according to Nävy	Percentage acc. to results of survey
Hardware	10 %	6 %
Software	20 %	45 %
Data acquisition	50 %	19 %
Other	---	3 %
Training	5 %	9 %
Consulting	10 %	9 %
Software adaptation	5 %	8 %

The results of the survey do produce a remarkable statement in terms of the software costs. These ac-

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count for 45 % in the survey, which is more than double the percentage quoted by Nävy (20 %) Nävy (2000).

4.5 *User assessment of the installation*

The reference customers were assured that the data would be analyzed anonymously in order to obtain the most objective result possible. When studying the completed questionnaires, it became evident that some users had certainly adopted a critical attitude with respect to the system. There was no way of checking the quality of the answers.

Users were asked to assess the system according to the grading concept used in German schools, which ranges from 1 (very good) to 6 (inadequate).

The response to "Usefulness of manuals" stands out against the other questions in a very negative manner. With an average grade of 3.17, this issue was regarded as definitely being in need of improvement. The other grades vary between 2.72 and 1.80, forming a tightly packed zone around the arithmetic mean value of 2.31. The result of the assessment is given in Table 9.

Table 9: Assessment of installation

Criteria	Note
Stability	1,80
Speed	2,25
Online help	2,47
Support by manufacturer during installation	1,95
Support by manufacturer during operation	2,11
Support by manufacturer for further development	2,37
Usefulness of manuals	3,17
User-friendliness of overall system	2,20
Functionality of overall system	2,10
User acceptance	2,50
Support of FM-processes in daily business	2,35
Feasibility of individual customization	2,20
Reporting of existing data	2,35
Assessment of cost-value ratio	2,72
Overall assessment of system	2,15
Mean value	2,31

5 SUMMARY AND OUTLOOK

Interesting results concerning the use of CAFM in practice were obtained within the course of the empirical analysis of CAFM installations described here. The results are not associated with any particular manufacturer and therefore stand out against data obtained from other sources.

Fundamentally important conclusions based on an analysis of the completed questionnaires:

- In practice, the main application of CAFM is found in the infrastructural segment. The technical and administrative segments are used to a lesser extent.
- CAFM is currently not being used as a tool for a holistic study of buildings. The objectives and effects pursued by the users are predominantly found in the infrastructural segment.
- CAFM is used almost exclusively during the utility phase. CAFM is not being used to study the buildings throughout the entire life cycle.
- Software and data acquisition account for almost 70 % of the CAFM implementation costs.

A typical CAFM system is employed in the infrastructural FM segment during the utility phase and is essentially used for organization purposes and for the acquisition and management of information.

The survey was only able to produce a certain amount of information regarding costs and savings associated with CAFM. The subject of costs is too sensitive to achieve a sound information base by means of a written survey. It is also possible that the requested information concerning costs is not available to the operators of the installations.

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Enabling Relationship Management: Agent Technology for Facility Management Integration

K. Ercoskun
Yeditepe University, Faculty of Engineering & Architecture, Istanbul, Turkey

A. Dikbas
Istanbul Technical University, Project Management Centre, Istanbul, Turkey

ABSTRACT: Integration is a common effort in every industry. On the operational level, establishing effective communication and collaboration between business actors is a vital contemporary need for “Total Quality”. Business patterns in construction industry depend on “Projects”. Despite the efforts of sharing knowledge in order to establish and discern excellence in construction, every project is naturally a closed system hiding great amount of “Information” from the participants of “other” projects. A reasonable amount of this hidden information may be “discovered” from post-construction phases of a project’s lifetime. Providing a strong relationship mechanism between different project actors is possible through facility management integration. This paper presents basic concepts of a “Customer service call tracking system for facility management” which by design puts the customer at the center of post-construction processes and enables various actors of construction industry to serve in collaboration within a platform providing effective communication and collaboration. The framework proposed within this research consists of various process models which are designed to resolve Business to Business (B2B), Business to Enterprise (B2E) and Business to Customer (B2C) relationship types. The Meta system in which the common standards and protocols of communication defined is implemented as a web based project model and agent technology is used to provide a loosely coupled integration mechanism. The core of the model is named as CC-Agent (Customer to Construction Agent) and is implemented as a series of web services.

1 INTRODUCTION

This paper presents a framework for collecting design data from use processes of a building, by use of agent technology and discusses the logic and technology of a project model developed within a PhD research. Taking into account that design quality is where the construction excellence begins, a continuous data stream between design processes and use processes of projects’ lifetime is considered beneficial. The function of agent technology within that framework is to initiate and trace the relationship between different parties of the AEC/FM cluster.

1.1 *Problem Description*

Construction project teams typically consist of numerous participants; “End users”, “Owners”, “Architects/Engineers and specialized Designers”, “Design - builders”, “Contractors and sub-contractors”, “Construction managers”, “Product representatives, suppliers and manufacturers”, “Financial institutions”, “Regulatory authorities”, “Attorneys”, and “Facility managers” (CSI 2004, OGC 2003).Various information and communication technologies (ICT) are available within the design and construction phase of a project including knowledge management tools and design data management systems to facilitate knowledge acquisition between those actors but the main problem resides in the building use phase of the process. Despite the common awareness that the information collected from building use processes is very important and valuable in order to keep track and increase the quality of architectural and engineering design and the design management process, very little effort is observed in the industry to efficiently achieve learning and facilitate information collection from use processes.

In practice, several factors make it virtually impossible that all the participants know and remember all the relevant requirements and especially their relationships to each other and to design solutions (Kiviniemi & Ficher, 2004). Main problems of design management are poor communication, lack of adequate documentation, deficient or missing input information, unbalanced

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resource allocation, lack of co-ordination between disciplines, and erratic decision making. Also, the design process usually lacks effective planning and control, to minimize the effects of complexity and uncertainty, to ensure that the information available to complete design tasks is sufficient, and to reduce inconsistencies within construction documents (Tzortzopoulos & Formoso, 1999).

Although the problems listed herein are related with design process and design data management; organized, analyzable and continuous end user feedback provides a means to develop standards among industrialization. As the number of standards and level of industrialization increases problems concerning design data management decreases. But there is very little effort in the field to bride the gap between design and use processes (Ercoskun & Kanoglu 2003a)

2 BACKGROUND

The competitive atmosphere of the Architecture, Construction and Engineering (AEC) Industry has a high cost, low profit nature and no actor taken part within a project would "care" about the "little problems" of the operation and maintenance phase of buildings though, many of the subcontractors, suppliers and manufacturers also provide support for Facility Management (FM) in which the economical and financial patterns of business environment dramatically changes and shows a low cost, high profit character.

Above determination gave an idea of using FM firms as agents whom would facilitate Post Occupancy Evaluation (POE) of buildings to designate dynamic progresses and enable a continuous and interactive data flow between use processes of buildings to a central data repository with the help of ICT. Thus it will be possible to reproduce strategic intelligence for design processes and design data management. However to design such a model, a multi-layer problem system has to be solved.

The agent technology developed will serve as a resource locator for every actor of the system and control the relationship between them. Every project within itself is a closed system in terms of knowledge management. While "On progress" information (information which is created, captured and used during construction phase) is essential in order to improve overall construction performance; "on use" information is also very important to have an idea about the performance of the final product, in terms of design, materials, cost and workmanship.

3 RELATED WORK

Related work of this research is listed under three topics, "The Building Design Process", "Relationship Management", and "Integration".

3.1 *The Building Design Process*

It is generally accepted that the quality of a product is largely determined in the early phases of design (Redelinghuys 2000). Building Design Process involves thousands of decisions, with numerous interdependencies, under a highly uncertain environment. As distinct from production, quality in the design process has to be achieved by a careful identification of customer needs and subsequent translation of those needs into specifications. (Tzortzopoulos & Formoso, 1999).

Ballard & Koskela (1998) point out the need for integrating the three views of design (conversion, flow and value generation) and suggest a number of practical guidelines for such integration. "Encouraging direct interaction between designers and customers" is a significant guideline designated in their research.

Quality of information, which the design based on, is extremely important. Baldwin works on the problem and suggests an information flow model for the early stages of design (Baldwin et al. 1999). Mokhtar works on managing design changes (Mokhtar et al. 1998).

Houvela and Seren defined customer oriented design methods for construction projects (Houvela & Seren, 1995). Kiviniemi defines a vision and states that design and construction will be closely connected to the core business of end users and must provide not only the physical spaces for activities, but also essential information for the use and maintenance of the buildings as well as services based on the information. (Kiviniemi et al. 1999).

3.2 *Relationship Management*

Relationship management is a Knowledge Management (KM) activity. Although not definitely defined, every integration effort in the AEC/FM cluster is a matter of Relationship Management (RM). Figure 1 shows the expected value by integration within various applications of RM. Fahey et. al. (2001) defines every aspect of KM, demonstrating B2B, B2E and B2C relationship types within a framework to indicate the rudiments of an action agenda that e-business driven change in business or operating processes can be handled to deploy a KM-based approach for transforming businesses.

Product knowledge, persuasion and problem solving are the basic tools of traditional sales process. Planning – customer goal discovery,

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communication and measures useful for assessing relationship milestones – is the primary tool for key account management. Thus Downey states that deepening relationships is essential in order to have a better position to understand how customers define value – what their goals are, how they prioritize them and what needs arise as a result (Downey, 2005).

3.3 *Integration*

Majahalme details an integration model by modelling significant activities and data flows due to facility management (Majahalme, 1994). Froese (1999) presents the requirements and a methodology for developing, implementing, and possibly standardizing, a set of message-based protocols for exchanging AEC information, thus supporting AEC/FM Systems Interoperability via Industry Foundation Classes (IFC)-Based Messaging Protocols. Halfawy and Froese (2002) gave examples of designing data models by implementing IFC. Turk states that the construction process information can be observed from two perspectives: as (1) information creation or publishing and (2) information use. The two need to be glued together by (3) an integration process (Turk, 1996).

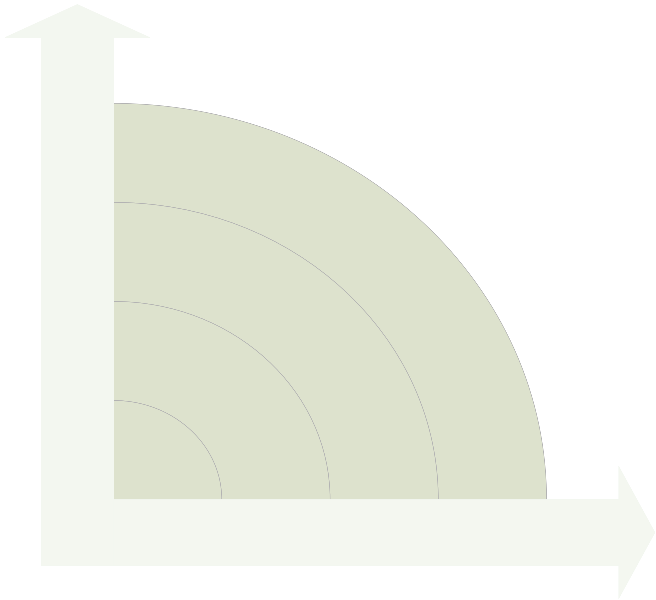

Figure 1. Expected value through FM integration (An IT perspective - Based on an illustration by Gunzer 2002)

4 AGENT TECHNOLOGY FOR FM INTEGRATION

The main objective of this research project is to define a meta-model for integrating Facility Management processes within a framework which is dependent on the service call requests from building users in order to track the final quality and performance of the "finished" building and its parts.

The proposed management information system will be consisting of following components:

- Performance measurement and quality assessment system for maintenance and services
- Relationship model(s) between different actors of the system
- Communication and collaboration protocols, between the actors of the system
- Security and privacy rules
- The database and coding structures (object model) of the system

4.1 *Technology, Development Platform and Methodology*

The new technologies give opportunities for integration in document and method-based models. As a result, the web and any integration protocols will change how data lives its life (Froese 2004).

The integration architectures we have today are very limited. IT Integration can be synchronous. If it is synchronous, it probably means that a proprietary direct object call is used. This option is tightly coupled and scalable.

It is possible to deploy an asynchronous integration option, which can be done with a message-based loosely coupled system such as a queuing application. The integration model using Simple Object Access Protocol (SOAP) can be synchronous or asynchronous, but because of its message-based architecture, it enables loosely coupled integration in all cases. Therefore, SOAP gives a solution to integrate heterogeneous objects, and objects in different physical boxes in a loosely coupled manner both in synchronous or asynchronous models. The core of the project model - "CC-Agent" is dependent on web services, and provides a loosely coupled integration mechanism.

Using asynchronous message-based architectures eliminates the need for systems to be tightly linked to each other. Loosely coupled architectures have the advantage that messages are passed, instead of method invocations. These messages provide a degree of independence between the sending system and the receiving system. The table in Table 1, The Integration Matrix shows a matrix of coupling versus invocation (Travis & Ozkan 2002).

Organizations have been successfully using methods to send messages to trading partners without knowing anything about their business implementations for years using paper documents. By deploying SOAP over HTTP, an organization can make DCOM or CORBA calls over the Internet in the same way, without knowing about the implementation details of the target organization. These technologies can also be used for business document exchange.

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Table 1: The Integration Matrix (Travis & Ozkan 2002)

	Tightly Coupled	Loosely Coupled
Method Based	• RMI/RPC • COM/DCOM • CORBA	• SOAP for RPC (Message is the Method)
Message Based	• IVAM • Proprietary	• SOAP for Messaging • Querying Systems

In real systems, there is a combination of message-based / method-based, synchronous / asynchronous, loosely coupled / tightly coupled interactions. In fact, these concepts are usually tied together to create reliable or efficient systems. The COM+ SOAP service in the .NET Framework platform allows taking an existing component and publishing it as an XML Web service (MSDN Library, 2005). Clients can continue to access the component using previous methods.

It is important to clearly distinguish Web Services and how they are related to traditional middleware. The definition given by WebServices.org states: "Web Services are encapsulated, loosely coupled contracted functions offered via standard protocols" where:

– "Encapsulated" means the implementation of the function is never seen from the outside.
– "Loosely coupled" means changing the implementation of one function does not require change of the invoking function.
– "Contracted" means there are publicly available descriptions of the function's behaviour, how to bind to the function as well as its input and output parameters.

Roughly speaking, Web Services are applications that can be published, located, and invoked across the Internet (Erl, 2004). Typical examples include

– Getting stock price information.
– Obtaining a complaint from user.
– Making an appointment (service call).

Middleware is a class of applications that provide a common method for moving data between systems and invoking applications or procedures from external systems. Early middleware systems, such as remote procedure calls (RPCs) and remote database access, offers developers a common transport mechanism for moving data and invoking services. Business processes are dependent upon multiple independent systems, each with their own purpose and lifecycles. When business processes change, multiple systems will have to change and each of those changes potentially creates ripple effects. To effectively manage a series of changes, organizations require Enterprise Change Management systems that capture asset configuration, dependencies, and attributes and provide real-time access to administrators and managers across an enterprise. The CC-Agent process model includes mechanisms to facilitate change management procedures.

The web services in CC-Agent are XML web services. Web portal is based on .NET technology. FM objects and building elements are modelled in accordance to IFC standard and Unified Modelling Language (UML) is used as the primary modelling language. Process models are prepared as IDEF0 activity diagrams. In this paper we elaborate on the logical layout of the model so only the general layout and the basic processes are included. SQL Server is used for database development.

4.2 *The logical model layout*

The proposed system consists of three main modules: "USER" – **U**ser **S**ervice **E**ntrenched **R**epository, "ITEM" – **I**ssue **T**racker for servic**E** **M**anagement and "SHAPED" – **S**ystem for **H**abitual **A**rchitectural **P**ractice and **E**ngineering **D**esign. CC-Agent (**C**onstruction **C**lient Agent) is the integration platform of these modules based on agent technology in which various data mining techniques are used in conjunction. By terms of implementation the solution will be consist of a "Call Center and a "Shared" Internet Portal. A more general layout of the proposed project model was presented in a previous work (Ercoskun&Kanoglu 2003b).

Table 2: Commercial Modules of CC-Agent RM Application

Marketing Modules • Campaign Automation • External List Management • Marketing Optimization and Refinement • Marketing Calendar • Supply Chain Integration • Enhanced Segmentation and Planning	**Sales Modules** • Enhanced Opportunity, Order, Contract, and Activity Management • Improved Contact and Account Management • Territory Management • Leasing
Service Modules • Professional Services • In-House Repair • Case Management • Service Parts Order Fulfilment • Product Service Letter Management • Planned Services • Enhanced Service Order, Complaint, and Contract Management, and Solution Search	**Analytics Modules** • Enhanced business content for, Customer, Marketing, Sales, Service and Channel Analytics • Real-Time Analytics

CC-Agent is still under development. It has been proposed as a research project to the Ministry of Industry and Trade of Turkey in collaboration with Siemens Business Accelerator (SBA) and Istanbul Technical University Project Management Centre

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(ITU-PYM) and when finished it will also include essential RM modules (Marketing, Sales, Service and Analysis) as shown in Table 2 (Gunzer 2002):

There are various change mechanisms hidden in CC-Agent and these mechanisms are established in order to enable continuous evolution in terms of business culture and industrialization. By providing professional solutions to issues collected from customers "State of the art" design solutions may be identified, collected and be shared. This leads to continuous quality improvement in terms of competence, standardization and industrialization. Figure 2 shows the general logical layout of CC-Agent.

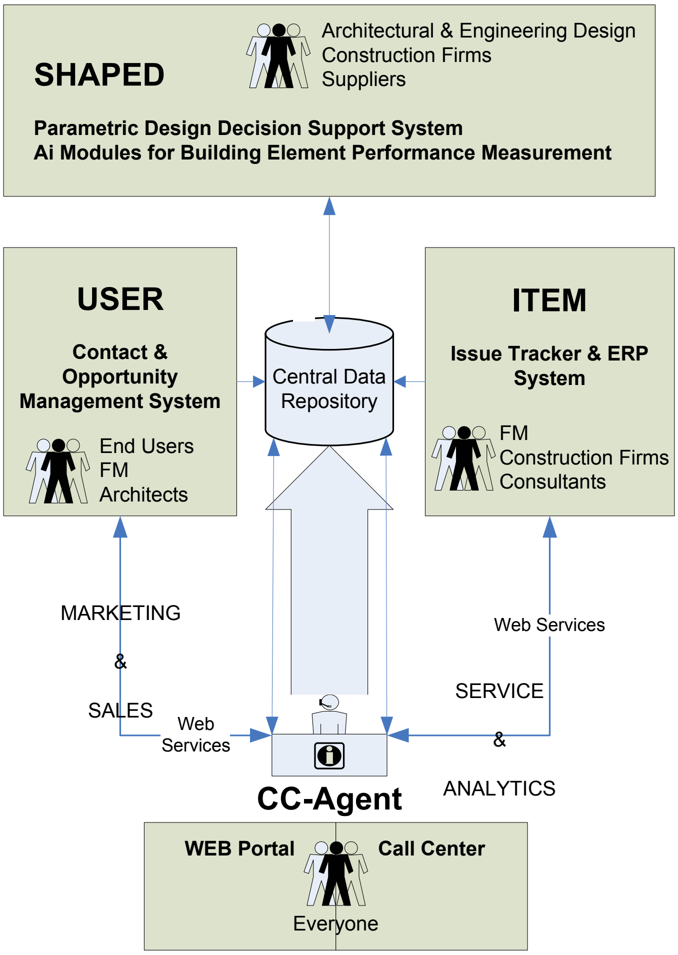

Figure 2: The Logical Layout of CC-Agent

4.3 *System for Habitual Architectural Practice and Engineering Design (SHAPED)*

SHAPED is a parametric product design decision support system. It is possible to track the performance of building materials bound to suppliers. Using this information it is also possible to design a building element and compute and guess the approximate performance of the parametric design. SHAPED is in its early stages of development but the logic behind is simple: In terms of building element design if the performance of materials is high it is expected that the performance of the designed building element will be high also. If the performance of the building element is high, it is also expected that the overall performance of the space created by those elements is high. The chain is continuous from the scale of materials to the scale of cities. Of course it is not possible to resolve every relationship within that chaos but it is possible to collect end user information in order to compute the performance of various architectural and engineering designs with regard to the associated feedback.

The main scope of SHAPED is to guide architects and engineers with “available” data about; “performance parameters (as far as possible)”, cost information, registered information about suppliers or manufacturers in terms of “Logistics, after sales service, workmanship quality, reliability, and Overall Customer Satisfaction”, of accompanying design Elements

SHAPED will be the integration node of CC-Agent with the CONNET – Turkey, the gateway to construction in Europe” (Dikbas et. al., 2004). SHAPED is modular by design. That is, because it is not possible to compute every performance parameter about a specific “design focus (object being designed)” various computing methods for various design parameters may be plugged-in later. Computing a specific performance parameter may deal a standalone research subject. Within CC-Agent, we only elaborate on customer feedback, cost, and supplier or manufacturer reliability.

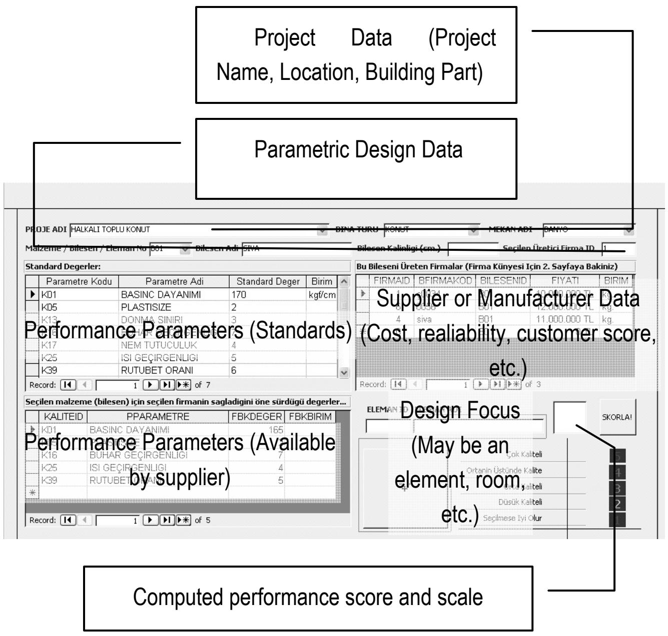

Figure 3: User interface of SHAPED

4.4 *User Service Entrenched Repository*

USER consists of an interface and a universal project database. It is designed to allow users to put data at the right place the first time. The main scope of USER is facilitating the process of “First Call Resolution (FCR)”. USER is not implemented yet. The database structure and object model is under

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development. USER is a door to let all kinds of feedback within a classified scheme. Omniclass (OCCS) classification system and IFC objects in conjunction is used to disseminate and classify those data.

USER is the welcome scene of CC-Agent. In the foreground, it deals KISS (Keep It Simple, Stupid) principle to interact with the user of the system. It is designed to enable communication with people whom does not have any idea or technical knowledge about the situation which made them to act with CC-Agent. In the background it deals intelligent classification algorithms to collect data as organized as possible.

At the user interface level, it will be possible to visually point the focus of the feedback. 2D visualization will be used for the beginning but we aim at implementing VRML in the future.

4.4.1 *The KISS Principle*

The KISS Principle is self-descriptive and recognizes two things:

1. People (including product and service users) generally want things that are simple, meaning easy to learn and use.
2. A company that makes products or furnishes services may find simplicity an advantage for the company as well, since it tends to shorten time and reduce cost. (Where the company is trying to use the principle on behalf of users, however, design time may take longer and cost more, but the net effect will be beneficial since easy-to-learn-and-use products and services tend to be cheaper to produce and service in the long run)(whatis.com).

4.5 *Issue Tracker for servicE Management*

ITEM is the heart of CC-Agent. All the activity within a service call is tracked through the ITEM module. As a user interface while USER serves for the end users, ITEM serves for the FM. Both USER and ITEM depend on same database however the data collected from USER is stored in static tables while data collected from ITEM is stored in dynamic tables within a data warehouse. The database behind is web oriented supporting all of the advanced features that a web oriented database (Turk, 1997) should have.

4.6 *The Process Model*

There is an increasing need for all actors involved in the construction- and facility management process to have a common framework for describing their work and creating a more efficient business process (Björk et al. 1999). Creating a more efficient business process facilitates knowledge acquisition. The acquired knowledge can be re-used for Strategic and Tactical plans of enterprises, standardization by design, and thus the industrialization of the entire AEC/FM cluster.

The knowledge acquisition process in CC-Agent creates a “Knowledge Circle (Information > Implementation > Dissemination > Knowledge)”. The overall progress consists of nine basic processes (Feedback, Redirection, Update, Inspection/Record as Information collection processes; Solution and Issue tracking and Analysis as Implementation Processes; Design, Promotion, Change as Dissemination Processes; Knowledge is acquired as an output of the whole progress). Here SHAPED, ITEM, and USER are not explicitly shown because they exist as sub-modules of CC-Agent. Where appropriate, the dominant function related with those modules is explicitly indicated (Figure 3).

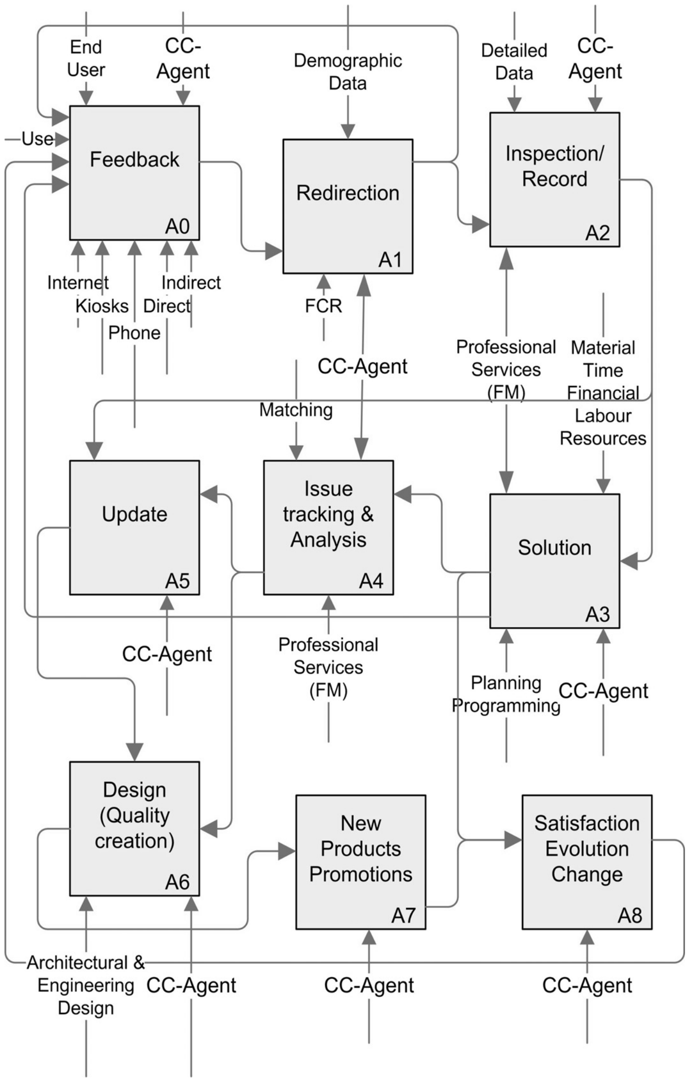

Figure 4: IDEF0 – Principle activity diagram for CC-Agent

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5 CONCLUSION

Neither maintaining good and efficient relationship with the users or in wider terms "customers" nor establishing an agent system to achieve such work are novel ideas but with emerging ICT the way that relationship handled is. The outcomes of those efforts may be listed as follows: (1) In terms of marketing, it becomes easier to catch up "up-sell" and "cross-sell" opportunities. (2) By use of ICT, customer needs, desires and requirements can be analysed making it possible to improve products and services to better suit those needs. CRM, by this way helps customers to become more aware of their rights and provides a means of driver towards "change" in long term. (3) Marketing of products "designed" according to the trends and requirements of society is much easier. Not directly related with the content of this paper but positive effects of the process is seen in terms of physiological health of society to quality of life, and productivity increase at work. (4) Reduced costs, shortened production periods, increased quality, and competitive advantage are natural outcomes of the process and all dependent on the "design quality".

Collecting data from various projects through "service requests" and analyzing them in one pool makes it possible to discover the secrets of design professionals and provide an open system for sharing knowledge. In long term CC-Agent will help to:

- Set performance criteria for buildings and building delivery processes that are based on the values and business practice
- Evaluate performance by getting feedback from customers, assessing the technical and financial performance of buildings, and comparing these evaluations to other benchmarks within and outside
- Analyze and interpret evaluation results in ways that allow staff of participants of the system and customers to apply the results to their own situations with future buildings.
- Broadly disseminate results in ways that are meaningful to key decision-makers, in language and formats that they can use on future projects.
- Create the conditions for effective implementation of results, including changes in work processes, adequate resources and organizational incentives and support.
- Develop marketing and training strategies for FM firms, customers and other stakeholders.

An other long term outcome from the system is that, CC-Agent would provide, various "Key Performance Indicators (KPI)", "CRM metrics", "New managerial tools and techniques" specific to construction sector. By using this information, construction firms would gain strategic intelligence for the next step and user requirements would be the major driver for the strength and length of that step.

The following (introductory but not limited to) KPIs can be output from the system:

- Customer preference index or Customer Loyalty
- Percentage of customer calls answered in the first minute (As an example of specialty KPIs)
- First Call Resolution Rate
- Customer Acquisition
- Life span of facilities
- Industrialization (In terms of lean design & construction, shortened production period, reduced amount of workmanship)
- Standardization (Of an accepted design solution in terms of preference)

CC-Agent will also provide support for the evolution and development of Deign Quality Indicators (DQI). CC-Agent is believed to be an essential tool towards construction excellence and industrialization in the AEC/FM cluster.

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Knowledge-Based Services in Building Management

R. Schach & J. Otto
Institute of Construction Management, Dresden University of Technology, Dresden, Germany

ABSTRACT: In recent years Facility Management (FM) developed as a know-how-oriented service. Equally the Building Automation attained a prime importance in the creation of optimized operations through digital systems for measurement and control. The target of future solutions is to combine the central Building Automation Systems with the FM-Systems for an integrative usage. Within the development of open date interfaces of the available Building Control Systems the present singularly used dates will be provided to services for an integrated FM. In that case the already existing services can be improved or new services can be created. The shown results of completed scientific research projects are determined in the creation of an applicative interface between the systems of FM und Building Control, the definition of the system architecture and possibilities for new services.

1 ACTUAL SITUATION AND FUTURE REQUIREMENTS IN BUILDUNG MANAGEMENT

1.1 Actual Situation

In recent years Facility Management developed as a new, know-how-oriented service. Main part is the grouping of the available special knowledge of individual disciplines. Clear efficiency-increases can be observed through the possible integrated building rationing.

Equally the Building Automation attained a prime importance in the creation of optimized operations. Today the digitalization of the technical processes allows a pursuing consideration of the central Building Control System in connection with the general management concepts in the real estate. Evolutions in this direction set up a combination of the automated processes to the overall consideration of Building Management. The consideration of the Facility Management requirements in the different parts of the Building Automation is at the moment not sufficiently available.

Proprietary and partial redundant data networks characterize the currently available systems of Building Control and Computer Aided Facility Management. The demanded dates are mostly available in the central Building Control System, but they cannot be used due to the missing completeness of the IT-environment (see figure 1). The interface with considerable format problems separates the two existing systems and prevent interacting advantages. If a Building Management service provider wants to use information obtained from Building Control Systems, the only chance mostly is to get the input data by the manual way.

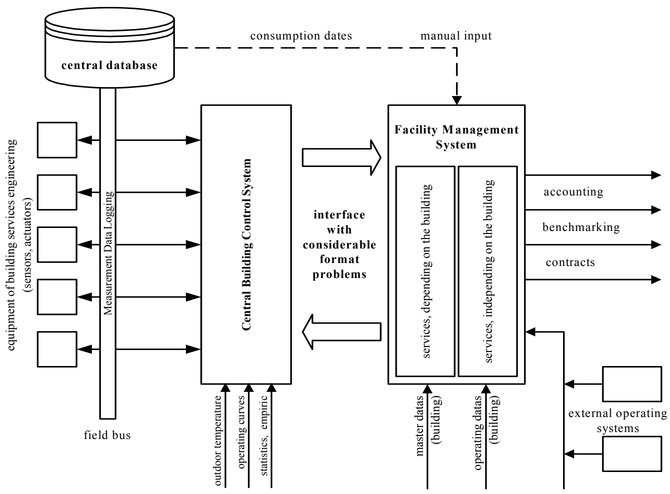

Figure 1. Facility Management Systems (CAFM) and actual interface problems

1.2 Future Requirements

Actual developments on the renting market for buildings and results from actual research projects show, that future requirements for offices and involved services will rise.

The daily project business is stamped by very flexible processes. Both, the timing horizon and the on-site horizon will be important to achieve good

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results in the project business. Services have to support the flexible processes in an effective and efficient way. Therefore service providers need realizable service structures, instruments for quality assurance and comprehensible, transparent methods on an acceptable cost level.

In case of influencing the operating cost for buildings a survey determined interesting developments, especially for the cost for energy consumption in single rooms. The target group of the represent survey has been office users in whole Germany, more than 450 different users has been questioned. Three selected results of the survey are shown in the following.

The requirements of office users are tending to a contemporary and room-specific billing of the rent. Figure 2 shows that 88 % of the office user wants to have a monthly bill interval for operating costs. Therefore any technical/administrative system does not exist at the moment, which could effort the short interval in an economical way for determining the heating, cooling or lighting costs.

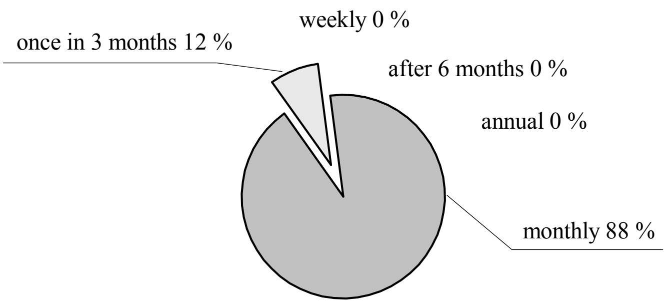

Figure 2. Bill intervals for operating costs

Another topic aimed to energy-saving behavior of the building users. In the survey the users have been asked, whether they see possibilities to save energy in their personal office surrounding. Half of the questioned persons specified, that they see obviously possibilities for energy saving (see figure 3). The answer shows the existing potentials for minimizing operating costs.

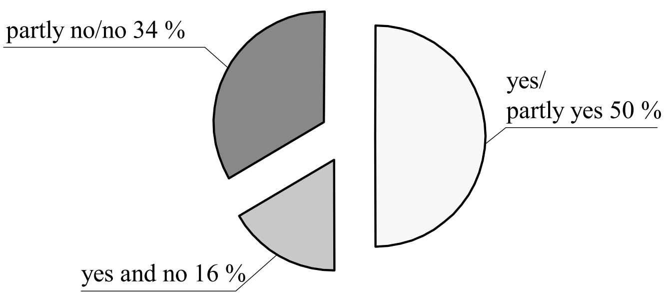

Figure 3. Office users answer of the question, whether they see possibilities to save energy in their personal office surrounding

The users expect from the single room automation possibilities of controlling their personal working environment. On the same way they demand a total automated procedure with integrated learning functions. Global aim therefore is the increasing of the comfort, combined with energy-saving settings of the actors in offices. Figure 4 shows clearly the preferential operating interfaces with the user for technical installations, especially heating, cooling and lighting.

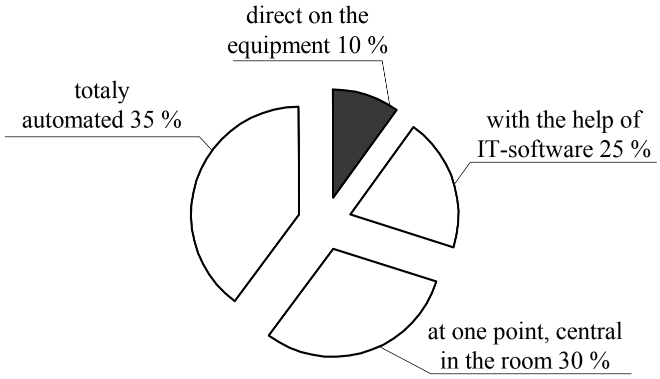

Figure 4. Preferential operating interface for technical installations in single rooms

The target for implementation of future service requirements is to combine the available central Building Control Systems and Building Automation with the established Facility Management Systems for an integrative concept. Within the development of open date sections and interfaces of the available Building Control Systems the present singularly and proprietarily used data will be provided to new knowledge-based services for an integrated Facility Management. Based on the gathered information the services can be more specialized to fulfill the users need. The supposition of such a system is an integrated database, that contains master data from the building and operating data from the Building Automations System.

2 IMPLEMENTATION OF KNOWLEDGE-BASED SERVICES

2.1 Knowledge-based Services

For services that use the information gathered from data of Building Automation System the word “knowledge-based services” will be introduced. Therefore the dataflow between the Building Automation System and Computer Aided Facility Management System (CAFM) needs to be open and standardized.

Figure 5 shows the different sources and interfaces that are required for a global data provision. For the most elements of the building information about their place, their producer or their state of the Building Automation (if existing) will be gathered in a central database. Therefore a unique data model and a large extend for standardization is needed.

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The development of open data interfaces for the different systems can provide a huge rate of information to service providers about building- and user-specific processes.

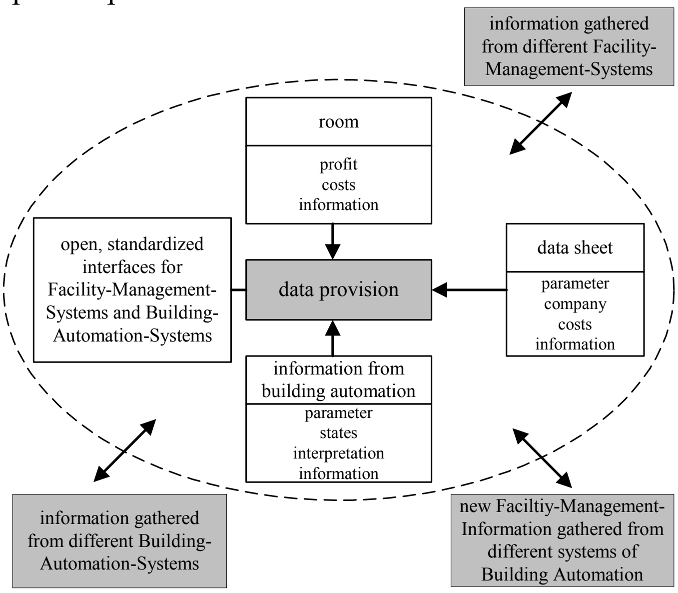

Figure 5. New data zones and interfaces between Facility Management Systems an Building Control Systems

As an example the following processes could be optimized or offered as new services:

- Maintenance of elements depending on the real amount of using,
- Allocation and billing of the used resources (energy, water) to their consumptions (room-specific and contemporary),
- Benchmark the behavior of the users with the provision of the depending controlling- and regulating-strategies,
- Justify services on conditions, which can be defined by evaluating data.

Profit of an integrated database for	
Building Automation	Building Management
- Adaptation of the regulating functions on the real room occupancy - Economical industrial management - Contemporary comfort	- Automatic transfer of data between the two systems (instead of manual transfer)
- Commercial and energetic comparison of consumptions and cashing - Free order of services	- Online information of building- and user- processes, like presence or disturbances
- Usage of the master data in the systems of Building Automation - Increase to building safety thru communication of different systems	- Contemporary monitoring and evaluation of specific benchmarks of the building, like cost of heating/m²·hour - Allocation of costs to separate renting areas

Figure 6. Advantages of open interfaces

Figure 6 summarizes many potentials for savings, which are provided by an integral database.

2.2 Concept of a Database-Structure and their Application

In the previous chapters the necessity and advantages of integrative data structures and a central database for Building Management was substantiated. Following the concept of a database-structure will be presented. The structure can be used even for the superior network-layer as for the field- and automation-layer in Building Automation Systems (LON, EIB). The diagrams in figure 7 show the tables of the database and describe essential functions of the performed attributes as well as the relations between the single components.

As an example the table Building-Automations-Information is described more in detail: They are standardized according to EN ISO 16484-3 (VDI 1314, part 2) and contain real and virtual information about the Building Automation states. Each information is dedicated to a physical address in the field-layer or is created virtual by the automation-layer. The table contains any kind of attributes like physical or virtual messages, states, analog measured values or switch orders.

In case of the sensor for open windows the following attributes in the table would occur:

– BA_ID	database-specific code for the window-sensor
– BA_info_name	00121=window
– BA_info_shortmessage	window 2 in room 123
– BA_info_type	0002=digital entrance
– BA_info_value	0=closed / 1=open
– BA_info_unit	0=none
– BA_info_time stamp	2005_09_11_14_25_12
– BA_info_actic/inacitv	0=active / 1=inactive

That specific information is primary used in the Building Automation for security reasons. In addition the window information can be used for heating, cooling and lighting. In combination with the presence-sensors the window-sensor can be used for an automatic controlling of room automation systems. For example the heating or cooling of the room could shout down, if there are open windows. In that case energy would be saved. Furthermore the information about the window can be use for Building Management tasks. For example the status of open windows could be monitored for the maintenance supervisor. If there is a need to close all windows at night, the supervisor can see on a screen which windows he has to close instead of watching all windows in each room separately. Such examples show clearly, in which different ways data can be used for services.

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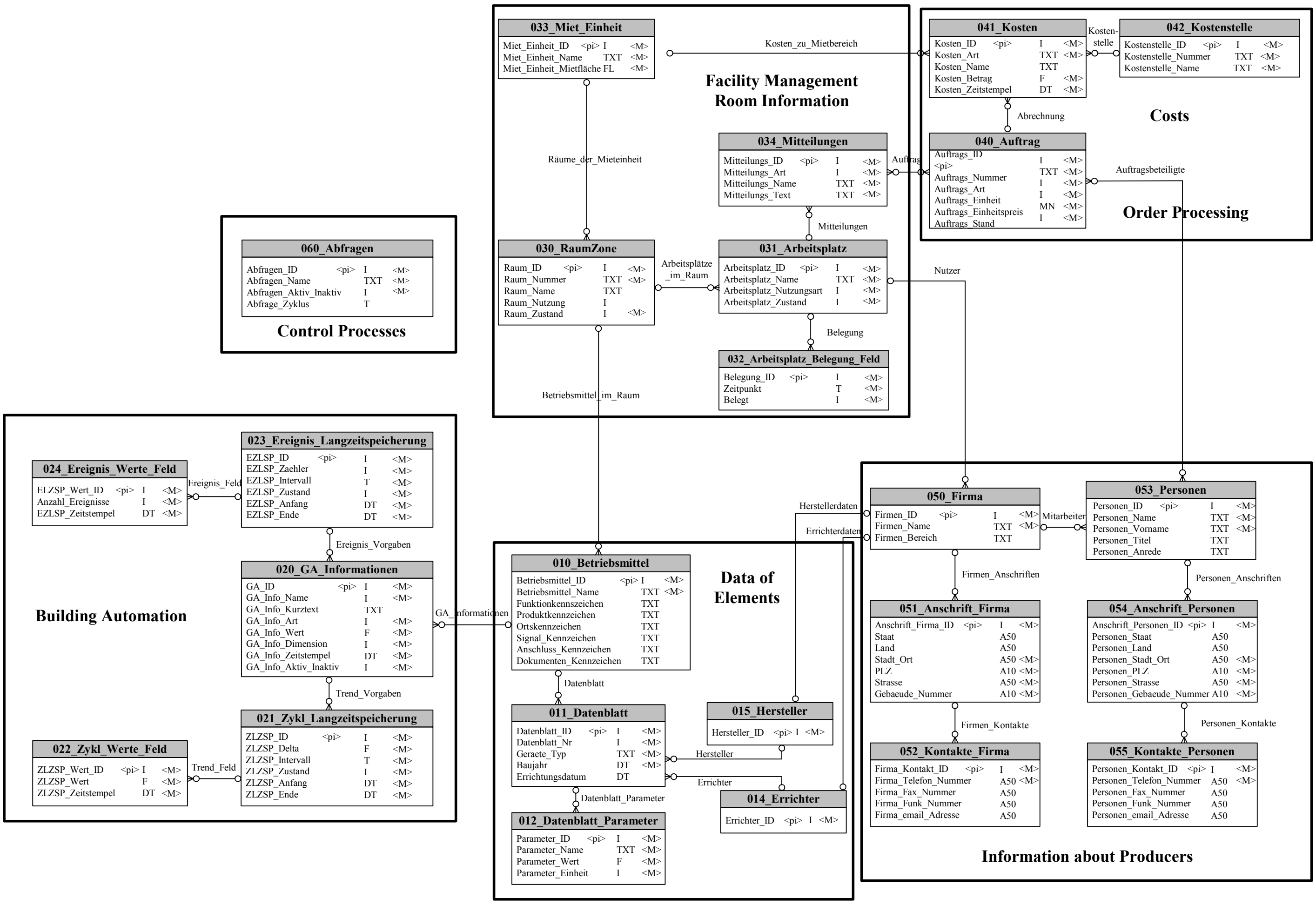

Figure 7. Concept of a database-structure

More examples for such knowledge-based services are described in chapter 3.

More detailed information of the database concept is specified in Schach/Kabitzsch/Höschele/Otto, 2005.

3 EXAMPLES OF KNOWLEDGE-BASED SERVICES

3.1 Virtual Counting and Allocation of Used Resources

German laws determine the accounting of heating in buildings, depending on the personal consumption. Through the introduction of that law the users are encouraged to safe energy, a total reducing of the heating energy consumption of 10 % to 25 % has been determined (Tritschler, 1999, p. 1). In opposite the personal and metrological expenditures have to be taken into account. Those financial expenditures are exceeded with the increasing heat insulation standard and much more efficient installation engineering (Koch, 2002, p. 1). Consequently the reduction of costs for the user-specific allocation is aspired. Beside the economical reasons the new requirements of the users need to be considered, like spatial and temporal allocation of costs for single rooms.

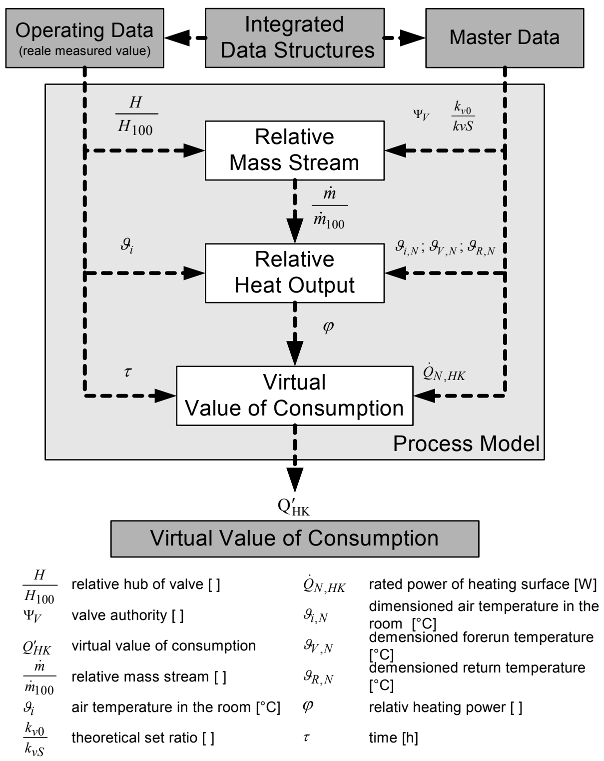

Figure 8. Process model of the virtual counting for a hot water heating with pumps

Therefore the virtual counting of used resources can be seen as a practical solution. Virtual counting means in that specific case the determination of the

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used energy for heating, cooling or lighting only by the master data and operating data (without special counters). A process model transfers the information received from the data into a virtual characteristic value of consumption. As an example a model of the virtual accounting of heating energy is shown in figure 8.

The figure shows the needed master data und the operating data, which have to be used for calculating the virtual characteristic value of consumption. Under the condition of free access to the data the registration and calculation could be totally automated. The kind of determination is very flexible and can be transformed without borders of time and space. Own tests resulted, that the safeness of correct results is higher than traditional measurement devices.

3.2 *Online Advisory Expert System*

The interpretation of the surveys gave the result, that office users wish to get support in the adjustment of their personal settings for air conditioning and lighting. Therefore a service like an Online Advisory Expert System could be provided. The system collects information about room conditions and evaluates the required results. The evaluation contains the automatic identification of energy-wasted settings (heating with open windows or lighting in empty rooms), gives a forecast of the expected costs and suggestions for optimizing the settings. The most important task for the Online Advisory Expert System is the communication with the office user. Each user has his own interface, which is available via Internet. On the same way the user can lay down settings via their personal desk computers. As an example figure 9 shows a possible user interface for the Online Advisory Expert System.

Figure 9. User interface for the Online Advisory Expert System.

The Advisory System is based on two different working regimes: the advisory and the automatic optimization. In case of the advisory the user gets presented the actual situation in the room, including the actual costs for using and advised recommendations for energy saving. In case of the automatic optimization the recommendations will be changed automatic by variation of the desired values. If wanted, the automatic optimization can be shut down.

More information, especially about the modeling of the background algorithms is given by Schach/ Kabitzsch/Höschele/Otto, 2005 or the conference article "Knowledge-Based Services in Building Management: Online Advisory Expert System" by Dementjev & Kabitzsch.

3.3 *Cleaning Management*

The cleaning of buildings is a service with high priority in Building Management. The fact causes on the conservation of the buildings value, high costs and the direct contact to the office users. Differences in the demanded price depend on

– expenditures of cleaning,
– frequency of cleaning and
– personal and material costs.

The most difficult problem with cleaning is the determining of the frequency (to keep the rooms in a defined clean condition) and the controlling of performance. Additionally it is nearly not possible to provide data about the real state of dirtiness and pollution. Often the rooms are cleaned without considering whether the room was used or not. For that specific case a research work determined that the dust pollution in used rooms is 10 times as high, as in rooms without any use. In conclusion a system needs to perceive, how often a room has been used. Figure 10 shows a possibility of a knowledge based cleaning service, that determines the real demand for cleaning from the data gathered from the Building Automation System. In that case it is possible to configure the cleaning activity conforming to the actual dust pollution. Therefore mainly the data of presence in room is needed to destine the value of usage.

The system bases on master data (areas, surfaces …) and operating data (presence, weather conditions …) of the integrated data structures. From the data base the data will be transferred contemporary to the software tool that derive the required information. Therefore regulations from the contract will be considered as well as administrative guidelines like performance benchmarks or number of available manpower. In addition the external short-term demands are taken into account (meetings rooms after their usage …). The result gives a cleaning plan for the building, which considers the actual cleaning demand with optimized sequences of operation.

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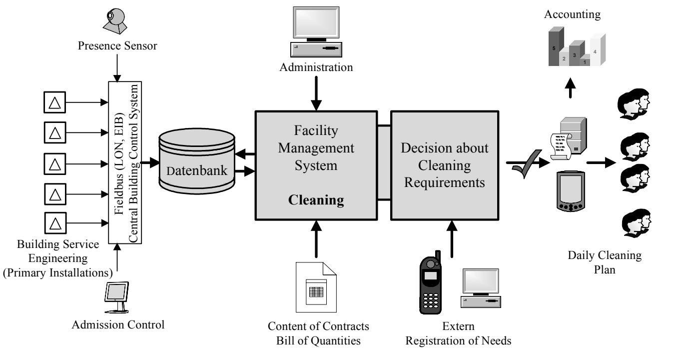

Figure 10. Registration and processing of the cleaning management

4 SUMMARY AND OUTLOOK

The present examples of knowledge-based services in Building Management give an overview in the different way of using integrated data structures. It can be seen as an attractive configuration and interactive support of the prime process of the clients. But for a practical implementation the appreciation of all responsible persons is needed for the necessity and advantages of open data structures. The main participants are the building owners and the producer of building service engineering. The building owners have to consider and plan a flexible and cost optimized using of their building. Therefore exact guidelines and sophisticated operating concepts, especially for standardized Building Automation Systems are prerequisites. On the other side the producers of building service engineering needs to disclose their proprietary data structures and use open, standardized structures like LON, EIB (KONNEX) and Backnet.

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Knowledge-Based Services in Building Management: Online Advisory Expert System

A. Dementjev & K. Kabitzsch
Institute for Applied Computer Science, Dresden University of Technology, Dresden, Germany

ABSTRACT: The results of investigations within the scope of the "Knowledge Based Services in Building Management" research project (Wissensintensive Dienstleistungen im Gebäudemanagement -WiDiG) and the concept of an online advisory expert system (consulting module) for building automation are substantiated in this paper. The trends of the further development of control algorithms of such systems are described. The objective of this project is to investigate the possibility and to produce recommendations for unification of the existing building automation systems and building management systems within the framework of a unified concept.

1 INTRODUCTION

Appearance of new services in facility management is possible only due to efficient usage of informational potential present in modern buildings. Such services (knowledge-based services) use information that is already present among the general data. Efficient usage of this information requires a close connection between the building automation and building management. This connection is carried out due to the application of universal database structures and open data profiles. Within the boarders of this project such structure has been developed and certain proposals to the open data profiles have been made. The concept of the online advisory expert system is presented here as an example of the knowledge based services in building management. In order to test the connection between the building automation and building management, a part of such unified database was created that was used further for conducting of experiments within this project.

2 STATE OF THE ART

Sufficient part of investments in the projects of construction or reconstruction of the buildings falls to the share of the building automation and building management. Joint action of such systems (i.e. common use of information and resources) has been difficult for a long time for the reason of extremely high costs of their combination. At present, as a result of attempts of standardization of information exchange methods (e.g. Data Communication Protocol (DIN EN ISO 16484-5, BACnet), Home and Building Electronic System (EN 50090, Konnex), Control Network Protocol (EN 14908, LONWORKS)), on the one hand, and reduction of hardware and software costs, on the other hand, combined action of these systems became profitable. The future trends in building automation are also described by Dietrich (2003a, b).

At present, the research in this line is conducted in many universities and research institutes. In (Laukner 2000), a decentralized intelligent control of building comfort parameters was proposed. The ventilation operation is optimized according to the criterion of minimum energy consumption with simultaneous support of air temperature within given limits. The proposed method guarantees the air exchange in buildings required by hygienic and construction regulations. In (Kuntze & Nirschl 1998), the development of an intelligent heating controller was proposed in order to optimize the admissible values of temperature depending on the initial climate and the number of persons in the building. In (Tamarit & Russ 2002), the Smart Kitchen project was presented. Its aim is to design a decentralized intelligent control system for a kitchen. Using a large number of sensors, this system has to recognize the situation and to react adequately using various actuators.

Recently, the capabilities of teleoperation and remote access have been used more frequently in building automation (Tarrini et al. 2002, Sauter & Schwaiger 2002). In (Corcoran et al. 1998), device variation for access to different home systems of automation and visualization of control processes such as web browsers, telephones with incorporated

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Java engines, TV sets with remote controls, and pocket computers with Internet access are described.

Modern state of building automation algorithms does not allow to involve users into the process of resource and energy management in a real time mode. At present, we do not yet have algorithms that could be able to explain to the user various alternatives of his actions to reach the desired comfort level, their sequence and their results. The subjective ideas of a user about what comfort is should be the source information for such algorithms. Information on energy consumption should be demonstrated to the user as an output, which may help him to find his individual compromise.

The present state of the art in the building automation, as it was already shown above, makes it possible to provide new services to users of buildings. Thus new solutions appear that make it possible to use limited resources more efficiently (Dementjev & Kabitzsch 2004b).

3 CONCEPT OF ONLINE ADVISORY EXPERT SYSTEM (OAES)

Considering different phases of building use, we can conclude that certain rooms in it should be considered main objects of automation. Note that, first of all, the main needs of users such as comfort, ergonomics, and efficiency should be taken into account. Consider the following examples of interaction of different automation subsystems aimed at meeting these requirements:

– Window opening with actuator connected to the room automation with using the blocking of energy supply in incorrect controlling cases, i.e. „heating actuator off";
– Use of building heat accumulation ability;
– Reduction of the lighting costs through various regulating strategies depending on the outdoor light intensity and room occupancy.

From the technical point of view, each building is a dynamic system offering therefore a certain potential for optimization. The analysis of the influence of various measures (e.g. choice of the required value of room air temperature, of air conditioning and of the way of heating) on the energy consumption proved that relatively large energy potential – up to 70 % - can be saved via reduced air conditioning (Hoh 2002).

At the same time, a building is a complex composed of a number of various service systems. The most processes within a building proceed in single rooms. As soon as the processes in each room are optimized, the whole building reaches the state of optimal mode.

Based on the most important cause-and-effect relations of physical processes in building automation (Dementjev & Kabitzsch 2004b), we can define several important rules for arranging such functional relations:

– „Heating actuators" can be replaced by „sunblinds", „windows", „ventilation", „lighting" and „inner heat sources". In former three cases the free of charge transportation of the necessary heat energy from outside into inside is used;
– „Cooling actuators" can be replaced by „sunblinds", „windows" and „ventilation", so the free of charge transportation of the needless heat energy from inside into outside;
– „Ventilation" can be replaced by „windows" , thus the free of charge transportation of the fresh air from outside into inside;
– „Lighting" can be replaced by „sunblinds".

The OAES was mainly aimed at solving the problem of optimal control of various subsystems of building automation. As a criterion of control optimality, the cost of the consumed heat and electric energy under supporting a given comfort level was taken.

The OAES should provide a user with the required information about the current state of the building (about the comfort level and the corresponding cost of its support), as well as recommendations in order to optimize the control of subsystems (suggestions of changing the setting of the building for controllers of temperature, illumination and recommendations for closing a window, opening jalousies, etc). The basic tasks of the OAES are as follows:

– consulting (short- and long-range data collections, recognition of the situations that lead to nonoptimal energy consumption, real-time calculation of the cost of the energy consumed, prediction of the development of different situations, consulting in itself),
– the connection with the building management (relation with external databases, remote access for users (visualization)),
– the connection with the lower automation level (the arrangement of connection with field level of automation, logical connection with a building (determination of the current building state)).

The Advisory System is based on two different working regimes: the advisory one and the one of automatic optimization. In case of the advisory mode, the actual situation in the room, including the actual costs for using and advised recommendations for energy saving, is presented to the user. In case of the automatic optimization mode, the recommendations will be changed automatically by variation of the desired values. The automatic optimization can be shut down if needed. Figure 1 illustrates algorithms of the energy consumption optimization.

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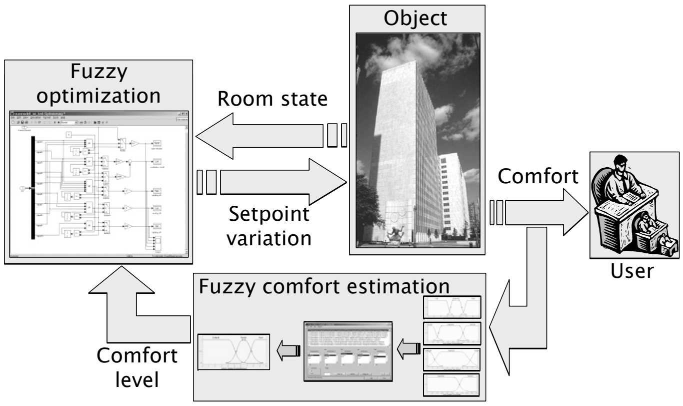

Figure 1. Algorithms of the energy consumption optimization.

Details of the online advisory expert system's architecture and of its realization are adduced in (Dementjev & Kabitzsch 2004a, b).

The main difference between the existing solutions and the Online Advisory Expert System consists in improved communication with the user based on a universal and open platform (open and independent service arrangement using the guidelines of Open Services Gateway initiative (see also www.osgi.org)). This system is not a purely automatic control system. It performs also consulting functions, e.g. the recognition of situations in the case of false or nonoptimal control of heating, ventilation, sunblinds etc., and warns the users (giving recommendations for optimal set point adjustment of controllers).

4 SIMULATION RESULTS

For checking the efficiency of the developed algorithms, a model showing the basic physical processes in a room was used. Results of the first simulations made in MATLAB proved that the offered algorithms let save up to 32% of consumed energy by heating (simulation of two weeks in winter with and without consulting module) and up to 36% of consumed energy by cooling (similar simulation for summer). Simulation results are presented in the Table 1.

Table 1. MATLAB simulation results for energy consumption.

Subsystem	Simulation period	Energy consumption, kWh		Saved energy, %
		conventional	with OAES	
Heating	2	39.82	27.32	32
Cooling	week in	0	0	0
Lighting	winter	6.08	6.07	~0
Heating	2	2.75	1.39	50
Cooling	week in	4.25	2.76	36
Lighting	summer	1.14	1.14	0

For solving the task of the prognosis of changes in the level of comfort and energy consumption, a neural network model showing the basic physical processes in a room was developed. The data of the simulation of the room model in MATLAB Simulink was used for training of the neural network. Neural network imitates the system of 14 inputs (actuators state, outer environment parameters etc.) and 1 output (e.g. comfort parameters: room temperature, light, air humidity or CO_2, or energy consumption for heating, lighting or cooling). Figure 2 illustrates neural network structure.

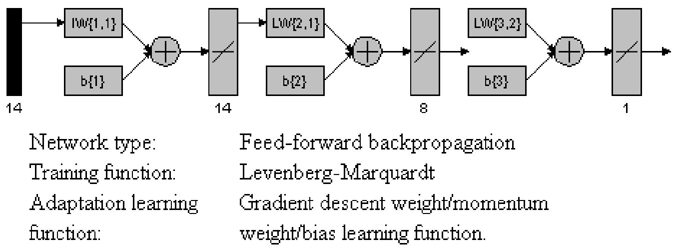

Figure 2. Neural network structure in MATLAB.

Figure 3 presents the neural network simulation results for room temperature. The maximum relative error by simulation is 3,53 % and the average relative error is 0,96 %.

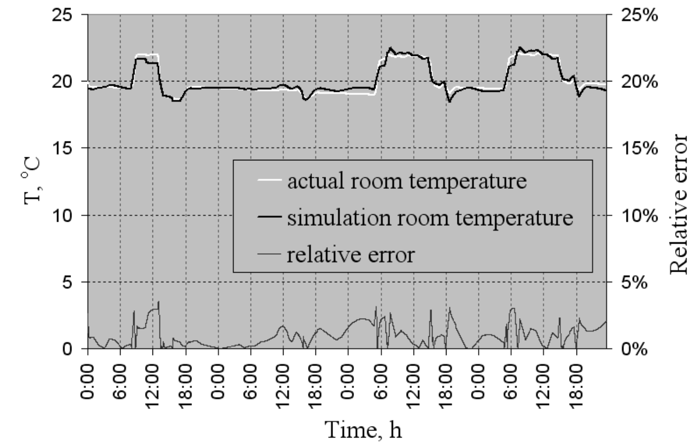

Figure 3. Neural network simulation results for room temperature.

To test the possibility of a hardware implementation of consulting algorithms, a physical model of a room (Fig. 4) was developed and produced. This model was equipped with all required sensors in order to determine the comfort level (sensors of indoor and outdoor temperature, relative humidity, and lighting), actuators (sunblinds, fans, lamps, heating and cooling elements), and controllers (a regulator of temperature and ventilation and a controller of the sunblinds and lighting).

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Figure 4. Room model for testing of the algorithms.

5 CONCEPT OF A DATABASE-STRUCTURE

As it was already mentioned in the introductory part, within the present project a universal database structure was developed providing the base for the cooperation of the building automation and building management, i.e. the base for new services in the building usage. More information, especially about this structure, is given by Schach et al. (2004), or by the conference article “Knowledge-Based Services in Building Management” by Schach & Otto.

To test the efficiency of the offered database structure, a part of it meant for data collection in the building automation and serving as an interface between the building automation and building management was realized. It is presented in the Figure 5.

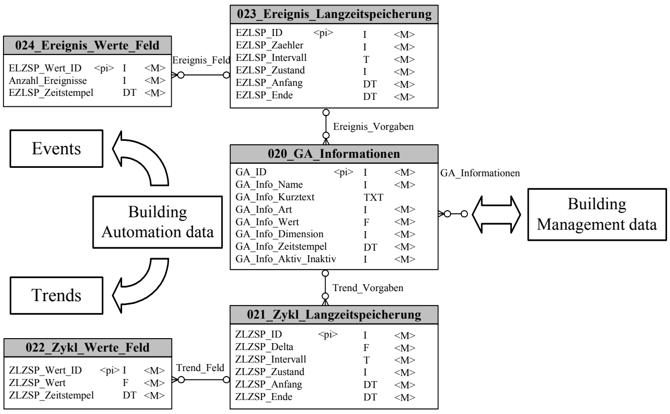

Figure 5. Database realized part’s structure.

That resulted in creation of the program LonMonitor capturing information in building automation (e.g. from LONWORKS) and saving it as events or trends (in the format MS Access). The program provides a wide range of possibilities of data acquisition filters setup, data collection's automatic start and stop, physical interface selection etc. Different variants of remote program's access to the building automation data are studied now. The gateway OSGi to LONWORKS has been already applied as one of the variants (see also Echelon 2003).

Developed program can be used not only as a simple interface between the building automation and building management, but also for the control network monitoring with the purpose of control processes investigation. The main suppliers of information for investigation of the control processes are the so-called network variables (i.e. process variables) whose values are recorded by the LonMonitor in the universal database together with their time stamps. The LonMonitor directly interacts the database of the automation system project (for LONWORKS it's LNS database) in order to get access to the process data chosen by the user in advance by means of the filters system. Gained data saved in the database are used later for the process analysis, its protocolling etc.

6 CONCLUSION

Consulting algorithms were developed on the basis of fuzzy logic and neural networks with corresponding development and simulation environment and the simulation results already exist. In order to test the algorithm, a room model in MATLAB Simulink (representing the most important physical features of a room) and a physical room model were made. During the testing of the proposed service models, an embedded server with OSGi framework was installed and the possibilities of remote access to field bus (LONWORKS) per Internet were proved.

7 ACKNOWLEDGEMENT

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Facility Management (FM) Information Systems, Key Tasks and Implementation Tools

G.G. Malycha & V. N. Kolchin
Moscow State University of Civil Engineering, Moscow, Russia

ABSTRACT: Facility Management (FM) Information System is designed mainly for the large enterprises and organizations with centralized management that have dozens and hundreds of buildings, many employees and pieces of equipment. FM system permits to create the modern information technology supporting the life cycle of the construction project during its maintenance. The main tasks of FM system are: financial and marketing management of the building; summarizing and presenting the technical and economic information; planning for and decrease of the maintenance costs; presenting the information about the realty status for strategic administrative decision-making; timely servicing, repair and reconstruction; inventory of the movable equipment and furniture; management of the buildings, staff and cleaning; management of the realty and rental.

Presently there are many information systems with various functions and many manufacturing firms in the software market. These systems allow solving at a high level practically any architectural, design, calculation and other tasks. However, availability of separate systems cannot give a certain actual idea about the construction project.

That is why FM system should become the module subsystem of the integrated information system (IIS), which is the assemblage of automated information systems realized on the common information basis and oriented on the optimal management of the construction project maintenance throughout its life-cycle.

The IIS core may become the basis for uniting all the subsystems of the automated information technology into a single whole. It provides for a possibility to integrate the technical, administrative and commercial information into a single system that shall contribute to ordering of the information development and storage, eliminate the losses of the information objects, accelerate their searching and decrease the number of errors in them. As an essential object, the core includes the information channel providing for the information interchange between the modules. The IIS shall include the hardware, software and dataware, and various modules-subsystems for maintaining the life cycle of the building.

1 INTRODUCTION

Facility Management (FM) is designed mainly for the large enterprises and organizations with centralized management that have dozens and hundreds of buildings, many employees and pieces of equipment. FM system permits to create the modern information technology supporting the life cycle of the construction project during its maintenance. The main tasks of FM system are: financial and marketing management of the building; summarizing and presenting the technical and economic information; planning for and decrease of the maintenance costs; presenting the information about the realty status for strategic administrative decision-making; timely servicing, repair and reconstruction; inventory of the movable equipment and furniture; management of the buildings, staff and cleaning; management of the realty and rental.

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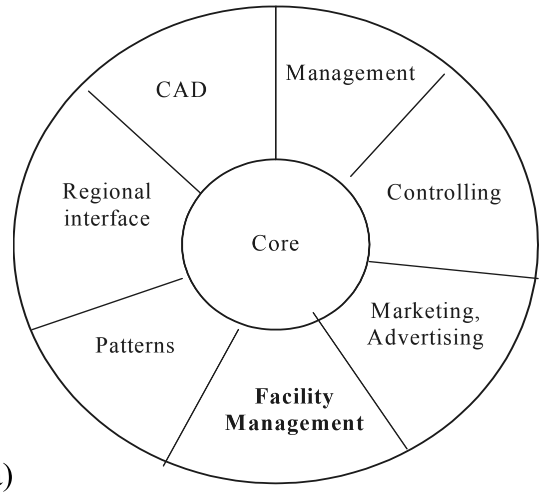
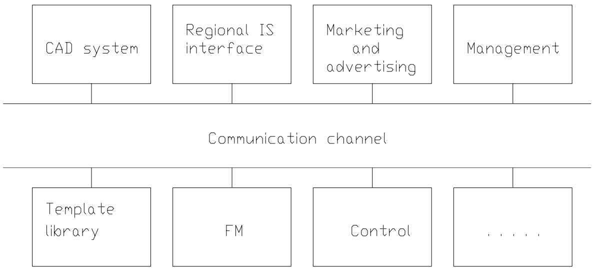


a)



b)

Figure 1. Module structure diagram of an integrated information system with a basis in the form of a: a) kernel; b) communication channel

The IIS core may become the basis for uniting all the subsystems of the automated information technology into a single whole. It provides for a possibility to integrate the technical, administrative and commercial information into a single system that shall contribute to ordering of the information development and storage, eliminate the losses of the information objects, accelerate their searching and decrease the number of errors in them. As an essential object, the core includes the information channel providing for the information interchange between the modules (Fig. 1). The IIS shall include the hardware, software and dataware, and various modules-subsystems for maintaining the life cycle of the building. The subsystems may also include the modules of automated designing, of interface with regional information system and the FM system modules.

The IIS core is a model management system and can be presented as a series of subsystems (Fig.2). Let us consider the core subsystems' functions.

Subsystem of identification and data processing permits to set and change inside the IIS core the system of identification of the information about the object. The conception of the integrated information system presumes the availability of a single system for identification of the object information model throughout its life cycle.

Configuration subsystem. This subsystem sets the configuration of the IIS, namely the task of the architectural network, of the hardware and software being used, and provides the system of accesses. It also processes the data and prepares the formats to be used in the next subsystems.

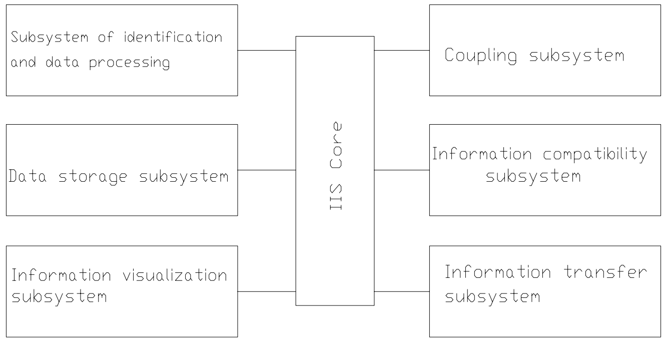


Figure 2. IIS kernel structure

Data storage subsystem provides for the archive management, selection of relevant data, effective and fast search, as well as for the communication between the core and the IIS databank.

Information visualization subsystem provides the user with user-friendly graphic and alphanumeric interface for reading the information about the object and taking decisions about further use of the information.

Coupling subsystem permits to create for all the module subsystem the single system of using CAD based on the object-oriented approach and making it possible to edit, change and save the relevant information model of the object.

Information compatibility subsystem processes the information model for use in the other CADs.

Information transfer subsystem permits to ensure the convenient servicing of the users working in the net, as well as to select only the relevant information out of the whole information being transferred, to be transmitted in the net.

It is necessary to keep in mind that the core does not have a function of controlling the entire IIS, but it only provides for its operation being to a certain extent the system's server. Each module within the integrated information system performs its own tasks under control of the responsible people in the interests of all simultaneously accomplished projects.

2 FACILITY MANAGEMENT SYSTEM IN THE INTEGRATED INFORMATION SYSTEM

The FM system may be presented in the form of a functional model that incorporates its own FM system kernel and FM module sub-systems, whose range depends on a specific list of tasks (Fig. 3).

The construction project model may be presented as files that store the graphic and alphanumeric information about the object (DXF, DWG, TXT, DOC and other formats). Apart from this, the model may

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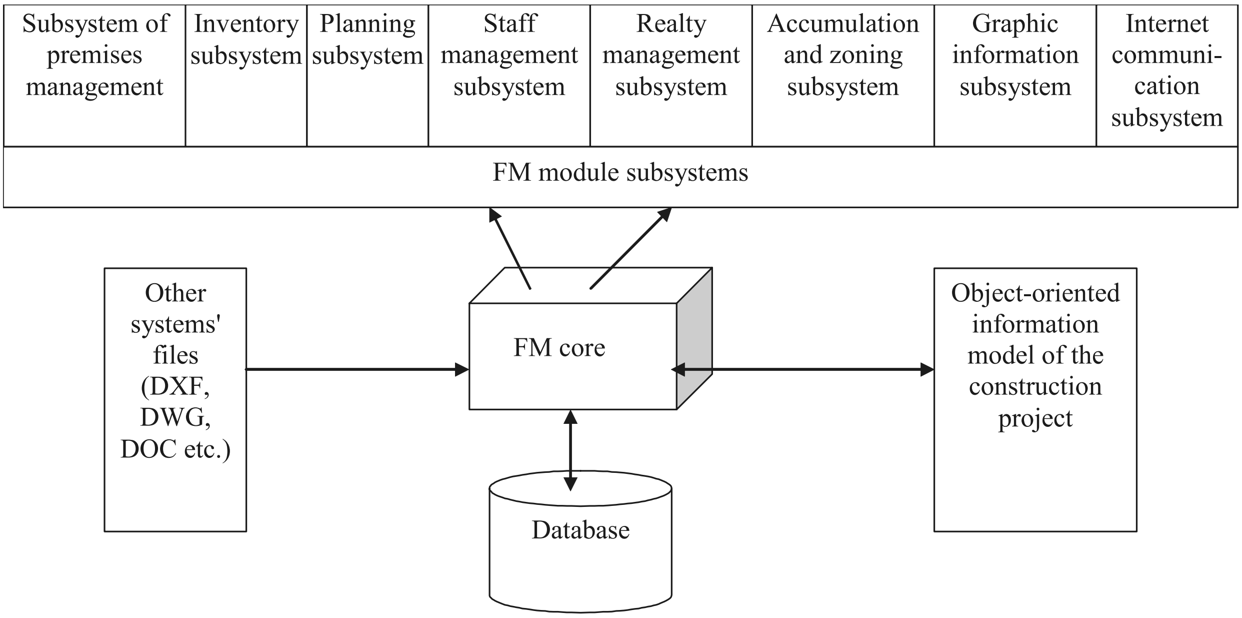

Figure 4. Architecture module of the Facility Management

be created using the object-oriented approach, which allows describing the graphic and alphanumeric information about the object as a class library.

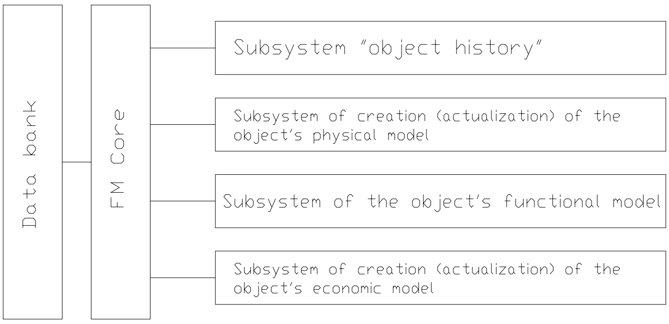

Figure 3. A functional model of a FM system

Subsystem "object history" permits to systemize all the information about the object as applies to the stages preceding the maintenance. The user is enabled to read the information.

Subsystem of creation (actualization) of the object's physical model permits to create, using the core subsystem, the new or edited model that stores the data on geometry, material, equipment, articles, technology, color of the object, and can present the decision in the user-friendly form: plans, sections, elevations, specifications, parts etc.

Subsystem of the object's functional model permits to determine and identify, based on the physical model, the premises, staff, communication system, inventory and equipment, to edit (change) the parameters in the graphic and alphanumeric mode, using the system core, and to store the actual model.

Subsystem of creation (actualization) of the object's economic model permits to solve, based on the physical and functional models, the economic tasks of the managing company and maintenance service, associated with the bookkeeping, calculation of costs and profit, managing the finances, planning for the expenses (budget), statics and assessment of the construction project effectiveness factors.

The architecture of the FM system is shown in the diagram (Fig. 4).

The FM module subsystems are usually divided into the following ones:

Subsystem of premises management ensures the optimal use of premises and working area;

Inventory subsystem unites the data distributed among various divisions and systems of the enterprise and controls the change of the information about the location and cost of the equipment and inventory;

Planning subsystem works out the strategic plans based on the scripts and current data;

Staff management subsystem plans and monitors the staff movement and ensures the integrity of the database under various changes;

Realty management subsystem monitors and analyses the property and rental relations; it also presents the financial, historical and market information that reflects the expenses on the purchase of the land, buildings, constructions and rental relationships;

Accumulation and zoning subsystem allocates the projects, organizations, individuals and equipment (in the cities, buildings, floors, zones and working areas);

Graphic information subsystem coordinates the graphic information in the wide spectrum of management functions. The data of the CAD systems are used for the information input. It is possible to use one's own or borrowed graphic expression system in the interactive mode;

Internet communication subsystem ensures the interaction of the distant management system elements.

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3 IMPLEMANTATION OF A FACILITY MANAGEMENT SYSTEM

This concept describes how to use computerized facility management information technologies or, shortly, “Facility Management”– FM.

Key objectives and characteristics of Facilities Management

The primary goal of the FM implementation project is to create a multi-functional facility management system with the use of modern information technology.

The key objectives of such management systems are the following:

- Provision of data for strategic decision making
- Examination of the characteristics of premises and of other components of a building
- Financial management and marketing of a building
- Real estate and leasing relationship management
- Inventory of movable equipment and furniture
- Personnel management.

The FM system is intended, primarily, for large companies and organizations with centralized administration and dozens and hundreds of premises, a large labor force, and a substantial body of equipment. It does not matter whether the premises are located in one building, one city or in different cities. The system is managed and updated on an on-going basis in accordance with the actual changes that take place in the organization. FM should be distinguished from automatic process control systems (APCS); the purpose of an FM is to provide information to the company’s management and to assist it in strategic decision-making, and not to directly interfere in technological processes.

The employment of modern information technologies makes it possible to transform graphics and related documents into electronic form; timely introduce changes and corrections; timely link accounting information with databases of other information systems of the company; and set up a required amount of automated workstations provding simultaneous access to current operational information. If needed, hard copies of graphic materials may be printed for operations.

Since graphic data is presented in electronic form, there are no longer any limitation on drawing dimensions. The user is able to move around the sheet in any direction thanks to the so-called “seamless” display of graphic data. The mechanism that scales and controls the content of displayed data allows to solve the problem of data limitation typical of hard copies. By selecting a facility on the diagram, the user gains access to all currently available data on this facility by switching from the diagram to data. Reverse action is also possible by switching from tabular data to diagrams with selected facilities.

3.1 Task definition

Design a system for managing premises and an inventory. For this purpose the following should be developed:

- Graphic user interface
- Sub-system and key principles of data storage and retrieval (including backup storage)
- Sub-system for displaying data in graphic and electronic form
- Sub-system for managing the units of the system and the key principles of these units interaction

3.2 Main development phases

In the course of the first phase, all the main attributes of the system were studied and identified, as well as its capabilities in terms of the defined task.

The basic principles and classes of graphic user interface were also developed during this phase and included the following:

- Graphic interface classes responsible for command buttons, menu, display field, and information panel
- Graphic interface classes responsible for the drawing of lines, nodes and cells
- Graphic interface classes responsible for text drawing
- Graphic interface classes responsible for equipment drawing
- A class responsible for data storage and retrieval
- Principles of object creation, interaction and deletion, as well as their storage during system operation

In the course of the second phase, both the graphic user interface and the general structure of the system were changed. In particular, the graphic user interface was completely modified, becoming much more attractive and, most importantly, more convenient for the user. New capabilities were added in the process of altering the graphic interface. They include:

- Scaling
- Employment of user units of measurement and automatic conversion of in-system measurement units (pixels) to millimeters
- A possibility to scroll the display field vertically and horizontally
- Grid parameter setting by the user and changing these parameters in the process of working with the program
- Returning to initial grid parameters

In the course of further alteration, the general structure of the system was changed to become as flexible and convenient as possible. This new structure allows to quite promptly and with minimal changes of the structure to install new upgraded functions and capabilities.

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This made it possible to include in the system a new class required for the smooth operation of the system. This new class is responsible for "Editors" which allow changing such attributes of graphic objects as lines, nodes, text, etc. This class is universal and may be applied to any object of the system, including those that are currently under development.

3.3 *Graphic interface description*

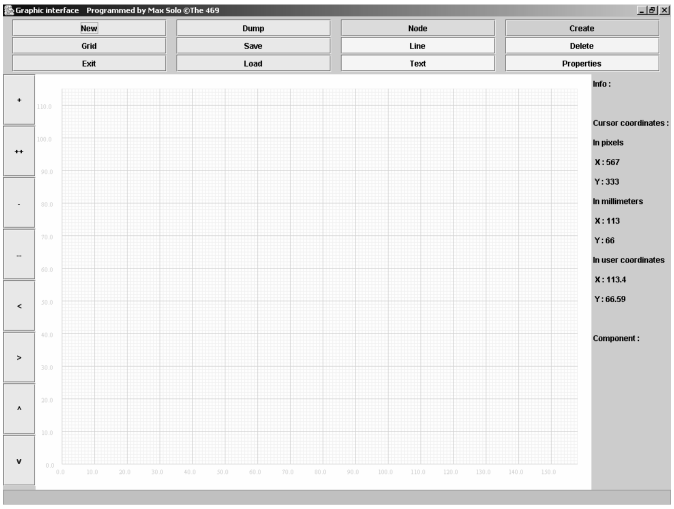

Figure 5. General view

The basic program modes menu is located in the upper part of the interface (cf. figure 5 and figure 6).

Figure 6. Basic Program Menu

– Basic modes: Create, Delete, and Properties, These three basic modes allow creating, deleting and changing or viewing the properties of graphic objects.
– Modes of graphic objects: Node, Line, and Text. These command buttons allow switching among graphic objects and working with each of them separately.
– The remaining buttons are responsible for creating a new display field, setting grid parameters, storing and retrieving entered data, etc.

Command buttons for controlling the display field and changing the scale and position of the display field are located in the left part of the interface (s. figure 7).

Figure 7. Command Buttons

The display field is presented as a graphic field with a grid (graph paper) and number marking for identifying the distance between the lines of the grid (s. figure 8). On this filed the user can draw and edit a floor plan. This graphic interface allows to create plans of practically any level of complexity.

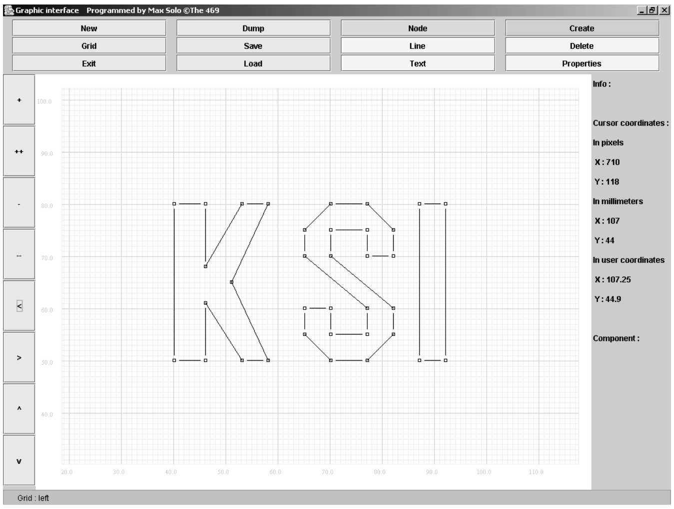

Figure 8. Display Field

The information panel is located in the right part of the interface. This panel shows information about the object, with which the user is currently working, the cursor position, and the coordinates in pixels (in-system measurement unit), millimeters and in user coordinates. This panel also shows information about the type of the object, its title and exact coordinates of its location (this data is stored in the object).

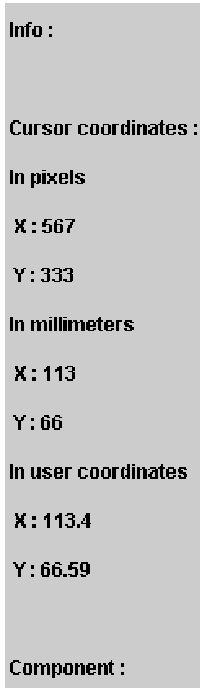

Figure 8. Information Panel

3.4 *Current development phase:*

At the current phase the following classes are being developed:
– Cell drawing class
– Equipment drawing class
– Class for displaying objects of the system in text form (as tables).

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RFID applied to the built environment: Buried Asset Tagging and Tracking System

K. Dziadak, J. Sommerville & B. Kumar
School of the Built and Natural Environment, Glasgow Caledonian University, Glasgow, Scotland

J. Green
Spartan Solutions, Glasgow, Scotland

ABSTRACT: Within this paper we argue that underground utilities are an area where RFID technology can be applied, with a high degree of accuracy, to locate the buried pipes and others underground equipment. The paper describes an ongoing project to develop a Buried Asset Tagging and Tracking System (BATTS) using RFID technology. Results from initial field trials are considered and issues and concerns relating to developing such an application of RFID are discussed.

1 INTRODUCTION

Underground pipes carry vital services such as water, gas, electricity and communications. In doing so, they create what may be perceived as a hidden map of underground infrastructure. In the all too common event of damage being occasioned to these services, the burst brings about widespread disruption and significant 'upstream' and 'downstream' losses. Digging in the ground without knowledge of where the buried assets lie could isolate a whole community from emergency services such as fire, police and ambulance, as well as from water, gas and electricity services. It is not only dangerous for people who are directly affected by the damage but also for workers who are digging, for example, near gas pipes without knowing their specific location (Dial-Before-You-Dig, 2005).

Time and effort, as well as thousands of pounds, have to be spent on locating and repairing damaged pipes (Northcutt, 2005). This is why accurate data and efficient maintenance of buried assets are a high priority for utility companies.

There is generally a lack of precision in the data with relation to the location of a wide range of underground infrastructure. Cases of significant discrepancies arising between 'what and where' buried assets should be and 'what and where' really are, are not uncommon.

In the United Kingdom there are a range of bodies searching for new solutions and techniques for best describing how we locate buried assets e.g. Water Research Centre (WRc), UK Water Industry Research and the Natural Environment Research Council (NERC).

Various methods are used to pinpoint the location of these buried assets. Some of these approaches utilise destructive methods, such as soil borings, test pits, hand excavation, and vacuum excavation. There are also geophysical methods, which are non-destructive: these involve the use of waves or fields, such as seismic waves, magnetic fields, electric fields, temperature fields, nuclear methods and gas detection, to locate underground assets (Statement of need, 1999).

What may be perceived as the current most effective geophysical method is Ground Penetrating Radar (GPR). This system uses radio frequency signals to penetrate, characterize and monitor items underground (New Techniques for Precisely Locating Buried Infrastructure, 2001; Olheoft, 2004). This technique has the capability of identifying metal assets but is not able to give accurate data about the depth of the object, which is important information for utility companies. The GPR approach is likely to be affected by other metallic objects in close proximity to the asset being sought.

Another widely used method of locating underground infrastructure is Radio-detection, which is based on the principle of low frequency electromagnetic radiation. This technique uses active and passive methods to locate buried assets. However it is unable to detect non-metallic buried plastic, water, gas and clay drainage pipes (Radio-detection, 2003). Some pipe materials are non-metallic and more difficult to locate with conventional pipe location technologies (Radio-detection, 2003). Combining Radio-detection with GPR opens up the possibility of locating non-metallic pipes (Underground Utility mapping, 2005). However, the technique becomes more complicated.

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All of the above methods are useful in varying degrees but none gives the degree of accuracy required by SUSIEPHONE and UK legislation e.g. the New Roads and Street Works Act 1991, the Traffic Management Act 2004 and Codes of Practice. Unfortunately, thus far none of these methods is able to provide accurate and comprehensive data on the location of non-metallic buried pipes (ITRC, 2003). The shortcomings of the above methods are summarized below:

- They cannot locate non-metallic utilities.
- They cannot be used in all types of soils.
- They cannot penetrate to required depths.
- They use perilous/dangerous/complex equipment that increases risks and costs of operation.

Utility companies are looking for a solution which provides a more accurate and comprehensive method of locating and marking modern flexible plastic pipes. They are also interested in data management methods that will facilitate the collection, storage and updating of information concerning the utilities (Statement of need, 1999).

It may be that a possible solution to this problem lies in the development of a Radio Frequency Identification Device (RFID) system which provides data on asset spatial functionality, and is tied into a high definition underground utilities mapping system.

Use of RFID has the potential to revolutionise the approach away from using inaccurate underground mapping systems to a more accurate and up to date approach.

2 AIM OF THE RESEARCH

The aim of the research is to develop a system capable of accurately identifying the precise location of assets buried underground (non-metallic pipes) using Radio Frequency Identification Devices RFID technology.

The ultimate goal of the project is to identify the location (depth) of buried assets up to 3m within an accuracy of +/-5cm and to relate the location of buried assets to a Global Positioning System (GPS), Geographic Information Systems (GIS), and UK's Ordnance Survey (OS) framework and to record it to the UK's Digital National Framework (DNF).

2.1 *About RFID*

RFID technology consists of three components: an antenna, a transceiver (the reader) and a transponder (the tag). Once activated, the tag transmits data back to the antenna. The technology benefits from the fact that no line of sight is needed to control/operate the system. The tags can have both read and write abilities whilst the device is in use. There are two types of tags: passive and active.

A *passive transponder* allows a computer to identify an object. It must be used with an active sensor that decodes and transcribes the data the transponder contains. The transponder unit can be physically tiny, and its information can be sensed up to several feet away.

An *active transponder* refers to RFID tags which have their own power source, so they can receive a weaker signal from the reader (i.e. be further away), and the power source on the tag boosts the return signal: battery life is a limiting factor in these tags.

Tags are available in different frequency ranges: LF (low frequency) 125 - 135 kHz; HF (high frequency) 13.56MHz; UHF (ultra high frequency) 868-930MHz; and, Microwave 2.45GHz and 5.8GHz. The performance characteristics of the tag change depending on the frequency.

In this research, LF devices will be tested: the reason for this being that a low-frequency RFID system is better able to penetrate non-metallic substances. It is ideal for scanning objects with a high liquid content. The system will also be more tolerant to obstacles.

2.2 *Objectives*

The objectives of this research are as follows:

- To construct and synthesise a detailed body of knowledge on the current approaches to buried asset location.
- To develop a route forward for a novel approaches using RFID.
- To develop a prototype system and trial in the field.
- To collect field data and analyse using appropriate statistical and drawing packages.
- To refine the system and relate to the developed body of knowledge.
- To validate the system developed and report on the work.

3 RESEARCH METHOD

This research is founded on a quantitative research methodology using an experimental design method. General principles of the usage of quantitative analysis in research are that it facilitates (Leedy, D Paul: Practical Research; E Arnold: RM in the SS):

- Planning the analysis before undertaking it
- Ensuring familiarity with the methods of analysis in the field of study
- Deciding upon the method of analysis to be used
- Deciding on the use of computer package(s) (if necessary) for the analysis
- Gathering data around this method of analysis
- Analysing the gathered data
- Testing the results to ensure reliability.

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The field methodology was bifurcated into two phases:

Phase 1

This phase determined an appropriate RFID tag/antennae and reader configuration which would give accurate depth and location indications at up to, and including, 2.0m below surface level.

Phase 2

After the basic principles of the location system have been proven in Phase 1, Phase 2 will focus on the following steps:

- Improving the tag reading performance to 3m below ground.
- Improving depth and positional accuracy to 5cm.
- Make the locating system mobile.
- Providing more accurate data on performance through differing types of
- ground/soil material.
- Providing a GPS system fix for the asset.
- Overlaying the depth and track data onto an Ordinance Survey (OS) map and GIS system.

Further improvement to the operating system can be envisioned using active rather than passive tags as the latter provides a much greater signal range. Using an active tag to optimize the performance of the system at a lower than standard frequency will require a custom manufactured tag.

4 FINDINGS

4.1 *Tests in the air*

Initial air tests were carried out at a training facility near Glasgow.

A series of air tests were run with the aim being to ascertain the connectivity between each of the three tags (transponder) with each of the four antennae. The data generated from these test is presented below:

Table 1 Tag's specification

Symbol	Transponder
T1	LTag
T2	MTag
T3	STag

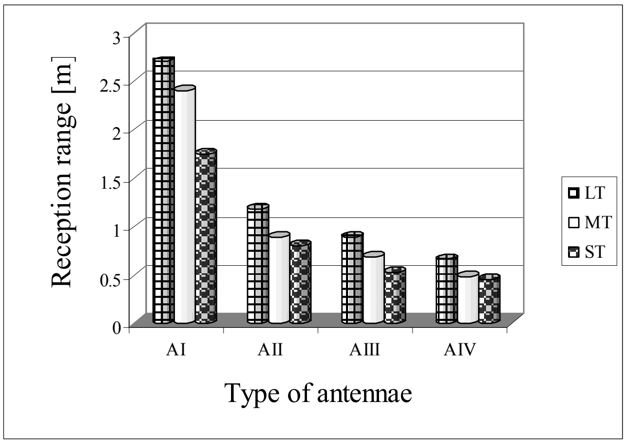
Table 2 Antennae's specification

Symbol	Antennae
AI	L1
AII	L2
AIII	M1
AIV	S1

Initially 12 tests were run to determine the greatest signal reception range between the antennae and the tags. The best results are summarized in the Table 3 below. It should be noted that due to weather constraints the general number of tests both in air and below ground were curtailed and will be expanded at a later date.

Table 3

	L tag	M tag	S tag
	metres	metres	Metres
AI	2.7	2.4	1.75
AII	0.664	0.485	0.455
AIII	0.895	0.69	0.53
AIV	1.185	0.885	0.805



4.2 *Data Analysis*

To make sure that the measurements are accurate the distance presented in Table 3 was taken when the signal sent from the antennae to the tag was continuous, without any interference.

Results in Table 3 showed that the longest acceptable signal reception ranges can be achieved when antenna AI is connected with T1 or with T2.

Air tests also showed that the worst performances are between antennae AIV when tested in conjunction with all tag types. Hence, AIV was eliminated from further examination. Antennae AI, AII and AIII were then tested with an underground signal.

Air tests allow testing effective performance of each tag and reader combination and create zones of magnetic field between each of the tags with each of the antennae. This information shows the range of magnetic field within which the technology can operate.

Figures: 1, 2 and 3 present a range of signal patterns created between antenna AI and tag T2 depending on the antenna position.

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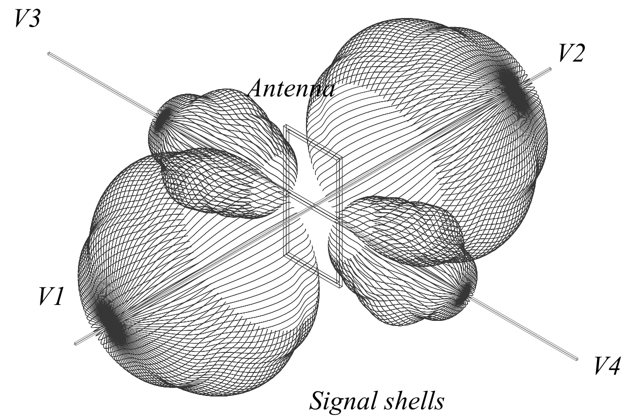

Figure 1. Antenna positioned vertically

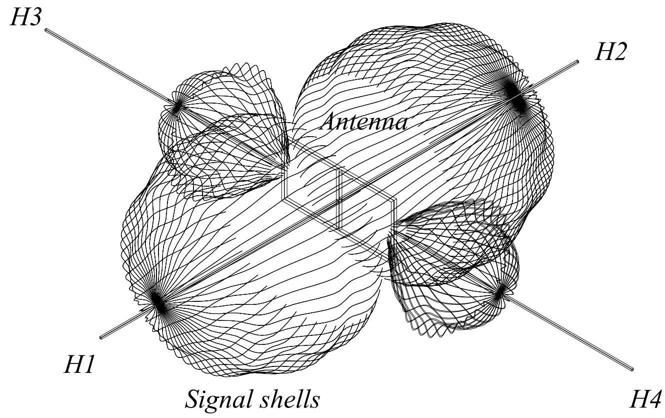

Figure 2. Antenna positioned horizontally.

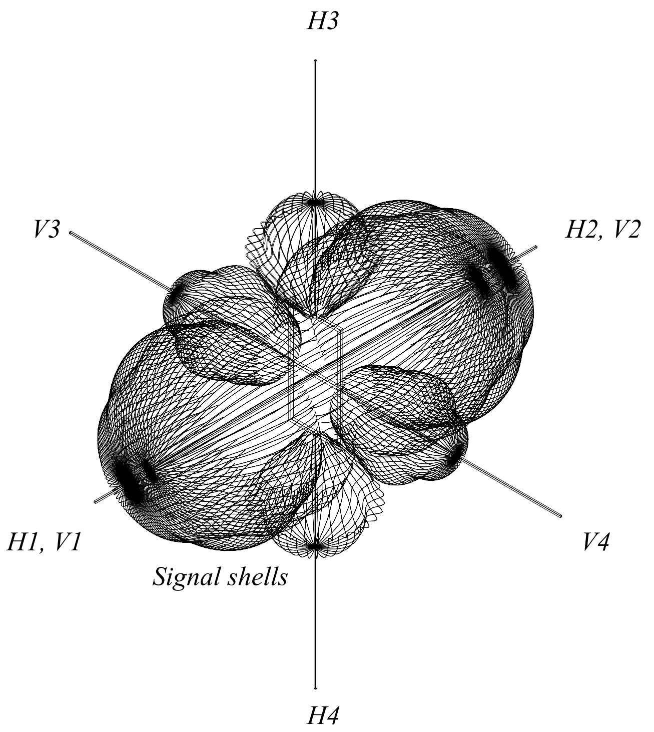

Figure 3. Superimposed reception shells.

In *Figure 1* antenna was positioned vertically. We can see that there are two sizes of shells. Bigger shells lie on axes *V1* and *V2* and smaller on *V3* and *V4*. The reason behind this is the size of the antenna: the larger the antenna is, the greater the capture of the magnetic field/signal generated by the tag.

Figure 2 shows the antenna in horizontal orientation. The description is similar to the one given in *Figure 1*. Again we can observe two sizes of the shells which shows the reception range of the signal in this orientation.

Figure 3 Indicates the combined reception shells for both orientations. It is clear that the antenna is capable of directionally locating the tag. This directional capability allows us to eliminate spurious signals and so concentrate on the desired signal from the tag i.e. the larger signals can be attenuated.

4.3 *Underground Test*

Due to weather and operational constraints, we have only been able to execute one series of field tests.

At this early stage of the field trials we have successfully tested antenna AI with tag T2. Tests were carried at increasingly different depths until the required 2m depth was achieved.

An implicit part of the investigation is aimed at ascertaining the extent of soil conditions that could affect the reception of test findings.

For completeness we carried out and compared tests when:

– the separation between the tag and antenna was only soil (Figure 4)
– half of the distance was in soil and the other half was air (Figure 5)

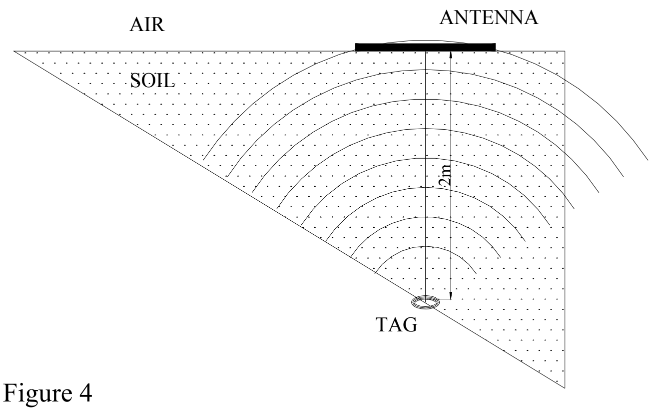

Figure 4

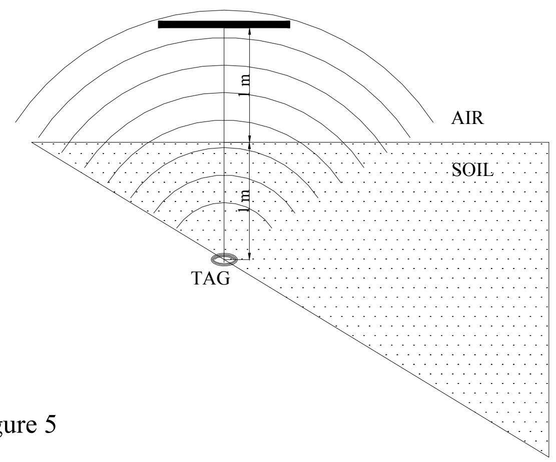

Figure 5

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The first test showed that the presence of soil had only a slight (negligible) effect on performance. However, in the United Kingdom there are six general types of soil: clay, sandy, silty, peaty, chalky, and loamy. All of them have their own characteristics. The most important properties of soil are: hydraulic conductivity, soil moisture retention and pathways of water movement (Jarvis, Soil Information, 2004). And it is possible that different soil condition/types can affect the performance and its accuracy.

Future work will focus on the impact of varying soil conditions on reception and accuracy.

The future work also include examining antenna AI with two more tags as well as antennae AII and AIII with all tags. It is anticipated that this will result in indications as to the size and shape of antenna which can achieve the required depth and accuracy. Upon completion the tests will be repeated to ensure that the data collection is accurate.

We will carry more tests by changing the soil conditions and pipe types respectively. Upon completion of this range of field trials and analysis of the generated data, we will have an overview of the system and its efficiency.

5 CONCLUSION

From the air tests we developed the ideal combination between antennae and tags. These tests allowed us to establish reception shells and expected reception ranges.

Underground tests let us established reception at a range of depths through one soil type. As the tests progressed we were able to receive a signal at the target depth outlined in *Phase 1* (2m). We also discovered that soil characteristic may not affect the reception.

These early results are encouraging, and they seem to indicate that an answer to identifying non-metallic underground/buried assets does lie in the use of RFID technology.

As had been stated, a considerable amount of development work is still to be done to arrive at a fully operational system. A successful beginning has been made at last. Our next step will focus on improving the accuracy of reception range.

RFID technology is becoming ubiquitous: the proliferation of RFID systems suggests that they will be all pervasive, and there is no doubt that RFID is set to have a tremendous impact on all major industries. As RFID systems become more widespread, so the technology itself becomes smaller and cheaper. Some popular RFID applications include: supply chain management, baggage handling, library information systems, rental car, inventory control, hospitals and animal identification.

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Municipal Infrastructure Asset Management Systems: State-of-the-Art Review

M. Halfawy, L. Newton & D. Vanier
Institute for Research in Construction, National Research Council, Canada

ABSTRACT: Significant advances have been made during the last decade in developing infrastructure asset management systems. However, there is an obvious need to extend the scope and capabilities of these systems to better support the sustainable development and management of infrastructure assets. This paper provides a state-of-the-art review of municipal infrastructure asset management systems currently available, and discusses the evaluation process of a number of commercial-off-the-shelf (COTS) software systems. The main features, capabilities, and limitations of the evaluated software are presented. The main objective of the paper is to provide asset management organizations with an objective review of these systems, and to identify areas where further research and development are needed.

1 INTRODUCTION

A municipal asset management system is used to store and manage asset data, and to support operational and strategic decision making processes. Municipal infrastructure asset management systems are used for land and property management, facilities and infrastructure management, and utility management. Danylo and Lemer (1998) envisioned the role of an asset management system as "an integrator, a system that can interact with and interpret the output coming from many dissimilar systems."

Many new techniques and software solutions have been developed during the last decade in an attempt to improve the infrastructure asset management process. Significant advances have been made in developing software tools to support activities in various domains such as pavement and bridge management, sanitary/storm water sewer management, and water supply management.

The Municipal Infrastructure Investment Planning (MIIP) project is being carried out by a consortium of researchers from the National Research Council Canada (NRCC) and ten collaborating municipalities/organizations from across Canada. The goal of the MIIP project is to develop and formalize a generic framework and decision support tools for collecting and storing information and knowledge related to prominent issues in sustainable infrastructure asset management.

One of the objectives of the MIIP Project is the development of a roadmap that identifies areas where further research and development are needed. In accomplishing this objective, it was necessary to evaluate the current state-of-the-art represented by a wide cross section of commercially available software solutions. This paper does not rate or rank the packages evaluated herein, but aims primarily to provide asset managers with an objective review of systems, and to identify areas where further research and development are needed.

2 GENERAL-PURPOSE VS. ASSET-SPECIFIC SYSTEMS

Asset management software can be classified into two broad categories: general-purpose software and asset-specific software. General-purpose systems typically offer generic functionality that need to be customized and adapted for specific data and work processes related to specific classes of assets. Asset-specific software solutions provide a set of built-in data models and processes to support the management of a specific class of municipal assets (e.g. facilities, sewers, roads, bridges, etc.).

The main functionality provided by general-purpose software systems is the data management of asset data using a Relational Database Management System (RDBMS). Add-on modules of the underlying RDBMS are developed to support a wide range of additional asset management functionality such as data management, work management, and procurement. They also support a range of data import/export options, and the capability to interface with other software (e.g. CAD or GIS systems).

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General-purpose software are not currently widely used in municipalities mainly due to the large installation and start up cost, the need for specialized expertise to set up and customize these systems to the processes of specific municipalities, and the high operational and maintenance costs of these systems.

Asset-specific software solutions implement specific data and process management procedures that are required to support the management of certain classes of infrastructure assets. A significant number of asset-specific software systems have been developed during the past decade. Examples of these systems include pavement management systems, bridge management systems, sewer management systems, and facilities management systems. A number of asset-specific systems are also available as Commercial-Off-The-Shelf (COTS) products for managing buildings, water distribution systems, sanitary and storm water sewers, pavement, among others. These applications typically use an RDBMS to support the development and maintenance of the asset inventory database. Many applications provide built-in GIS capability or support interfacing with other commercial GIS software.

Asset-specific software solutions extend the data management functionality by implementing procedures for estimating and measuring the performance level of a particular infrastructure asset based on the physical and condition data. An example of software in this class includes systems developed for condition assessment and rating of sewers based on Closed Circuit Television (CCTV) inspection, such as Flexidata (www.flexi-data.com) or CIMS (www.cobratech.com).

3 THE SOFTWARE REVIEW PROCESS

A representative sample of infrastructure management software systems has been selected for detailed evaluation. The selected systems cover a wide spectrum of software capabilities and scope, as they are currently available by COTS software. Due to space limitations, this paper only provides highlights of the evaluation process, focusing on the features, capabilities, and limitation of these systems. A more detailed description can be found in (Vanier et al 2005). The systems presented in this paper are: Synergen; CityWorks; MIMS; Hansen; RIVA; Infrastructure 2000 and Harfan. The information provided herein is based on trial versions obtained directly from the developer and represents the most current version of the software, or they are based on literature surveys and demonstration of the software.

3.1 Synergen

Synergen is a web-based work management and procurement system that is mainly targeted to large organizations with extensive data and process management requirements. According to the taxonomy of asset management systems described in Section 2, Synergen can be classified as a general-purpose system. Synergen defines a set of applications organized in a hierarchy of subsystems and modules. The subsystems include: Resources, Maintenance, Purchasing, Inventory, Customer, and Administration. The Resource subsystem provides common data management functionality needed by all other subsystems. The Resource data include items such as assets, accounts, inventory, personnel, etc. Each of the five other subsystems represents an area of functionality that is typically supported by a municipal department. The Maintenance subsystem supports work management functions; the Purchasing subsystem supports procurement and contracting processes; the Inventory subsystem supports the tracking, ordering, and receiving of parts and equipment needed for maintenance operations; the Customer subsystem maintains customer data and service requests; and the Administration subsystem manages the set up and customization parameters of the entire software.

A module represents a group of functions that can be accessed through a set of “Views” or forms to display and edit the data records selected by the user. A module roughly corresponds to a “table” in a relational database, where each View or form displays a subset of the fields in that table. For example, the Asset module in the Resource subsystem would correspond to an Asset table in the database, where each record in the table represents an asset, and each View displays a group of the data fields that are related to a particular aspect of the Asset record, such as Depreciation, Manufacturer data, Cost, Operational data, Work history, etc.

In addition, each module defines a set of “Actions” that represent data manipulation and analysis functions, or a procedure that a user may need to perform while in a particular module. Some actions, such as search for records that satisfy multiple criteria, modify search criteria, and display or save search results, are generic in nature, and therefore, are common to all modules. However, some actions are module-specific, such as the actions for creating or updating work orders in the Work Order Module.

Synergen includes extensive data import/export capabilities, and can interface with external applications such as GIS, email, or Supervisory Control and Automatic Data Acquisition (SCADA) systems. Figure 1 shows a screen capture that displays the Asset default View, and a list of other Views and Actions in the Asset module, in the Resource Subsystem. The figure also shows Synergen GIS interface.

Due to its general-purpose nature, Synergen can be customized and configured to manage assets in virtually any organization. However, the set up and customization process and the investment required may be significant, especially for small to medium

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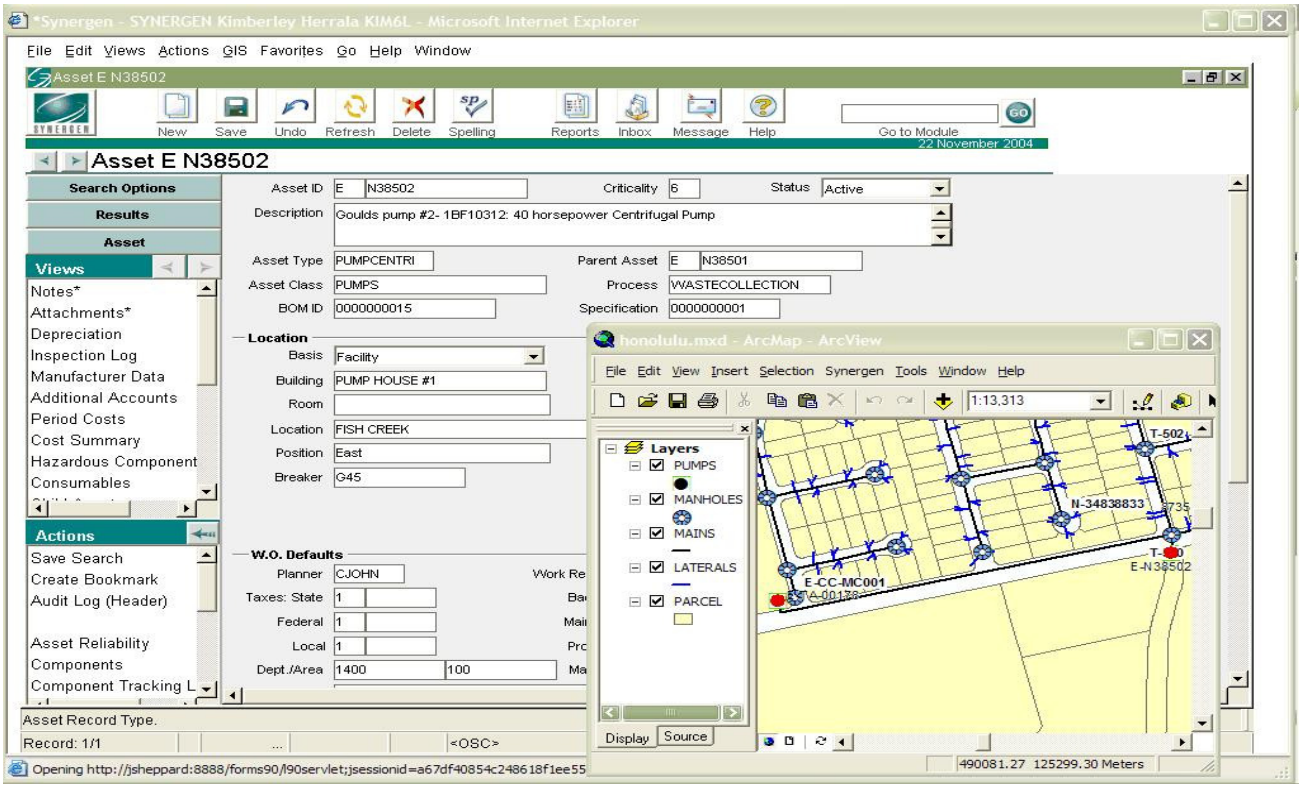

Figure 1. Synergen Asset module in the Resource subsystem, and GIS view of selected assets (Courtesy of Synergen).

size organizations. On the long run, the rewards of using the system may prove to outweigh that investment for smaller municipalities.

3.2 CityWorks

CityWorks is a GIS-based solution for operational and maintenance management of municipal assets. CityWorks supported functions including asset data management, work order management, recording inspection and condition data, and report generation. It also supports logging and tracking of service requests using the add-on “Call Center” module, and supports procurement and inventory management operations, using the “Storeroom” module. CityWorks includes several built-in spatial data models based on the schemas defined by ESRI (ESRI 2005). The models support a wide range of municipal assets such as water, wastewater, storm water, and road networks. Users can modify or override the schemas to suit the specific requirements of their organizations. Figure 2 shows the ArcGIS add-on showing a map of water mains and associated work orders.

A distinguishing feature of the software is its tight integration with GIS. Unlike most of other applications r, CityWorks uses the GIS database (or geodatabase) to maintain and integrate asset data. This approach of using a single centralized database has the advantage of ensuring the consistency of asset data, and eliminating the need to duplicate the data in multiple databases or to update different databases to keep the data synchronized.

CityWorks can be deployed as an extension to ESRI ArcGIS or as a standalone system. The database managed by both versions have the same geodatabase schema, and therefore, both versions can co-exist and be used by different teams in an organization, depending on whether a GIS interface is required. CityWorks also offers the capability to spatially link work orders and service requests to specific assets or to street addresses. The first approach would be useful for municipalities that already maintain a GIS asset inventory, while the second approach was designed for municipalities with incomplete asset inventory to link work orders and service requests to addresses. When the complete asset inventory is developed at a later stage, these addresses can be processed and associated with the physical assets instead. A useful feature of the software is the link it maintains between the assets and street addresses. This link would facilitate the identification of customers who may be affected by an asset failure or a planned maintenance operation, and serving proper notices to these customers.

A distinguishing feature of CityWorks is its ability to support field operations by enabling browser-based wireless access (using a PDA device) to the asset geodatabase, and allowing field staff to access and update work orders and service requests, and to view asset maps. The DataPump module enables field staff to run CityWorks in a “disconnected” mode by checking data in and out of the database, and keeping the data synchronized between sessions. Another module, called Inbox, routes work orders and service requests assigned to responsible personnel, and enables them to locally or remotely access these work orders.

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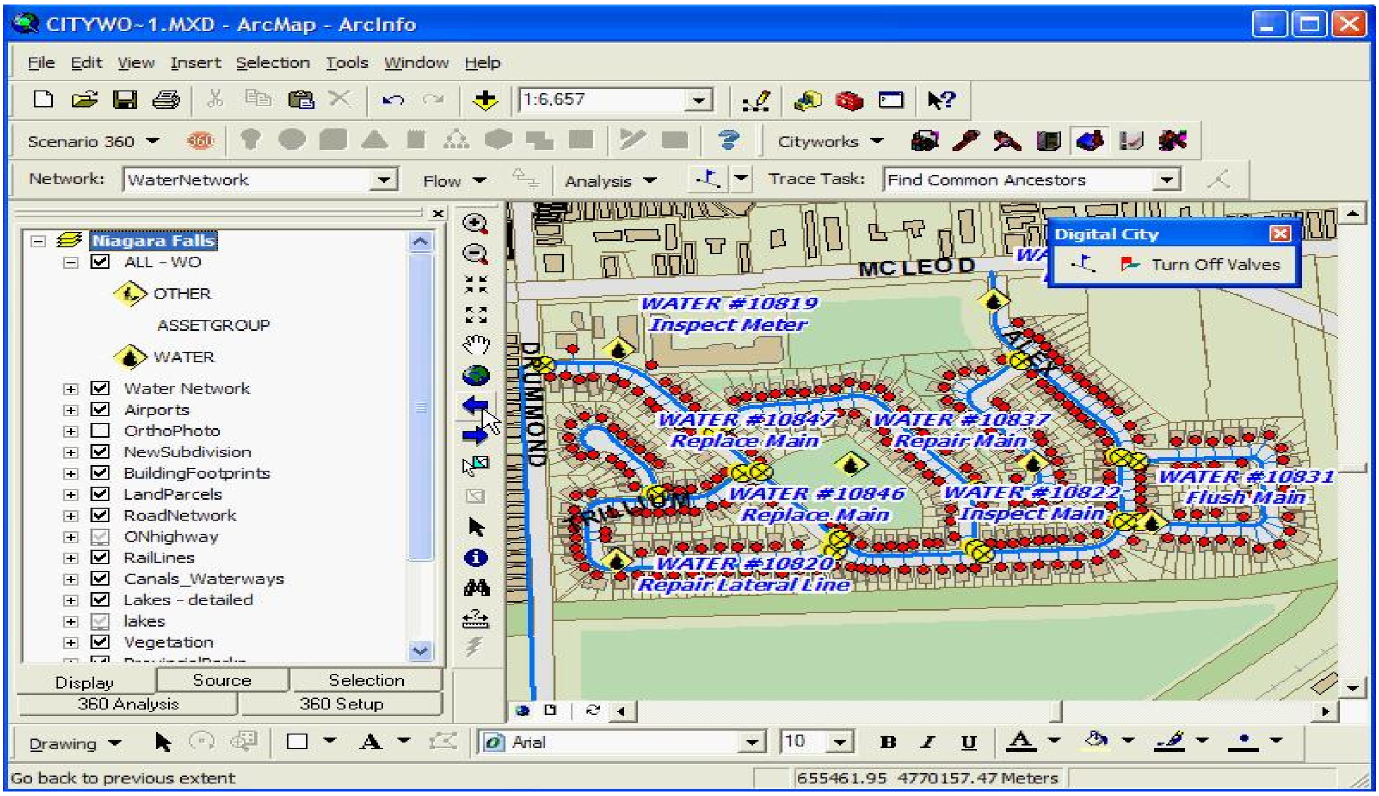

Figure 2. CityWorks ArcGIS add-on showing a map of water mains and associated work orders (Courtesy of Azteca).

3.3 *Municipal Infrastructure Management System (MIMS)*

The Municipal Infrastructure Management System (MIMS) is primarily a data management system for water, wastewater, storm water, and road networks. It also includes modules for managing gas pipelines and municipal buildings. The system is targeted to small and medium size municipalities. MIMS has extensive data import/export and reporting capabilities, and incorporates a wide range of pre-formatted reports. MIMS provides the users with a consistent set of forms and tools for managing different infrastructure assets.

Each class of assets is broken down into its main components, which are in turn subdivided into asset types. Each asset type is roughly represented as a table in the underlying relational DBMS. For example, the water, sanitary and storm water network asset classes are broken down into lines, features, facilities, and equipment components, and the lines component is subdivided into pressure mains, gravity mains, service/leads, and channels asset types. Figure 3 shows a screen capture that displays the main form of the four main asset classes.

MIMS implements its own GIS functionality through the use of ESRI MapObjects. The GIS component provides access to the asset maps and database, and maintains a link between asset IDs and spatial features' IDs. It also includes a "Data Quality" wizard that allows users to identify missing links between assets and spatial features. Users can navigate through the map using typical GIS viewing functions. Users can perform spatial queries to locate assets relative to a user-defined shape or to create thematic maps based on selected asset attributes (e.g. asset condition rating). Users can retrieve an asset record using the Find tool, where users can search for assets satisfying multiple criteria, and access the asset record or view the asset location on the map.

For each asset type, MIMS supports five main functions, which can be accessed from the asset data form. The "Locate" function activates the Map Viewer and zooms to the location of the current asset. The "Costing" function enables users to record cost data related to the asset. The "Functional Adequacy" function allows users to rate the overall performance and the level of service delivered by the asset (good, fair, or poor) for later use in the maintenance planning and prioritization process. The "Condition" function allows users to rate the condition of the asset using a consistent standard for assessing the structural condition of the asset.

3.4 *Hansen*

Hansen is a major application developed by Hansen Information Technologies to provide capabilities for managing government operations including asset and property management, utility billing, permits, financial and human resources management. It includes inventory collection, valuation, determination of deferred maintenance, condition assessment, estimateing remaining service life and prioritizing maintenance and rehabilitation (M&R) options.

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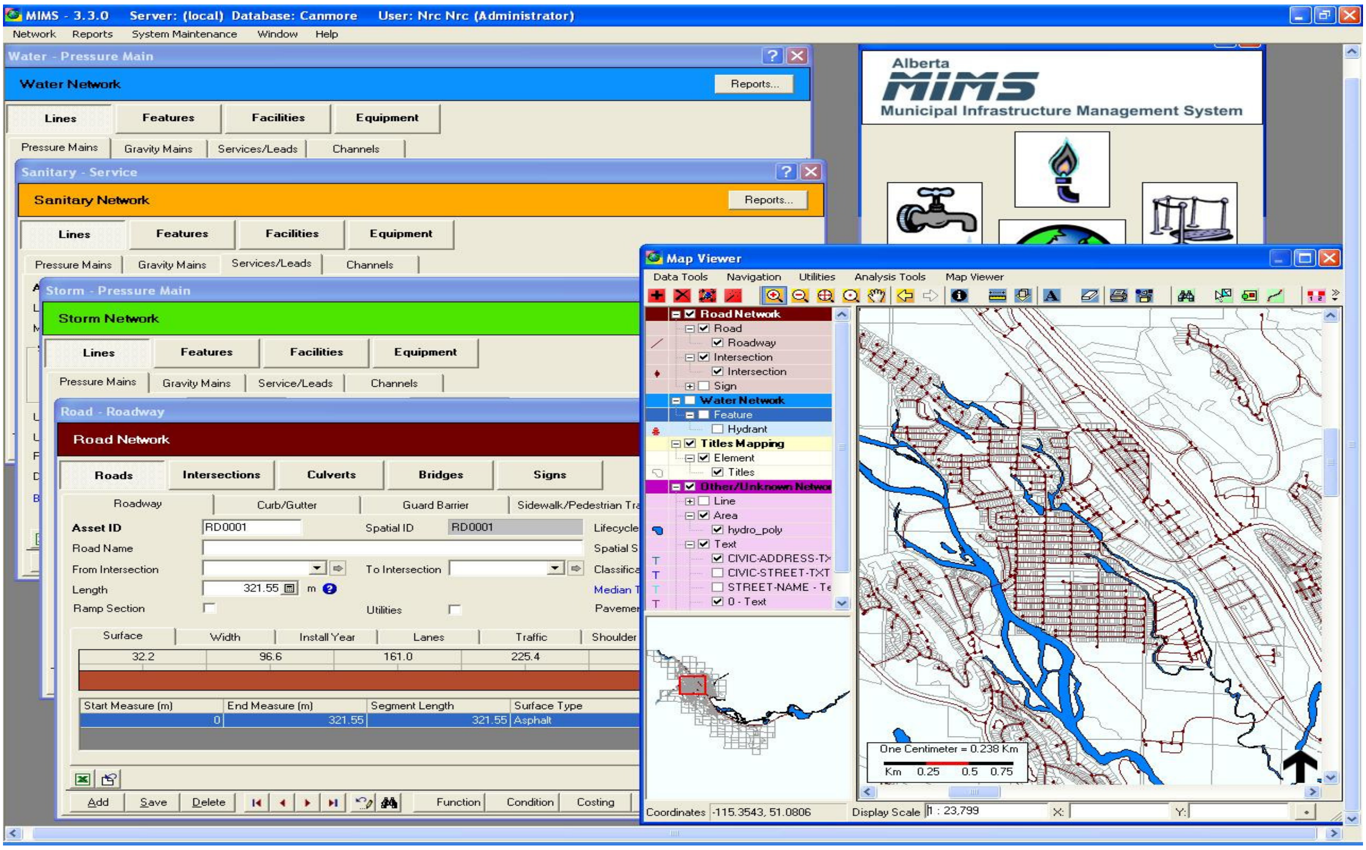

Figure 3. MIMS MapViewer and forms for managing water, sanitary, storm water, and roads networks (Courtesy of MIMS).

Hansen is client-server application installed on individual desktops. Interfaces written by Hansen to allow data import/export include the GeoMedia-Hansen Interface and Integrated Map Viewer, which allow a GIS link to Intergraph and ESRI applications. Other software interfaces include those for Flexidata and CIMS sewer condition assessment software. The next version of the product, will be web-based thus, eliminating the need for most interfaces and desktop installation. Hansen applications are typically used by medium to large organizations.

Hansen's asset management tools incldue two main modules: Public Works solutions and Transportation solutions. Each module is GASB Statement 34 compliant with an asset specific infrastructure accounting model. The Public Works module contains divisions for: industrial waste management, parks management, plant and fleet management, street management, water and wastewater management, and works management. The Transportation module contains: bridge management, facilities and equipment, inventory management, pavement management system, property management, railway management, roadway management, sign management, street management, and work management.

Hansen provides a detailed asset inventory and valuation capability using one or more of the following asset data models: hierarchical, directional, pressurized, segmented, point, area, linear and network. Hansen does not have an extensive condition assessment capability. Only the pavement management system sub-module has integral condition assessment tools including deterioration curves and decision models. Other condition assessment data are fed into the Hansen database through compliant applications such as Flexidata and CIMS. The user can define condition rating criteria within Hansen and obtain asset conditions. Activity based costing, and budgeting and planning capabilities in the Transportation module appear to allow for prioritization of M&R activities. It was not clear from the product literature if this capability extended to multi-year asset management. Hansen has recently teamed up with RIVA (See Section 3.5) to use RIVA's long-term asset management capabilities to extend Hansen's operational management functionality. Figure 4 shows sample screens displaying elements of the public works and transportation modules.

3.5 RIVA

RIVA (Real-time Asset Valuation Analysis), developed by Loki Innovations (www.loki.ca), provides capabilities for long-term asset planning in a 10 to 200 years planning horizon. RIVA is a web-based application that can interface with most common applications. The data can come from any ODBC-compliant source so the user can pull data from other databases, such as Hansen. It supports inventory data collection, valuation, determination of deferred maintenance, condition assessment, estimating remaining service life (RSL) and asset prioritization.

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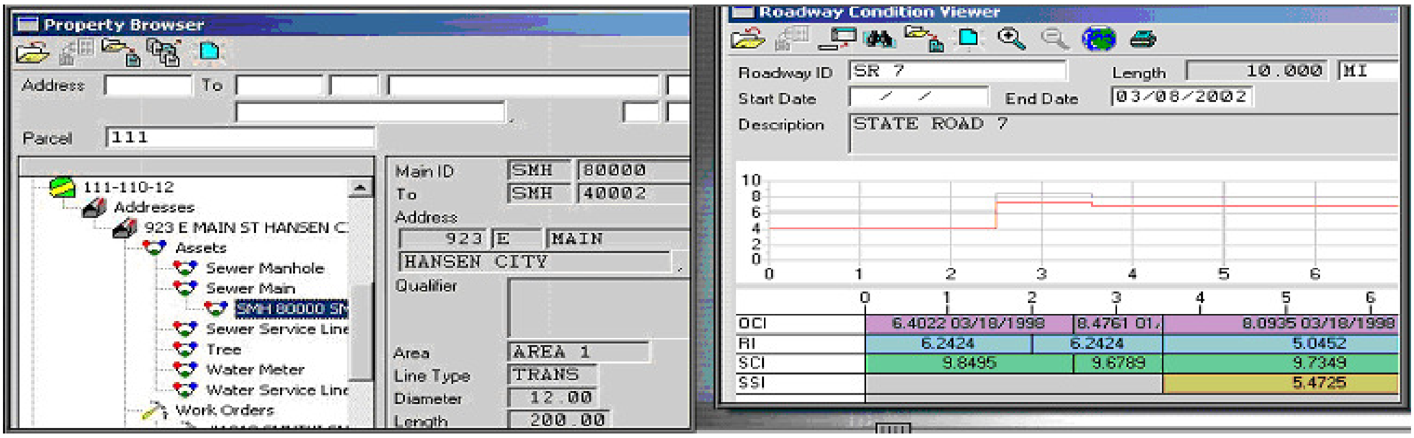

Figure 4. View of Hansen demo screen showing Property Browser from Public Works and Transportation modules.

RIVA has a modeling capability that can be used for valuation, determination of deferred maintenance, condition assessment, estimating remaining service life and prioritizing M&R. Deterministic and probabilistic models can be created using formulae set up by the user or with help from Loki. The Formula Builder allows the user to create, change and test the formulae that drive calculations and models. Models can be trial models, in which the user can vary the model parameters to undertake a comparison of various asset management scenarios, or corporate models. Changes made to the models are automatically reflected in data and model outputs e.g. deterioration curves, priorities, etc.

The asset inventory and valuation capability within RIVA can retrieve information already in the user's existing databases and permit the user to set up new asset classes. This allows the user to begin using the application almost immediately. The application is limitless in the number of asset classes it can contain. The hierarchical structure allows the user to specify the level of data detail required for each asset. This enables the user to drill down through the asset from city-level to street to component. The asset inventory can be viewed both geographically and by asset "silos" for any level of detail. RIVA has a built-in valuation capability that uses integrated economic factors to value assets. These factors can be amended by the user if desired. RIVA supports both ESRI and Intergraph GIS applications. Figure 5 shows the GIS integration capabilities of RIVA and the ability to rollup costs to a network level to demonstrate the long-term impact of infrastructure funding on cumulative shortfalls.

The deferred maintenance capability within RIVA is also user defined. The user defines "best practices" and RIVA calculates the level of deferred maintenance based on set of events triggered by the practice. The application allows modeling to see the impact of various M&R strategies on the size of the maintenance backlog. In modeling the data, the user is able to vary economic factors such as rate of expenditure (% per annum), discount rate, etc. RIVA is not a work order system but it can import work order data and allow the user to access these data.

RIVA can import condition assessment data from other sources and directly link them to assets at any level of detail. The application allows the user to set up models, based on user-defined parameters or on pre-existing systems (e.g. Water Research Centre-WRc), to determined asset condition. RIVA allows the user to compare condition and shortfall adjusted condition to show the impact of deferred maintenance and maintenance strategies. Any condition assessment tool and any scoring metric can be used, and can have the resulting data incorporated into RIVA for analysis and modeling. An important part of asset condition is to know the estimated RSL. In RIVA, user defined RSL models allow users to vary parameters such as M&R strategies to estimate RSL. RIVA has the capability to set priorities within classes and across all assets, which enables users to harmonize priorities and generate an event priority list. RIVA's "thin client" architecture means that new features can be added seamlessly.

3.6 Infrastructure2000

Infrastructure2000, developed by Vanasse Hangen Brustlin Inc, provides capabilities for asset management planning, and is targeted to small to medium size organizations. Infrastructure2000 is a client-server application installed on individual desktops. It supports inventory collection, valuation, determination of deferred maintenance, condition assessment, estimating remaining service life and prioritizing maintenance and rehabilitation. The software can be integrated with popular GIS applications such as ArcGIS. Other interfaces and custom applications can be created to convert data to a compatible format.

Infrastructure2000 consists of RoadManager, with five modules, and the following work management tools: WorkManager, EquipmentManager, and PermitManager.

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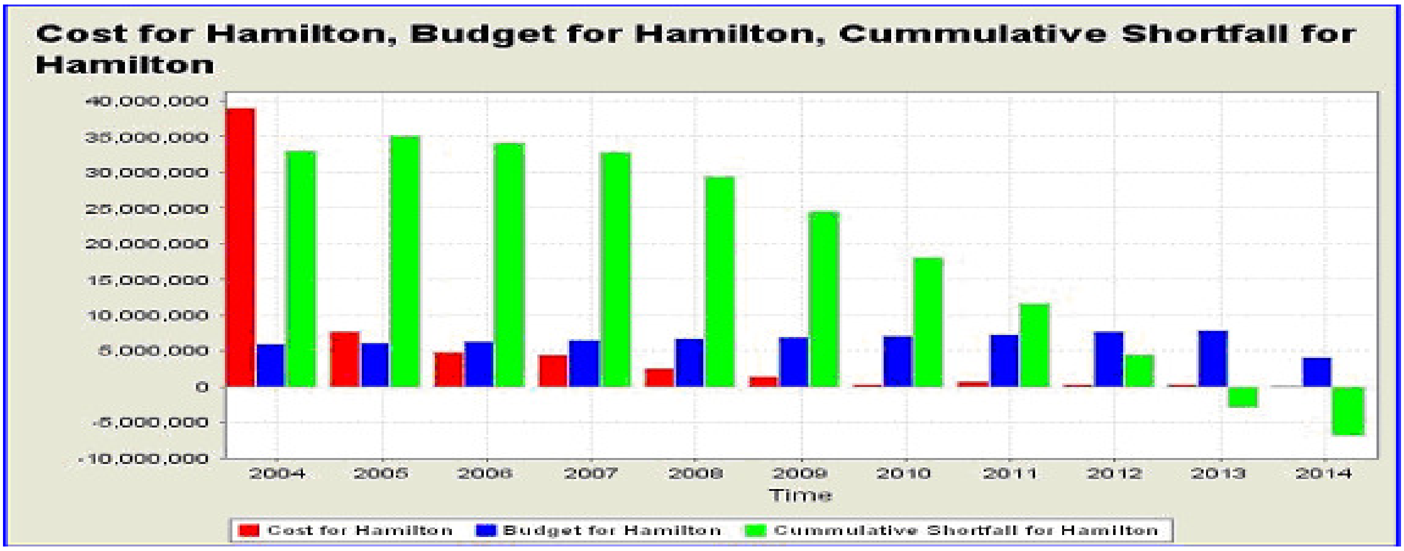

Figure 5. View of RIVA showing long-term impact of infrastructure funding.

The RoadManager modules are: Pavement, Sidewalk, Traffic Control, Drainage/Utility, and Budget Analysis. The Pavement, Sidewalk and Drainage/Utility modules provide a detailed inventory and valuation capability. The pavement module provides a condition assessment capability using the standard rider comfort index (RCI) or the pavement condition index (PCI). The 0–100 index score is mapped to a condition score where "one" is defined as a "do nothing" intervention and "five" is defined as a "reconstruct" intervention. This module also includes a GASB 34 notebook. The remaining modules are not based on established condition assessment protocols. Other asset classes such as bridges, structures, channels, and pipes are included in the Drainage/Utility module. The Budget Analysis module provides the capability to define repair alternatives, create and compare funding scenarios, define and view deterioration models. This can only be accomplished for pavement assets, however. Figure 6 shows a sample screen demonstrating the pavement module notebook and table options.

3.7 *Harfan*

Harfan's method and software is geared to be a generic solution to municipalities. It attempts to be flexible in its design so that it can be adapted to support: (1) extending the asset service life, and (2) optimizing the long-term investments. The software can be applied to areas such as: water and sewer networks, roads, gas and telecommunications networks, electricity networks, street lighting, buildings, marine assets, airports, and rail systems. It is possible at the upper levels of the data structure to drill down to the basic level of inventory data and search for information. Harfan uses an Oracle RDBMS and allows one-way integration with popular GIS systems (e.g. ArcGIS and MapGuide).

Harfan philosophically recommends a five-step methodology that addresses typical asset management issues such as: what do you own, what is it worth, what is the condition, what is the remaining service life, how much you should invest to ensure sustainability, and what needs to be done and when. As a result, the software modules are designed to produce answers to these questions.

The inventory module is the data warehouse that permits both the design of the input forms for the data storage, and the entry and retrieval of relevant data. The condition assessment module allows users to select an existing assessment protocol or to define their own protocols. For example, a weighted factor method can be used to assign weights to a variety of assessment metrics to produce a physical, functional, sustainability and global index. Typically infrastructure assets with similar physical and functional properties can be lumped together as "families of behavior" for the purpose of harmonizing future condition.

The service life prediction module uses deterministic curves selected by the user to calculate the remaining service life. An interactive program to develop "decision trees" is available to the user; this rule-based decision tree can then be used to suggest the most appropriate renewal strategy given condition, service life, maintenance strategy, funding levels, etc. The maintenance prioritization module can produce multi-year capital improvement plans based on analysis of existing data. Techniques such as weighted factor method are used to prioritize the infrastructure projects; however, other decision prioritization methods are currently under consideration. The software permits the user to select and compare different renewal options. Figure 7 shows a screen capture of integrated capital plan and the resulting Global Condition 10 years into the future, after having applied a scenario of roughly $22.4 million of rehabilitation and reconstruction works.

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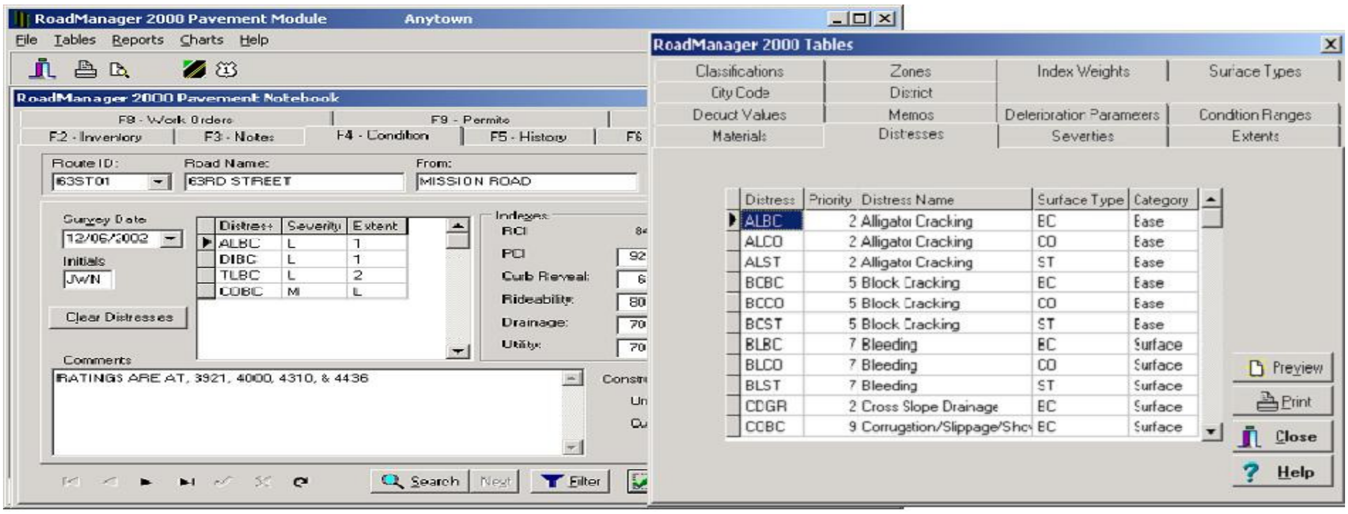

Figure 6. Sample screens from RoadManager showing the Pavement module notebook and table options.

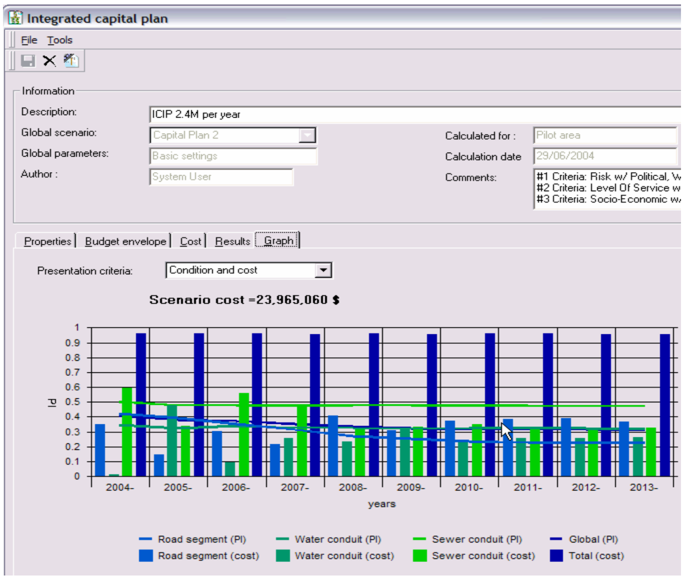

Figure 7. Harfan Integrated right-of-way 10-year Capital Plan.

4 CONCLUSIONS

This paper presented a review of a number of COTS municipal infrastructure asset management systems. The main features, capabilities, and limitations of the evaluated software were briefly discussed. The evaluated software comprised seven well-known systems available in North America that are commonly used by municipalities, and that constituted a representative sample of the available systems.

Although the majority of asset management systems supported interfacing with GIS, very few systems could support integration with Enterprise Resource Planning (ERP) or financial software systems. Historically, ERP systems have been the main source of financial and personnel data, and the need to link asset management systems to these data sources is a critical step towards supporting long-term asset management strategies.

In light of the software review results, some directions for future research can be identified. Of particular interest is the development of methods and tools for long-term renewal planning of infrastructure assets. The vast majority of the existing systems focus primarily on supporting the operational day-to-day management activities, and an extremely small number of software tools implemented limited support for long-term renewal planning. Also, many fundamental asset management functions, such as performance modeling, and maintenance prioritization, are not supported by most of these applications.

Developing industry wide standard data models for infrastructure systems is another critical area for future research. The data models supported by existing software are mostly proprietary, which impedes the ability to share and exchange asset data. Standardizing the data models would enhance the role that the systems can play to enable better integration of the management processes, and the interoperability between various software applications.

5 ACKNOWLEDGEMENT

The authors would like to acknowledge the support of the MIIP consortium and the Natural Science and Engineering Research Council of Canada (NSERC).

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GIS – based DSS for sustainable infrastructures and management of tourism in the Leningrad Region

M. Yu. Kononova & O.G. Nikonova
St Petersburg State Polytechnic University, St Petersburg, Russia

ABSTRACT: The paper deals with analysis of a wide-sense role of GIS – based decision support system (DSS). Formalisation of approach towards preparation and realisation of visualisation of tourism infrastructure of Leningrad Region for ensuring stable development of territory is given. The meaning of the GIS – based DSS as a system-forming part of the geoecological account (monitoring, management and audit) of tourism infrastructure within the frame of monitoring area and territory is shown.

1 INTRODUCTION

The purpose of the research is making of a technique for the substantiation of selection of terrains suitable for management of recreational activity, reduction of the concrete guidelines on their realization and usage, delimitating of the zonation scheme of objects according to recreation kinds on the basis of analysis of natural-technical environment. The technique runs in a view of a decision support system (DSS) on the basis a GIS technologies.

2 THE LENINGRAD REGION DESCRIPTION

The Leningrad Region occupies a large area in the Northwest of Russia from the Gulf of Finland to Lake Onega (Fig. 1).

Figure 1. Diagrammatic layout of the Leningrad Region districts

The region is one of the most dynamically developing subjects of Russian Federation and consequently is attractive to many of the people. The developing tourism infrastructure, safety and proximity of Saint Petersburg attract tourists, as well as investors to region. The trends of development and monitoring of recreational zones of the Leningrad area are especially attractive in these conditions. The territory of the Leningrad region includes 350 places, attractable for the tourists. The table 1 demonstrates the recent state of infrastructure quality and the tourist load for 2004 in the Leningrad Region.

The table demonstrates that the greatest amounts of means of accommodation now have such municipal formations of the Leningrad Region, as Vyborg, Priozersk and Luga district. Gatchina and Lomonosov are objects of the most interest. There are residences of Russian tsars settle down in their territory.

Development of tourism infrastructures should be friendly for the nature and the people. It provides the geoecological analysis of territory of development. Also it necessary to consider recent and perspective design of engineering networks and communication, real-estate market and territories development, localization processes optimization.

3 RELEVANCE OF THE RESEARCH

Increase of population and economical growth of advanced countries entail step-up per capita off-hours, idle time of the social groups and the sociality that averages about 30% of day-time according to several calculations. Consequently, everybody will

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aim to realize his off-hours including recreational time (tourism, sport etc.). Therewith town, land, rural & industrial development decreases per capita potential recreational territories.

Table 1. Number of collective accommodation objects of the Leningrad Region and its saturation points on 01.01.2005. (www.lentravel.ru, the information-statistical collection 2005. Tourism development of Leningrad region in 2000-2004 and the forecast for 2005. The statistical account and the analysis in tourism sphere of Leningrad region.)

Leningrad Region and districts	Total area of the region /district [km^2]	Total population [10^3 the inhabitants]	Collective means of accommodation (CMA)		Including					
			Number of objects (NO)	Seats of accommodation /Beds (SA/B)	Organisations of a hotel type		Sanatorium and resorts		Organisations of rest	
					NO	SA/B	NO	SA/B	NO	SA/B
Leningrad Region	85,900	1659.90	432	44,422	66	3505	13	1442	353	39,475
Volosovsky District	2680.50	47.10	5	485	1	40	0	0	4	445
Volkhov District	5043.20	54.50	8	410	2	100	1	100	5	210
Volkhov	108.21	50.50	5	329	4	229	1	100	0	0
Vyborg District	7431.20	176.20	85	10,150	16	701	0	0	69	9449
Gatchina			5	267	3	177	2	90	0	0
Gatchina District	2864	114.70	17	2729	2	74	0	0	15	2655
Lodeinopolsky District	4911	39.80	19	721	3	198	0	0	16	523
Luga District	6025	86.70	41	7696	1	68	2	265	38	7363
Podporozhsky District	7705	38.90	7	195	2	58	0	0	5	137
Priozersk District	3597	38.90	109	10,029	4	126	1	350	104	9553
Tikhvin District	822	77.4	12	486	1	150	0	0	11	336

Thus, questions of acquisition of building land, architectural and landscape design, management and development of recent and future recreational areas, making new recreational resources become a very important (Fig. 2). Especially it is a vital question for heavily populated areas like the Leningrad Region.

Organization, operating and developing of recreational zones of tourism and sports objects, and their interplay with residential, industrial, nature protection and other zones is necessary to conduct with allowance for many components:

- the schedules of the area perspective development;
- a geographic setting;
- climatic conditions;
- a level of development of an infrastructure and industry;
- location of the residential districts;
- density of population;
- availability of a cultural-historical value;
- traditions of the population and etc.

Besides many recreation kinds demand availability especial residing conditions: climatic (for example, seaside health resorts), landscape (for example, mounting skiing resorts), circumstance by resources (for example, hunting, fishery). The relevant factors are the transport accessibility, seasonal predilection and potential selectivity of the population on recreation kinds. Seasonal usage only of recreational

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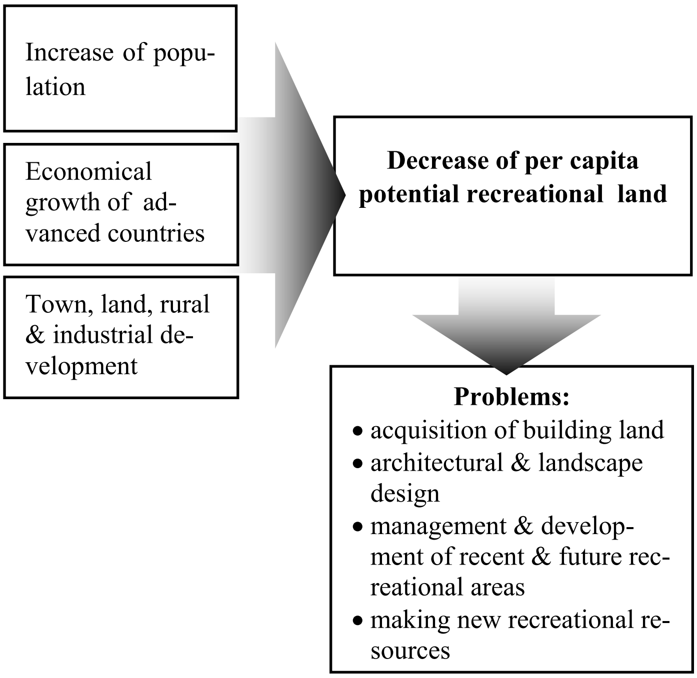

Figure 2. Effectiveness function of geoecological analysis within DSS

objects is a great problem for developers and managers of this object in conditions of market economy. Thus, it is necessary to select season compossible recreation kinds with allowance for of psychological comfort and whenever possible by similar modes of operation. In this connection it is necessary to envisage a legible zoning of recreational territories with allowance for time of usage for rest (long-lived short-lived) and duration of work (year-round, seasonal), kinds of strain-relief crystallization, social and age composition of the people. The special attention should be given to a geoecological estimation of the territories, which is directional on definition of methods and means of the sustainable development of the recreational zones.

4 GIS-BASED DECISION SUPPORT SYSTEM

4.1 DSS description

Making DSS consists on the three steps:

1. Identification of the existing situation
- screening existing sources for data (archives, athorities, etc);
- evaluation of data;
- examination of existing monitoring systems, data bases, systems of indicators and models with respect to their suitability for the envisaged task;
- formulation of task to be achieved in order to establish DSS;
- suggestions for selection of the pilot area;
- suggestions for the methods to be applied.

2. Implementation and operation of gauging (measurement) system interfacing the DSS
- gauging of the monitoring bodies;
- identification of required GIS – layers;
- interfaces for databases, models nature quality (external load, internal load, critical load), GIS and recorded data.

3. Elaboration of the decision support system.
- elaboration of models for monitoring and decision making;
- working out of the DSS consisting of the following modules: data bases, GIS, system of indicators, simulation models, decision-making models, on-line recording of data;
- testing and validation of the DSS for the selected pilot area.

4.2 GIS function

The recreational zones are large area objects, and consequently demand special means of interpretation and analysis. In this research GIS uses as the basic tool for serving, visualization, processing and saving data. Level-by-level organization of the information reference for GIS is especially comfortable, because enables fast and qualitatively to select, to process and to present a demanded data volume. Each layer represents a separate component of the data or its part. Thus the information on recreational zones is divided into two interdependent kinds: graphic (maps, schemes, figures, case history etc.) and attribute (blocks of the text, table, diagrams, design modules), - also is partitioned on theme layers.

A generally recognized instrument of work with spatially distributed information is geographic information systems (GIS).

The chief advantage of the GIS is the ability to map not only the object's characteristics but also its location in a particular point in the environment of a certain combination of other objects. The systems open widest possibilities of spatial analysis and drawing own maps supplemented by functions of work with databases and preparation of reports and printouts.

The information basis of GIS is electronic maps of a particular town or region. The map objects of a type (for instance, buildings, blocks, streets) are grouped into so-called information layers. The figure 3 demonstrated the key macrolayers of GIS-based DSS which are required for for sustainable quality infrastructures and quantity management of tourism in the urbanized and nature area of the Leningrad Region. Every macrolayer presents a group of thematic layers of homogeneous objects. The landscape layer which is base of the system includes surface relief. The hydrological network contains natural

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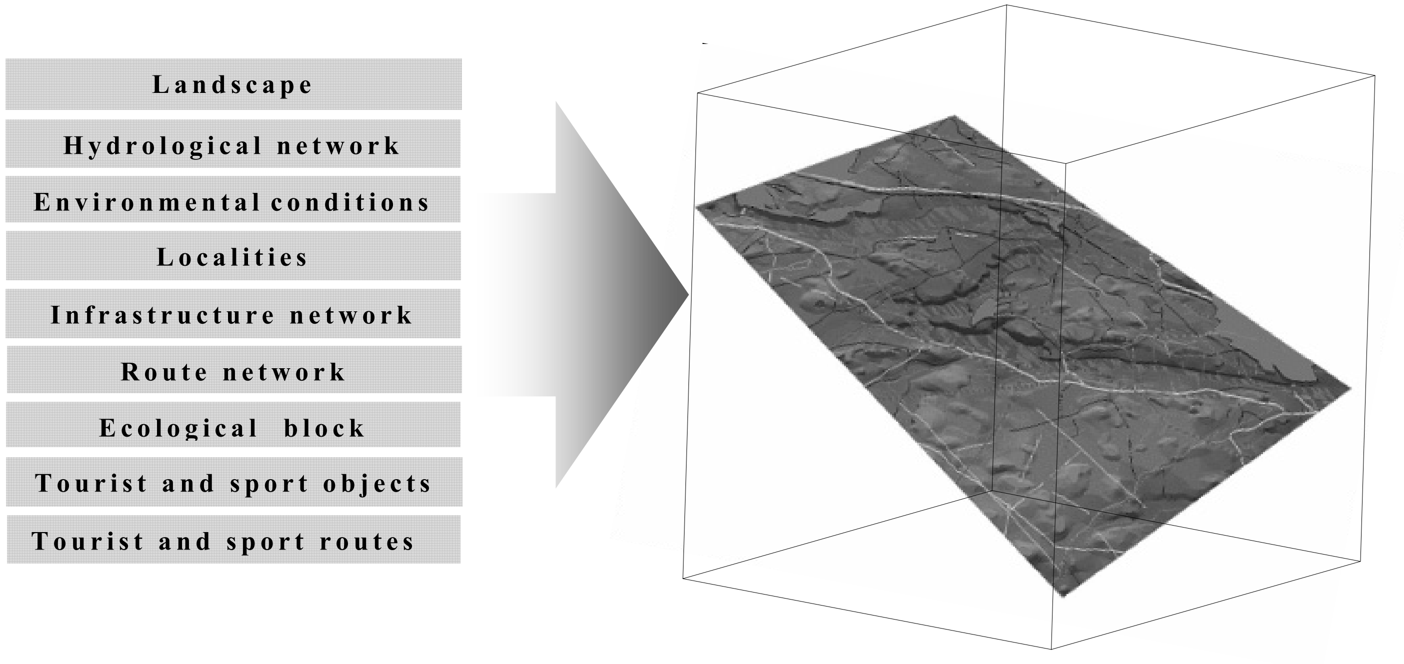

Figure 3. Thematic macrolayers of GIS – based DSS for sustainable quality infrastructures and quantity management of tourism in the urbanized and nature area.

and artificial surface and ground water bodies. Environmental conditions are a very important because they directly influent on type of recreational resource. The most of localities inside recreational areas are a recreational resource or a place of accommodation. Good quality of infrastructure and route networks is sine qua non for negotiability and boosts of the recreational areas. Well-working tourist and sport objects as well as routes are the goal of DSS.

4.3 *Some additional GIS possibility of use within DSS*

The GIS software makes it possible to solve a widest range of problems:

- drawing of screen maps of various scale, composition, design etc., comparison of maps with tables, texts and diagrams;
- editing of existing graphic objects, creation of user's information layers based on address data;
- work with databases and spatial analysis: all possibilities of standard database management systems;
- thematic mapping and preparation of mapping reports: automatic drawing of maps with visual display of the information for the user supplemented by texts, diagrams, tables.

4.3.1 *Satellite investigation*

A promising direction of the GIS application is their incorporation as the electronic mapping basis in global positioning systems (GPS). The chief direction of the use of such systems is control over mobile objects (collection services, mail and messenger companies, transportation of expensive cargoes) and operational management of mobile objects (security companies, public services, ambulance etc.).

4.3.2 *Design and maintenance of engineering networks and communications*

Large organizations and municipal services need good knowledge of the territory to keep record of "departmental" objects, to provide operative mapping of problem parcels and rational distribution of available resources. The telephone company needs an electronic map of STS location, the emergency-control service must know the locations of the most worn-out sections of heat pipelines, the traffic police needs to know the road signs location. The GIS are the unique basis to which any specific information for the user can be easily attached.

4.3.3 *Real-estate market and territories development*

Real-estate agencies were among the first ones in business to recognize the importance and efficiency of application of the GIS-technologies. For any real estate object (flat, office, building parcel), its location is one of the most significant factors determining the object market qualities. Developers and realtors should also know the characteristics of the territory around the object: its ecological indicators, traffic location, level of the infrastructure development etc. The GIS make it possible to solve all these

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problems: from the real-estate object's location on the map to fundamental analysis of its location.

In outside advertisements the range of GIS application is quite wide: from regular control over pictures on billboards to analysis of competitors' advertisements layout and choice of constructions with the maximum efficiency of advertisements. The GIS make it possible to calculate significant mediametric indicators (GRP) automatically.

4.3.4 Optimization of localization processes

The GIS provide shops, cafes, petrol stations etc. with an opportunity of optimal choice of location based on such data as distribution of the population and labor places, characteristics of traffic and pedestrian flows, location of competitive enterprises etc. It is possible to calculate the potential visitors of each shop, cafe or petrol station and the efficiency of allocation in each of the possible places.

5 CONCLUSIONS

1. Making DSS, development of the technique and comprehensive analysis all spectrum of the involved information allow to receive qualitative and quantitative state estimations of recreational resources, to recommend their rational development directions, to reveal of the main preference of the recreational zone users, i.e. full picture of presence state of recreational zones and an extended forecast.

2. The GIS – based decision support system (DSS) provide the sustainable quality infrastructures and quantity management of tourism in the urbanized and nature area of the Leningrad Region.

3. The GIS – DSS must be made in the frame of the tourism development for North West Russia goal government program.

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Process Complexity and Cultural Baggage – Barriers to Change

A.D. Dawson & N. Pham
Deakin University, School of Architecture and Building, Geelong, Australia

ABSTRACT: Recent research at Deakin University in Australia has focused on developing a highly detailed understanding of current organisational interactions and information flows in the construction industry. This is leading to the development of a detailed process model which is being tested against a field study construction project. The field study reveals highly complex information flows and interdependencies between stakeholders such as designers, project managers, clients, contractors, subcontractors and suppliers. This, combined with the results from a recent project identifying inhibitors to the take up of IT in the construction industry undertaken by the IAI-Australasian Chapter allow conclusions to be drawn as to whether the current construction industry structure lends itself to increased levels of ICT or whether fundamental cultural changes are required before further beneficial ICT implementation is able to be achieved.

1 INTRODUCTION

The construction industry has come under considerable criticism both from outside and from stakeholders within the industry. Observations from outside the building industry see the use of IT as an enabler for addressing criticism and leading to greater productivity, higher quality and better cost control all leading to a better outcome for the client and society in general (Dept. Industry Science and Resources 1999). This has led to considerable effort being put into the key technology initiatives such as increasing the levels of interoperability in the building industry. The Industry Foundation Classes developed by the IAI are the most notable of these. At least one of the rationales for interoperability is that the seamless transfer and reuse of information will reduce or eliminate the preparation of duplicate information. In addition interoperability opens up the potential for new methods of carrying out what are currently manual operations such as automated code checking. Much of the new ICTs suggested for use in the building industry rely on the development of 3D building models. Certainly three major CAD system developers, Autodesk, Graphisoft and Bentley Systems see the future in 3D building models which contain both geometric and component attribute data.

Technologies, including the use of 3D building models and the application of interoperability, are currently struggling for broad acceptance in the building industry. Uptake has been slow and patchy by all but those most committed to the long term vision of a virtual building model supporting design, construction and facilities management.

Two key pieces of research have recently been undertaken which assist in explaining the reason for the slow uptake of what appears to be compelling new and productive technologies.

One of the authors (Pham) is undertaking a field study which is investigating detailed process modelling within the design and construction of a building project. The other (Dawson) has recently coordinated a series of workshop sessions and industry consultation seminars conducted by the IAI - Australasian Chapter which has investigated the reasons for the slow uptake of ICT in Australia.

These research programs have revealed the level of operational complexity which characterise the building industry today.

2 METHODOLOGY

2.1 *Field Study*

The field study has tracked the formal and informal information generation and communication processes used in a building project in Victoria, Australia. The investigation commenced in the initial briefing stages of the project and tracked the participation of all stakeholders through the design,

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documentation, letting of contracts and on to the completion of construction. It is therefore a comprehensive snapshot of the processes each participant used at all stages in the project.

The data was collected by the following methods:

1 Observation of project meetings,
2 Semi structured interviews with project participants from client to sub-contractors,
3 Observation of the design and construction process,
4 Analysis of the project documentation and records including those from the client, architect, design engineers and suppliers.

From this a detailed process model of the design and construction program is being developed.

2.2 *IAI workshop Sessions and Industry Consultation*

The IAI-AC during 2004/5 carried out a project to develop a Technology Roadmap for the building industry in Australia (Dept. Industry Science and Resources 2001, Phaal et al 2004, Barker & Smith 1995). This was undertaken in two broad stages.

Stage 1 - Workshop Program: This was designed to obtain views as to the current nature and the future of the construction industry in Australia. The aim of these groups was to identify key issues of concern to the industry related to four themes:

1 Characteristics of the industry in 2030,
2 Nature of the industry in 2004,
3 Medium term changes needed in the industry,
4 Immediate changes required now.

Each of these themes was discussed in a facilitated group discussion session with the key issues being identified and recorded for further discussion. The participants in the groups were selected based on representation from key stakeholders in the construction process. They were not selected to represent their industry groups but to provide an insight into their industry sector based on their extensive experience in the construction industry over many years. This was a key element in what they could contribute to the discussion.

The stakeholders participating included clients, architects, design engineers, construction managers, subcontractors and suppliers.

Stage 2 - Industry Feedback and Industry Consultation: Draft results were developed from the workshops and together with a series of ICT Demonstration Projects were presented to a series of industry workshops. The workshops were held in Brisbane, Sydney and Melbourne. The Technology Roadmap has been prepared from the initial group discussions and feedback from the draft report (Dawson, in press).

3 PROCESS COMPLEXITY

The field study project has revealed a highly complex set of relationships between the project participants. One section of the building investigated in the field study appears to be relatively trivial in terms of both its complexity and potential interactions between project participants. However, the investigation of the design, documentation and construction of a simple kitchenette (Figure 1) demonstrates the level of interaction between participants in the design process and the degree to which errors and resultant rework can creep into the construction process.

Neither the design nor the construction process is fully described below however, they serve to demonstrate the nature of the current interactions between project participants and some of the difficulties which arise in the process.

3.1 *The Design Process*

The design process is described below using the method discussed in Pham & Dawson (2004) in which the information distributed, the communication links required and the tasks to be undertaken may be described using various modes of reviewing the project interactivity structure.

The interactions between the participants (Table 1) in the design process are described in Figures 2-4. The commencement of the task is in the centre with the task being completed at the outer surface of the sphere. Subtasks to be undertaken are identified by nodes.

3.2 *The Construction Process*

The construction process may be described in a similar manner to that of design with the aggregate and time dependant views (Figures 5-6) of the process including the construction participants. The processes described in the stakeholder views (Figure 7) are similar for all subcontractors. It is evident that the level of the complexity of the interaction between the individual participants during the construction phase is less than that of the project participants during design.

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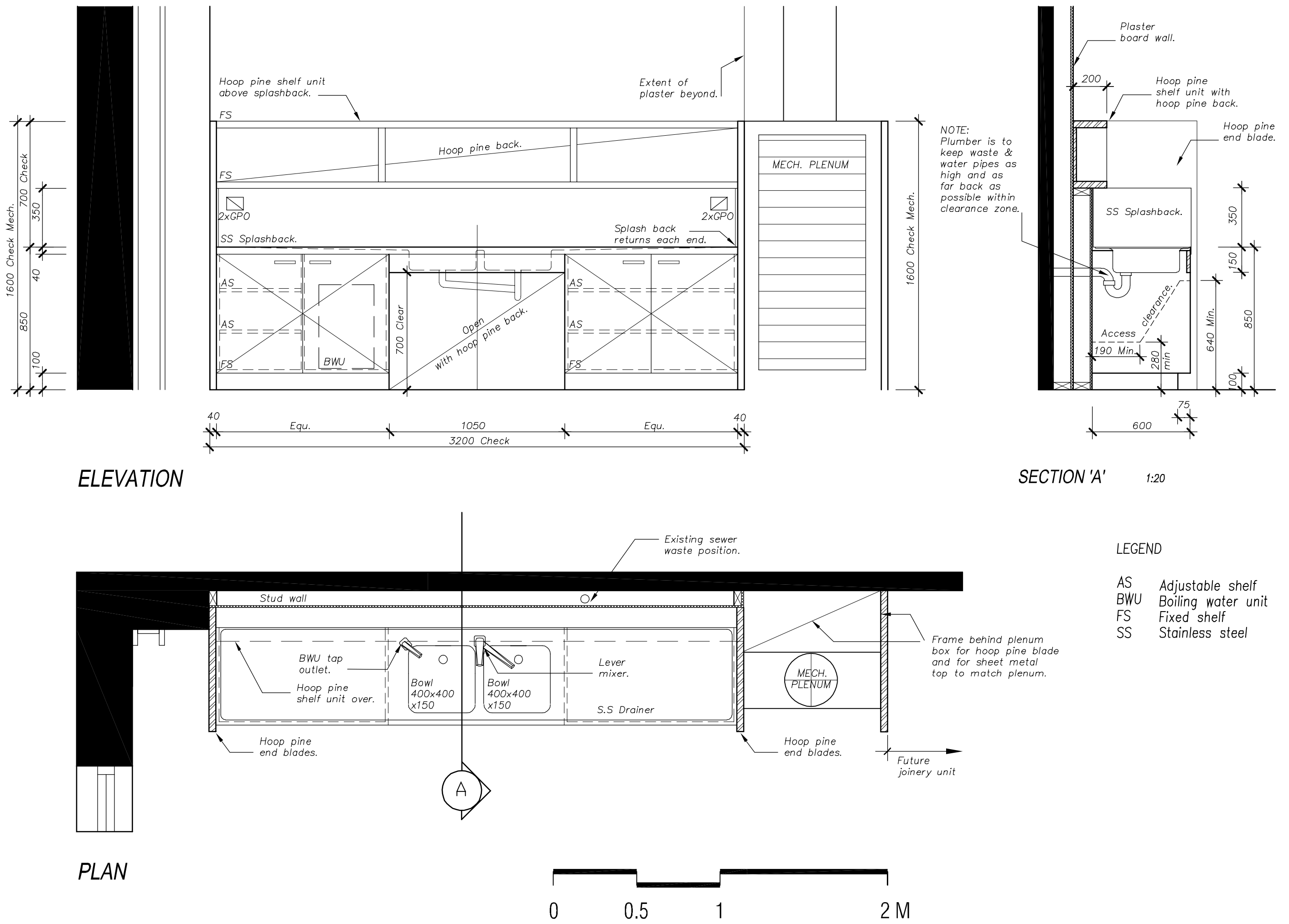

Figure 1. Architects' Documentation of Kitchenette

This may be explained by the greater fragmentation which is experienced in the industry at the construction phase of the project.

Table 1. Project Participants

AR	Architect
QS	Quantity Surveyor
SB-WA	Statutory Body-Water Authority
CL	Client
CM	Construction Management
PM	Project Management
SM	Site Manager
PC	Plumbing Contractor
BS	Building Surveyor
SU	Supplier
SC	Subcontractors: JN Joiner PC Plumbing Contractor CA Carpenter PA Painter PL Plasterer

While the architect, the project or site manager, coordinate aspects of the project at a broad level each subcontractor focuses on their own segment of construction at the detailed implementation level. As a consequence of this, the subcontractors are required to deal with any difficulties which arise during construction.

The views of the joiner are of particular relevance to the construction of the kitchenette and point to a set of problems which he was required to deal with during the project.

Several key points arose during the interview:

1 There was a slope on the floor which had to be resolved on site. This was known due to a site visit at which the stud wall behind the unit was measured. The fall meant that on site cutting was required.
2 Plywood for the joinery was ordered but the incorrect panels were delivered. This caused delays in the fabrication.
3 The sink as delivered was 166mm too short.
4 The joinery was made off site to the 3200mm dimension as per the documentation (Figure 1) but had to be rebuilt on site due to the incorrect sink length.

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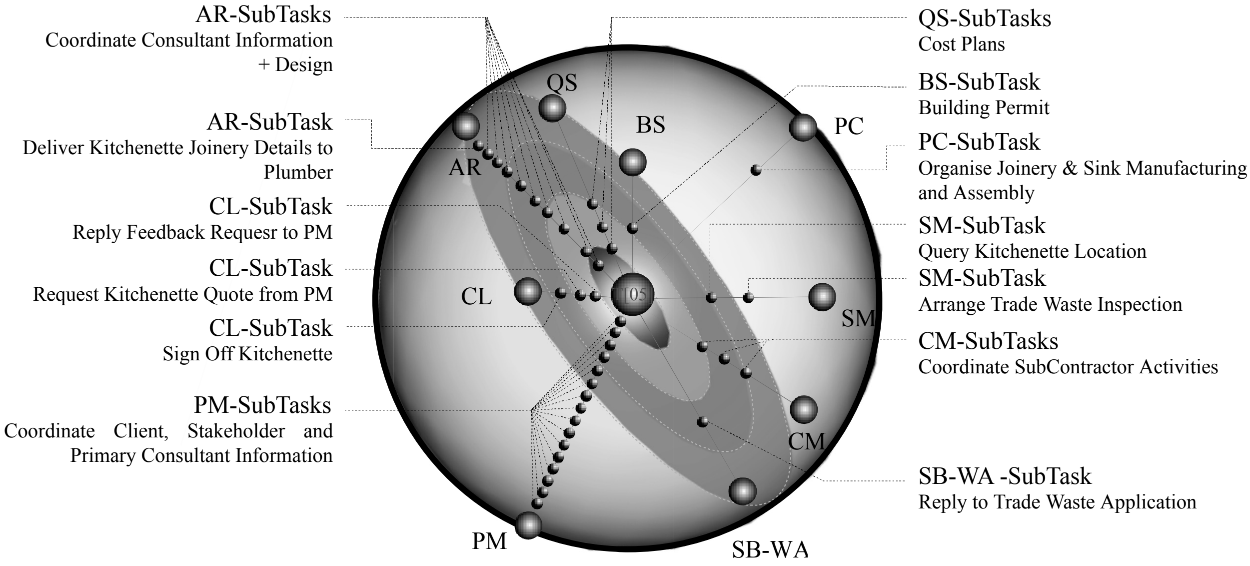

Figure 2. Aggregate View – Kitchenette Design

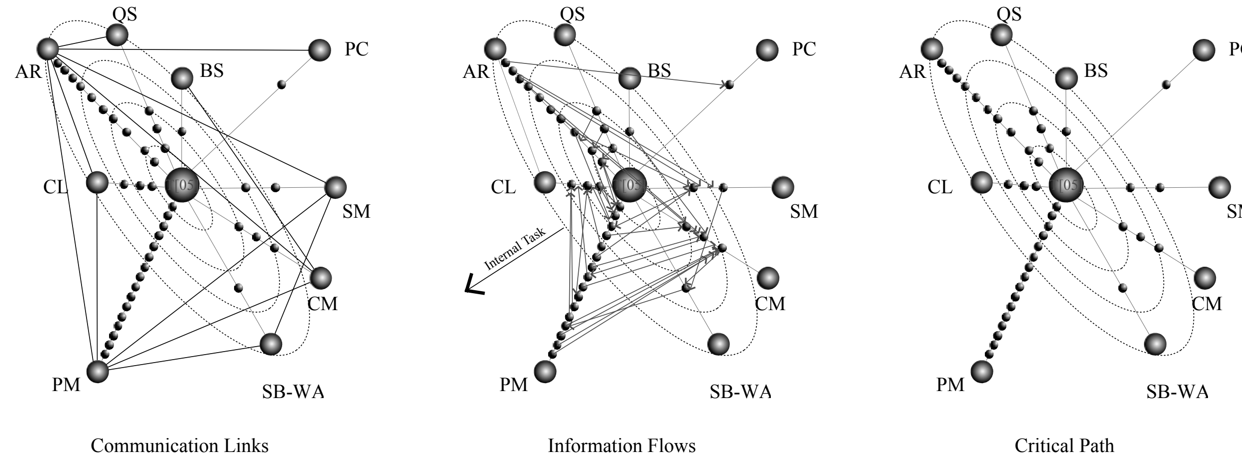

Figure 3. Design Phase - Time Dependant View

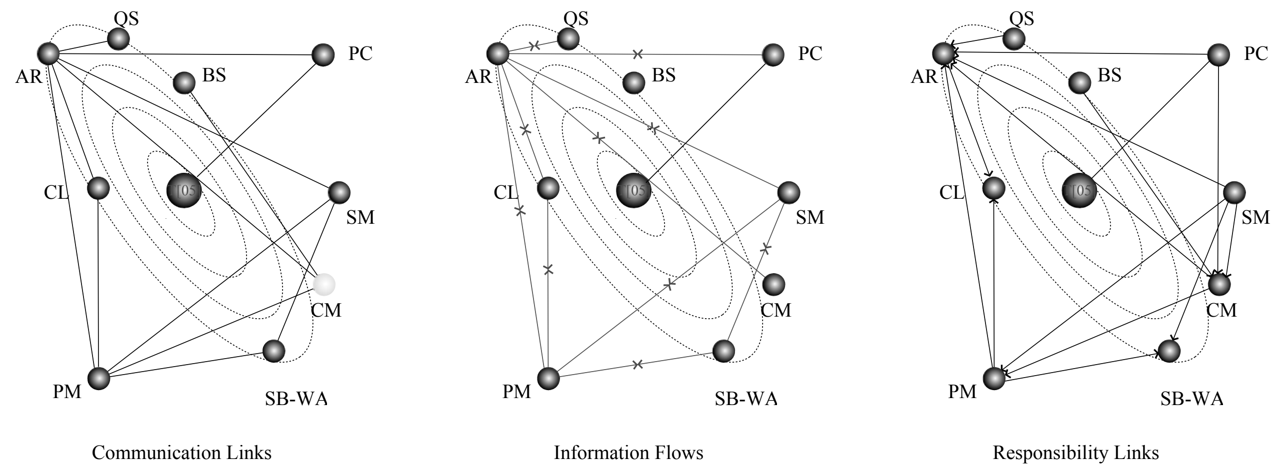

Figure 4. Design Phase - Stakeholder View

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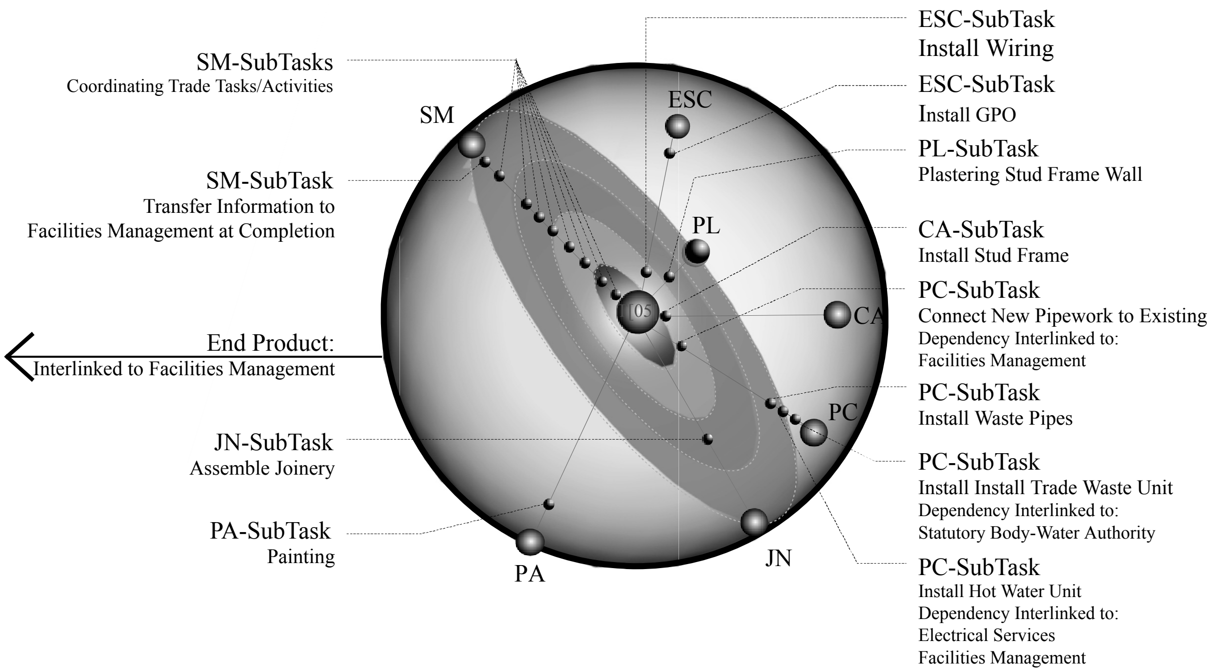

Figure 5. Aggregate View – Construction Phase

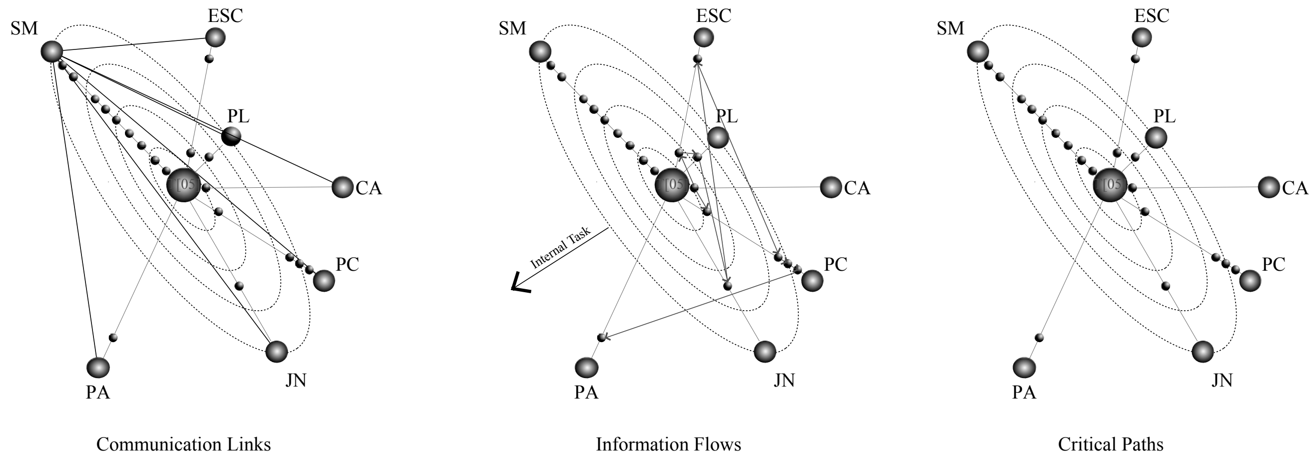

Figure 6. Construction Phase – Time Dependant Views

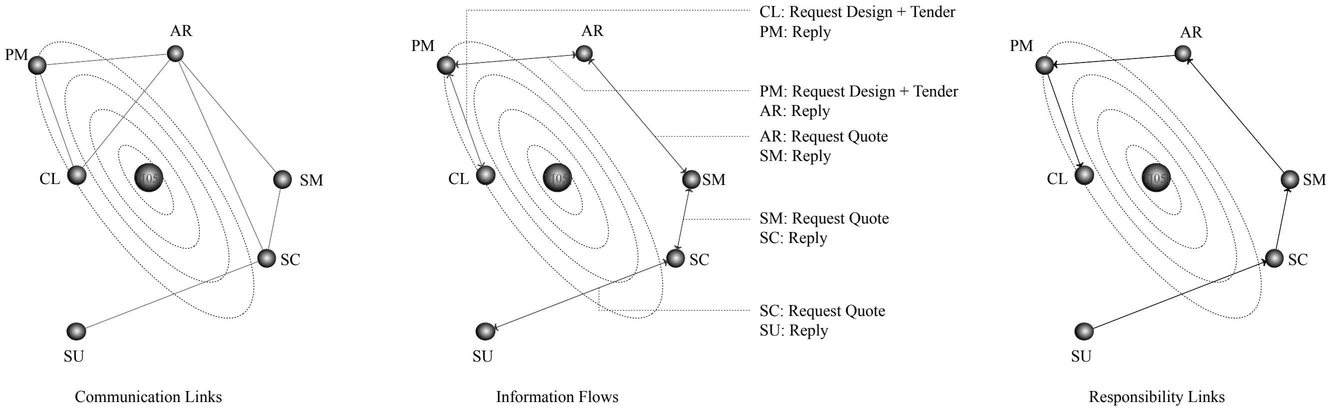

Figure 7. Construction Phase – Stakeholder View

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It is apparent that both the existing conditions in the building and errors made by others had a direct impact on the joinery work. Some of the conditions could be (and were) allowed for, including the floor slope and the wall conditions. Other issues were not predicted. These included delivery of the incorrect panels to the joinery shop resulting in a delay to the assembly and problems with the sink which was of the incorrect size creating additional work and delays in completion. The options for resolving the sink problem were either deal with the problem that arose or not install the joinery until a new sink was manufactured and delivered. Making alterations to the joinery was the chosen option with the cost of the additional work and materials born by the joiner.

Other participants in the construction process also reported similar issues throughout the project, again causing delays.

4 INDUSTRY STRUCTURE

The building industry has certain key characteristics which are a fundamental part of both its operation and the way industry stakeholders expect to operate. The industry is founded on small specialist sub-contactors each operating independently from one another and competing against each other for work. Some level of alliancing does develop with a relatively small number of contractors working consistently with each other within niche markets, generally in residential housing. These alliances often develop on an informal basis rather than with formal long term contractual relationships. Such a competitive industry based on subcontracting has several key impacts.

4.1 *Cost Driven Focus*

The focus on cost in a project has a number of consequences:

1 Obtaining work is based on cost competitiveness not on the quality of outcomes or product,
2 There is a tendency for a flat rate for work irrespective of the level of complexity,
3 Competition tends to drive costs of work down such that there is a perception by clients that they can get more for less,
4 The pressure for driving costs down starts with the client and continues down through the project, putting pressure on project quality,
5 Pressure on project budgets reduces the ability to provide for unexpected events in the construction process.

The cost driven focus results in the percentage of profits being highly variable and dependant on the smooth progress of a particular job. One contract may be highly profitable while a loss is made on the next. This leaves little reliable surplus income for process improvement and investment in skill development or technology.

4.2 *Risk Shedding vs Risk Management*

As a consequence of a highly competitive commercial environment and the increased preparedness for the use of legal action to settle disputes, there is increased risk shedding as a means of managing risk. This has developed in an environment where, if a subcontractor needs to be more competitive, they may be prepared to take on more risk than they would normally accept. The contractor has therefore effectively shed that risk to someone further down the contracting hierarchy. This also applies to clients shedding risks to head contractors. The process of risk shedding has the tendency to pass the risk on to others irrespective of whether they are able to manage that risk or not. This occurs whether accepting that risk may be seen to be part of the activities which may normally be expected of a project participant. The classic note on drawings related to checking or verifying dimensions on site (see Figure 8) shows an attempt to pass responsibility for dimensional accuracy of the design documentation to the recipient of the documentation.

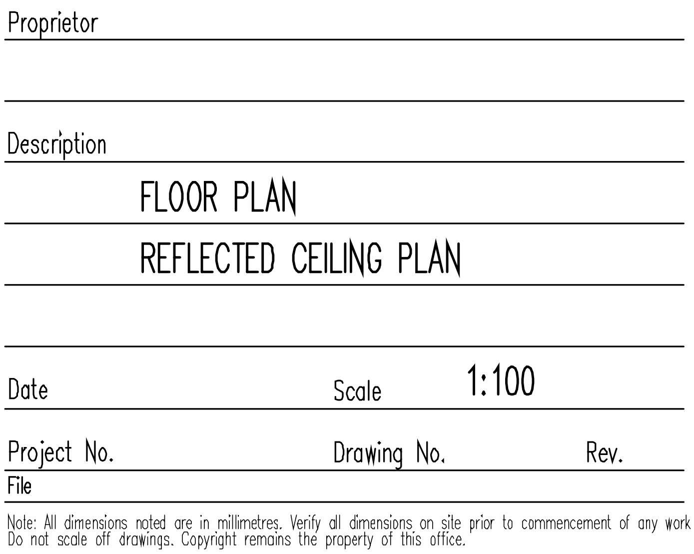

Figure 8. Extract of Drawing Title Block

4.3 *Trust (or lack thereof)*

In the adversarial and competitive environment described above, trust between participants in the building industry is difficult to develop. This results in most participants in the industry expecting relationships with others with which they deal to be adversarial and potentially litigious.

The outcome of this is that all dealings with others in the industry are treated with suspicion. Along with the process of risk shedding, this makes

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downstream participants in the design and construction process highly suspicious of any work which has previously been carried out. This encourages and often mandates a checking of all work previously done by others and with which you need to interact.

4.4 *Pressures on Skills*

In an industrial environment in which a level of robustness in dealing with others is required and where much of the on site work is dirty and considered dangerous, it is very difficult to both attract and keep highly skilled participants. In the areas other than the professions such as architects, engineers, quantity surveyors and construction managers, this is particularly the case.

5 DISCUSSION

The development of ICT is moving toward a level of usability by the building industry with increasing support for the virtual building model and the building information model by three major CAD vendors. Developments in interoperability have reached a standard where there is an opportunity for the transfer of data between software packages although this by no means applies across the industry. It is clear that a further commitment to interoperability standards, such as the IFCs, is required before comprehensive and seamless data transfer can be achieved.

While full interoperability and full integration of the design and construction processes may be highly desirable and achievable from a technical standpoint, whether it is achievable within the current industry operating structure is doubtful. Fragmentation has been targeted as an issue preventing integration of processes within the industry. This of itself should not prevent process integration. What prevents integration is the participants expectations of an industry which is fragmented.

Buildings generally get designed and built mostly by individuals or small organisations which compete with each other to carry out focused and limited tasks within the overall building operation. The nature and extent of the tasks are only described using instructions which recognise that each participant has a set of specific knowledge and skills which they contribute to the project. The instructions they are given are often only a general description of the outcome required for the specific part of the building for which they are concerned. For each participant, there is generally little or no need to give consideration as to where the task they carry out fits within the design or building operation as a whole. The participants, particularly during construction, generally wish to get in and out as quickly as possible and get on with the next job.

This type of fragmentation encourages a culture of isolation and self interest within the industry.

While this may be less true of the design professions, particularly architects, who need to integrate a range of disciplines to complete a design, there appears to be developing an increased level of specialisation and therefore isolation even within the design process.

This self interest and isolation mitigate against the development of trust within the building industry. This results in information being regenerated multiple times on multiple drawings across multiple design disciplines and is the outcome of not trusting that the information received is accurate. The industry workshops have provided several examples. A door supplier will prepare their own door schedule as they do not trust that the one prepared and supplied by the architect is accurate. Drawings will not be provided in editable electronic format as the architects are not confident that their intellectual property rights will be respected. The cabinet maker can not be confident that the space in which the joinery work is to be installed will be constructed accurately to the dimensions on the drawings.

6 CONCLUSIONS

In the current building industry there are several key elements which are missing if ICT is to be fully used in core methods of operation:

- A strong level of connection with others in the building industry,
- A cooperative approach which focuses all participants on quality outcomes,
- Reliable availability of capital for technology and skill development at all levels,
- The ability to develop and retain high skill levels in all segments of the building industry,
- Continuous skill development in all segments of the building industry,
- Trust that others will achieve the highest quality outcome.

Without these elements, the development of ICT in the building industry will be on the fringes of core operations in most segments of the industry now and into the future. The lack of development of high levels of advanced IT implementation in the building industry is not a technical problem; it is primarily social and cultural. Without addressing these issues, the best technical solutions in the world are doomed to failure.

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State of the Construction Information Technology Development Industry in Canada

T.M. Froese & Z. Han
University of British Columbia, Vancouver, BC, Canada

ABSTRACT: This paper studies the state of companies that develop information technology (IT) for the construction industry in Canada. The study collects survey results and other data about these companies. It explores the number and nature of companies, their products and markets, and their opinions about IT trends, opportunities and barriers, and collaboration with government and university resources. The study concludes that a small construction IT industry exists in Canada with some established, successful companies and a number of younger ventures.

1 INTRODUCTION

Various survey and research projects in the field of information technology (IT) for the architecture, engineering and construction and facilities management (AEC/FM) industry have been done worldwide in the past few years. Such surveys were conducted in New Zealand (Doherty 1997; Joo Ting 2000); United Kingdom (Amor 1998; Ingirige et al. 2001); Denmark, Finland and Sweden (Howard et al. 1998; Samuelson 2002); Hong Kong (Futcher 2001; Futcher and Rowlinson 1999); Saudi Arabia (O'Brien and AL-Biqami 1999); South Africa (Arif and Karam 2001); Malaysia (Mui et al. 2002); and recently in China (Xiang et al. 2004) and Turkey (Sarshar and Isikdag 2004).

In the United States, a survey of E-business implementation in the construction industry was conducted in 2003 (Issa et al. 2003); moreover, the American Construction Financial Management Association conducts a regular IT survey for the construction industry every two years (CFMA 2004). Most of the above studies focus on computer usage or impact of IT on the AEC/FM industry or related trades. These studies significantly benefit both users and suppliers of IT products and service; however, surveys that focus on the developers of IT (rather than the users) in this area are rare.

In Canada, many parties have an interest in the field of information technology for the AEC/FM industry. Rivard (Rivard 2000) carried out a survey on the impact of information technology in the Canadian AEC industry in 1998-1999. Another survey of innovation, advanced technologies and practices, including IT application, in the construction and related industries was conducted by Statistics Canada and National Research Council of Canada in 1999 (Anderson and Schaan 2001). A recent survey result of IT applications in construction was presented by the University of Alberta (El-Ghandour and Al-Hussein 2004). A significant amount of research was carried out in this field in the Department of Civil Engineering at the University of British Columbia (UBC). Froese (Froese 2001; Waugh et al. 1996) analyzed the future trends in information technologies for project management. Similar to the international construction IT surveys, those in Canada have focused on IT usage or on IT research and trends. There is very little data upon which to assess the actual current state of the IT development segment of the Canadian construction industry.

This paper is the result of a collaborative research project, "A Study of Information Technology Development for the Canadian Construction Industry", which was sponsored by the Industry Research Assistance Program (IRAP) of National Research Council of Canada (NRCC) and carried out by the Civil Engineering Department of UBC in 2004. Both of these groups pursue a mandate of supporting the Canadian construction industry with a particular focus on technology development in general and IT in particular. Both have been involved in many close collaborations with Canadian construction IT development firms in the past. Yet neither group had any objective information about this industry segment as a whole.

The objective of this project, then, was to survey the state of the IT development sector within the Canadian construction industry. The following questions illustrate the type of information being sought:

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- What are the primary categories of construction IT development in Canada?
- What are the approximate number and size of construction IT development companies in Canada?
- What is the general level of technology for Canadian construction IT developers?
- How does this level of technology compare with the level of technology currently in use within Canadian construction companies?
- What is the relative market share for Canadian companies nationally and internationally?
- How does the level of technology of Canadian developers compare with international leaders in the respective fields?

The project was launched in August of 2003. Pre-research and other preparation for the project was completed at the end of 2003 and the project was officially launched in the early part of the year 2004. The project involved an examination of Canadian companies involved in the development of IT products for the construction industry, including the identification of such companies, investigation through web sites and other public information sources, and an on-line survey of the executives and managers of these companies.

2 STUDY METHODOLOGY

2.1 *Overall Project*

The research project consists of four phases:

- *Phase one:* Identify, catalogue, and categorize as many Canadian organizations as possible involved in the development of IT products, IT research and development, offering of IT-based services, development or promotion of IT standards, etc., relating to the AEC/FM industries and identify key trend setting IT-related organizations or initiatives internationally.
- *Phase two:* Develop a questionnaire for data collection from targeted organizations. This task defined the information that needed to be gathered from a selected set of the identified organizations and constructed an appropriate survey tool, such as a project website, for collecting this information.
- *Phase three:* Carry out data collection. The survey designed in Phase two was carried out in this stage.
- *Phase four:* Data analysis and reporting.

2.2 *Sample Population*

The task of sample collecting was to identify, catalogue, and categorize Canadian organizations that are involved in the development of IT products related to the AEC/FM industries. The sample selection criteria were as follows:

- Companies that are located in Canada,
- Companies that develop IT products as part or all of their business activity,
- Companies whose IT products are marketed within the AEC/FM industry, either as stand-alone products or as an integral part of a service offering.

The initial survey sample information was acquired through the Strategis online database of Canadian companies from Industry Canada (Industry Canada 2004), supplemented by additional sources such as information provided by IRAP staff. The initial search identified 362 potential candidate companies that identified their focus as both IT and construction (a database was established to track information about the target companies). Among these selected companies, 258 companies were IT-based firms and organizations, while 104 companies belonged to construction-related businesses. The figures represent 4.8% of the 5402 IT-based companies, and 5.2% of the 1988 construction firms that were listed in the Strategis database. Next, the web site of each of the companies was investigated to further evaluate their fit within the target scope, leaving 178 samples. Later, a further review by the IRAP and UBC team further refined the list to excluded companies that did not appear to be within the specific target scope of this study, leaving 86 companies. This figure suggests that 1.1% of IT-based and 1.4% of construction-related companies are involved in the development and selling of IT products to the construction industry in Canada.

3 SURVEY FINDINGS

3.1 *Respondents Profiles and Company Information*

3.1.1 *Response Rate*

Survey return rates vary around the world. Most mail surveys in the construction industry hover around 10%. The rate was 7% for the general survey in New Zealand (Doherty 1997); 10% in Denmark and 16% in Sweden (Howard et al. 1998); 10% in Saudi Arabia (O'Brien and AL-Biqami 1999); and recently, 10.5% in China (Xiang et al. 2004). The number of responses for this survey was 38, of which 33 were complete and valid responses, corresponding to total and valid response rates of 44% and 38% respectively. With a relatively low population sample, this survey will have a high margin of error. In general, survey research cannot be considered statistically significant with anything less than a 50% return rate. However, even though a low response rate was obtained, when combined with the Internet research and several follow-up conversa-

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tions with some of the companies (email exchanges, personal interviews and telephone conversations), the findings of the survey are still thought to present useful information about the respondents and show tendencies in the development of IT for the Canadian construction industry.

Of the responses, 34% were from Ontario, 27% from BC, 24%% from Alberta, 9% from Quebec, and 3% each from Saskatchewan and New Brunswick.

3.1.2 *Company Type Regarding Head Office and Branch Office*

Among the respondents, over 90% were from head offices of Canadian companies, while 7% were branch offices of Canada-based firms and only 3% were branch offices of non-Canadian companies. Also, about 90% of respondents held senior management positions (e.g., owner, president, or CEO), while the balance included IT managers, marketing managers and/or chief representatives.

3.1.3 *Company Size*

Table 1 lists the size of the respondent companies. The companies were generally small to medium-sized (the only large companies were large engineering companies that included IT as a minor part of their product and service offerings). Table 2 shows what portion of their business activities are related to construction IT.

Table 1. Number of Employees

Response	Percentage
0 to 4	21%
5 to 9	12%
10 to 24	34%
24 to 50	12%
51 to 100	3%
Greater than 100	12%
No response	6%

Table 2. Percentage of business relating to construction IT products

Response	Percentage
100% of business	37%
51-99% of business	18%
10-50% of business	24%
0-9% of business	15%
No response	6%

3.1.4 *External Resources Used*

The last question of Section 1 asked about the external resources employed by the companies in the development of IT solutions. Government technology assistance programs and research and development tax credit programs were each used by about one third of the companies. 18% of the companies used venture capital, while 12% reported that they have not used any significant external resources.

3.1.5 *Companies with WebPages*

In conducting the study, it was found that 100% of the respondents were found to have their own e-mail addresses and as well as a home page on the World Wide Web. The proportion of companies with their own web site was 38% for the Canadian construction industry in 1999 (Rivard 2000) and 81% across the overall United States construction industry in the year 2004 (CFMA 2004).

3.2 *Product and Market Information*

In this section of the questionnaire, up to three major products could be detailed in the response form. Only one fourth of the firms reported more than one major product. Some firms indicated that additional products were being developed.

3.2.1 *Product Category*

Question 2.2 evaluated the types of products developed in the surveyed companies. As shown in Table 3, planning and scheduling, project team communication and collaboration, and project estimating top the product category list. Of the companies that responded with "Other", most described their systems as a combination and/or variation of the described the other categories (particularly those relating to collaboration).

Table 3. Product category

Response	Percentage
Planning scheduling	35%
CAD, 3D models, visualization, and GIS to support construction	16%
Project estimating	26%
Project team communication and collaboration	28%
Project procurement and bidding	14%
Project performance monitoring and control	16%
General business application areas	14%
Economic and risk analysis	2%
Planning and design of construction operations	2%
Coordinating construction operations	12%
Cost/schedule/productivity analysis	14%
Planning, controlling, and advising, for quality, safety, and environmental	9%
Field automation and robotics	2%
Advisor systems for construction methods	2%
Other	16%

3.2.2 *Implementation Technology*

Question 2.3 asked about the implementation technologies used to implement the products. About half (49%) of the respondents used web-based systems as their implementation technology, followed closely (47%) by "stand-alone" desktop PC applications. "Add-on" tools for CAD, Spreadsheets, databases, etc., and embedded IT (i.e., software embedded into other devices such as tools, buildings products, etc.) each represented a small proportion of the responses.

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3.2.3 *Product Overall Technology Level*

Question 2.4 asked respondents to assess their products' overall level of technology relative to a technology evolution life-cycle. 16% described their products as emerging technology (pre-commercial or limited early-adopter users). The largest group (59%) reported that their products are at the level of early-adopter technology, which we defined as technology that is currently in use by industry leaders and is comparable to the "best-of-breed" products available in its class available anywhere in the world. About one fifth described their products as mainstream technology level. While this self-assessment can be expected to reflect bias towards an over-assessment of respondents' own level of technology, it shows a strong emphasis on new and innovative solutions rather than well-established, mature (legacy) product lines.

3.2.4 *Primary Competitive Advantages*

Question 2.5 asked about the primary competitive advantages of the products. The comment-based responses were summarized into the categories shown in Table 4.

Table 4. Types of Competitive Advantages

Response	Percentage
Features/Technology	42%
Ease of Use	24%
Price/Value	24%
Strategic relationships/tie ins with other products and services	21%
Integration/compatibility issues	18%
Specialized knowledge/expertise	18%
First to market	12%
Ability to customize	9%
Established reputation	9%

3.2.5 *Critical Strategic Partnerships*

Companies reported on strategic partnerships that were critical to their products. Of these, customized links with other products or services were the most frequently cited (35%). Companies also identified reliance on platform software (19%), Outsourced software development (9%), and research collaboration (7%). Others (16%) include cooperation with international developers, marketing partnership with third parties, and marketing alliance with Construction Specification Canada.

3.2.6 *Primary Intended Product Users*

Many of the respondents reported that their products were aimed at more than one target user group. The highest number of responses related to the three primary parties to construction projects: contractors (head office) (51%), engineers (47%), owners (42%), and architects (42%). All of the other user groups, however, were also frequently identified. In terms industry segment, commercial and institutional building construction was the most highly targets segment (54%), but again, all of the segments were frequently identifies as targets with the exception of the renovation/do-it-yourself segment, which was identified by only 19% of respondents.

These results suggest that no single user group represents a dominant market target for the developers. Rather, they are pursuing users from across the range of project professionals. This is consistent with the emphasis placed on collaboration and integration issues by many of the products, which implies that the products are useful for users from across the project teams.

Developers are strongly focused on international (56%) or, to a lesser extent, North American (28%) markets. It seems that developers believe this Construction IT is truly a global industry; that their products have the potential to compete internationally; and that this international market is necessary for their commercial success.

3.2.7 *Estimated Product User Number and Targeted Market*

Table 5 shows how respondents reported the number of users for their products. While there were several products in each category (including several with more than 10,000 claimed users), most reported less than 100 users. Respondents' estimate of their current market share is shown in Table 6. Of the figures provided (40% did not provide an estimate), most again indicated a small market share (37% estimate their market share at less than 10%).

Table 5. Estimated Product User Number

Response	Percentage
Less than 100	42%
100 to 1,000	14%
1,000 to 10,000	23%
More than 10,000	19%
No answer	2%

Table 6. Current share of target market

Response	Percentage
Less than 10% market share	37%
10% to49% market share	14%
50% to 99%	7%
100%	2%
No answer	40%

The consequences of these two results, particularly combined with the previous results indicating the small size of the development companies and the focus on international markets, suggest that a large percentage of the products are in very early commercialization stages. In an industry with a traditionally high failure rate, it must be assumed that a significant portion of these products will ultimately fail to reach long-term commercial success. Still, the results also show that successes are possible.

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3.3 *Opinions on Construction Information Technology*

3.3.1 *The Level of Technology of Canadian Construction IT Developers*

Respondents were asked to assess the level of technology within Canadian Construction IT developers compared with the rest of the world. The results show some differences in opinion. Forty percent of the respondents believe that Canadian construction IT developers' technology level is as good as or better than the world-wide industry leaders, 27% rates the Canadian developers as similar to other advanced countries, and 33% thought that the Canadian developers were somewhat behind many other advanced countries.

Overall, then, there is support for both the proposition that Canadians believe they can compete with the best in the world in construction IT, and the proposition that Canadian's feel somewhat behind the world leaders in this area. It may be that Canadian's believe the capabilities of individual people and companies are as good as any, but that Canadians may lag behind in construction IT as an overall industry, or in terms of the level of technology of the Canadian marketplace relative to other leading countries.

3.3.2 *Important Trends for the Construction IT*

Respondents were asked to describe the IT trends that they think will be important for the construction industry over the next 10 years (Table 7). The strongest response (67%) was for Web-based collaboration and project management systems. The categories of software integration and knowledge management, which could be related to web-based collaboration) also received strong support. The other category that also received a significant number of responses was 3D CAD and visualization. These responses indicate a strong belief in the importance of the various collaboration technologies that are still emerging.

Table 7. Important trends for the construction IT

Response	Percentage
3D CAD and visualization	33%
Web-based collaboration an project management systems	67%
Integration of software tools across the project lifecycle	43%
Artificial intelligence, expert systems, etc.	17%
Knowledge management	40%
Other	7%
No answer	3%

3.3.3 *Opportunities for Improvement*

In the first of four open-end questions, respondents were asked what they thought were the biggest issues in the Canadian construction industry that could be improved through IT solutions. The responses were grouped into categories and subcategories as listed in Table 8 (responses may have identified more than one category or subcategory). Again, the most frequently identified issues related to collaboration (including communications, document management, and interoperability). There were also several responses that identified issues relating to efficiency and productivity, as well as comments about project management systems (project control, estimating, etc.). Other topics were raised but were only mentioned once (3% corresponds to a single response).

Table 8. Opportunities for Improvement to Canadian Construction Industry

Opportunities for Improvement Categories and - Subcategories	Percentage Category	Subcategory
Collaboration	33%	
- Collaboration/communication		*27%*
- Document management		*15%*
- Interoperability		*3%*
Efficiency/Productivity	18%	
Project Management Systems	12%	
- Project control/management systems		*9%*
- Estimating		*3%*
Embedding new construction expertise in design	3%	
Simplified systems for small contractors	3%	
Training	3%	

3.3.4 *Barriers for Development*

The second open-ended question asks about the biggest issues and barriers that cause difficulties for Canadian companies developing IT solutions for the construction industry. Most of the respondents believe that the biggest barriers relate to the acceptance of new technologies by the industry. The second largest category related to the financial issues for IT development (some responses related to both of these categories). Table 9 summaries the responses.

Table 9. Barriers for Construction IT Developers

Barriers for IT Developers Categories and - Subcategories	Percentage *Category*	*Subcategory*
Industry acceptance	58%	
- Resistance to change		*27%*
- Awareness/understanding of technologies/opportunities		*18%*
- Reluctance to invest in IT systems		*9%*
- Reluctance to invest in R&D		*9%*
- Lack of "trail blazers"		*3%*
- Limited computer use in field		*3%*
Financial barriers	30%	
- Reluctance to invest in IT systems		*9%*
- Reluctance to invest in R&D		*9%*
- Cost of accessing markets		*6%*
- Cost of development		*3%*
- Cost of senior resources		*3%*
- Availability of investment capital		*3%*
Market barriers	9%	
- Small Canadian Market		*6%*
- Marketing Support		*3%*
Resources barriers	6%	
- Cost of senior resources		*3%*
- Loss of programmers to US		*3%*
Technical barriers	3%	
- Wireless access		*3%*

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3.3.5 *Government Support*

The third open-ended question asked how government support programs could better support businesses (summarized in Table 10). The most common topic related to providing some form of leadership in developing the market for new construction IT, followed by responses calling for various forms of financial assistance (tax related, R&D support, etc.). A number of the responses made a point of stating that the companies had no need of government support programs.

Table 10. Government Support

Opportunities for gov. support Categories and - Subcategories	Percentage *Category*	*Subcategory*
Leadership in Market Development	33%	
- Leading by example		*9%*
- Industry Education/providing information		*15%*
- Encouraging change		*6%*
- Trade missions		*3%*
Financial (Taxation, R&D support programs, etc.)	21%	
None	12%	

3.3.6 *University Collaboration*

The final open-ended question inquired about opportunities the respondents perceive for potential collaboration with University researchers and students. A wide range of responses were given (summarized in Table 11). The largest category related to various ways of utilizing university-based expertise (relating to both technology and marketing). Other responses commented on the role of universities in training students and industry practitioners. Several responses also discussed what IT developers have to offer to University programs, e.g., bringing industry experience to students.

Table 11. Opportunities for University Collaboration

Opportunities for Univ. Collaboration Categories and - Subcategories	Percentage *Category*	*Subcategory*
Expertise	36%	
- Development of/collaboration on technical components or standards		*18%*
- Assessment of developers' products		*9%*
- "Pure" research		*6%*
- Analysis of trends and markets		*6%*
- Marketing support		*6%*
Training	12%	
- Use solutions in training students		*9%*
- Training		*3%*
Providing Co-op programmers	3%	
Developers providing experience/expertise to students	9%	

4 ANALYSIS

This section presents subjective interpretation of the survey results. It first considers the status of the Canadian construction IT industry, as suggested by the results. Next, it outlines the main issues raised by the survey responses. Finally it suggests the potential role of government that might be implied by the findings.

4.1 *Status of the Construction IT Industry*

Based on our analysis, the following conclusions can be drawn regarding the state of the construction IT industry in Canada:

– The number of Canadian companies competing in the relatively mature areas of construction IT (e.g., Stand-alone analysis applications) is very small. These companies should be considered on an individual basis, but as a group they do not appear to have the potential to make a significant impact on the field of construction IT.

– A larger number of Canadian companies are competing in newer areas of construction IT, most notably Internet-related systems. Although the number of companies is still small, this could justifiably be described as an industry "cluster". The characteristics of this cluster are typical of an emerging industry; they are mostly small, entrepreneurial ventures. Some have already achieved a degree of success and market leadership, but most are in the early phases of the corporate lifecycle (and a high attrition rate may be expected over the long term). As a group, this cluster could not be described as having made a significant impact on the overall construction IT landscape and it is behind similar clusters in other countries (an international comparison is discussed later in this section). However, the potential for impact and success exists as this cluster seems to be well positioned in terms of both market and technology. As a whole, the technology for this category of systems is well-proven and is in everyday use in industry, yet the technology and its applications are still evolving and have yet to be adopted by the majority of industry.

– There is no significant group of companies pursuing construction IT relating to emerging technologies such as integration and interoperability. A commercial market for this technology may not exist at this time, but this may well be an emerging technology segment in the future.

4.2 *Issues for the Canadian Construction IT Industry*

This section summarizes key issues facing the Canadian construction IT industry.

4.2.1 *Technology*

The survey results gave no indication that Canadian construction IT industry faces any particular tech-

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nology-related challenges. Within the young but proven IT areas such as internet-based applications, there appears to be no reason that Canadian companies cannot compete technically with any international competitors. However, there was also no information to suggest that Canadian companies are leaders in IT (see international comparisons).

4.2.2 *Financial Resources*

While it did not appear to be an overwhelming issue, financial issues where mentioned by almost a third of the respondents as a barrier to IT development. These related to both the willingness of the industry to invest in IT (addressed further in the market issues section following), investment in R&D, and the cost of development. These issues may be reflective mainly of the early venture phase of many of the respondent companies.

4.2.3 *Market Issues*

The most significant issues identified by respondents as facing the construction IT industry related to their market—in particular, over half of the respondents described weak industry acceptance and resistance to change as key barriers. Respondents described this issue in a number of ways: resistance to change; awareness/understanding of technologies/ opportunities; reluctance to invest in IT systems or in R&D; and lack of "trail blazers". One possible explanation for industry reluctance, of course, is simply that the offerings are not sufficiently of value to the construction industry. However, the degree of adoption to date suggests that the overall uptake of these technologies is probably following similar trends to previous IT such as CAD, scheduling software, etc., as the technology slowly matures and establishes itself as an essential tool. While it may be typical for such technology, the challenge of market development (establishing a clear understanding and desire for the technology within the industry) is clearly a major issue for many of the companies in the construction IT cluster.

4.2.4 *International Comparisons*

Approximately two-thirds of respondents felt that Canadian expertise was at least as good as other advanced countries. No data was collected during this study to objectively compare Canada's construction IT industry with other countries. However, this section provides a brief comparison of our understanding of the state of construction IT in Canada, as suggested by this study and other information, with our knowledge of construction IT in certain other countries. We share the respondents perception that, within their target areas of activity, the Canadian construction IT companies appear to be generally on par with activities in other countries. The level of adoption by industry of this IT appears to be somewhat lower than might be expected in several other countries.

In more advanced areas of construction IT (e.g., the technology such as the use of building information models) Canadian companies and researchers are contributing but are under-represented relative to several other countries. In particular, a number of other countries have embarked on significant initiatives specifically targeted at improving construction IT (or at improving the effectiveness of construction as a whole with IT as a significant component). Common characteristics of these initiatives include the following:

- The initiatives involve participation from most or all of: individual construction and IT companies, industry organizations, research organizations and universities, government bodies, and public R&D funding agencies. The initiatives are being lead by government, research organizations, or industry organizations.
- Knowledge of the initiatives is widespread in industry.
- Some commercial development based on the technology, pilot projects, and some innovative uptake of the technology by industry is underway. Mainstream use of the technology is not yet occurring.

Countries that are known to have such initiatives include Australia, Finland, Japan, Norway, Singapore, Sweden, the UK, and the USA. No similar initiatives are known to be underway within Canada.

4.2.5 *Community of Practice*

The most significant issue facing the Canadian construction IT cluster may be market development, but it is very difficult for the individual small construction IT companies to foster widespread change throughout the industry. Perhaps the most notable difference between Canada and the leading construction IT countries is the existence of definable communities of practice for construction IT, which do not appear to exist within Canada. Some of the typical characteristics of these communities of practice in other countries are as follows:

- Organizations and individuals with a particular interest in advancing construction IT exist in construction and IT companies, industry organizations, research organizations and universities, and government bodies (both as construction clients and R&D agencies).
- These members are generally aware of each other as having common interests.
- One or more organizations play a centralized, leadership role in providing some form of organization for this group.

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- There is a degree of clarity of vision regarding future goals and objectives.
- There are effective forms of communication and regular interaction among the groups members (e.g., regular technology seminars).
- There are various collaborative activities that cross segmental boundaries (e.g., pilot projects involving research organizations, industry, and government).
- There are some degree of common resources (e.g., targeted government industrial R&D funding programs).

4.3 *Possible Roles for Government*

The results from this study suggest that existing governmental programs such as the Industrial Research Assistance Program (IRAP) are well-received by the construction IT companies. Based on the previous analysis, government could provide leadership and support in two key areas: market development activities and the development of communities of practice in construction IT. Both of these activities should be considered from the perspective of improving the overall Canadian construction industry in addition to the Canadian construction IT sector in particular.

5 CONCLUSIONS

The overall conclusion is that a Canadian construction IT cluster exists. It has some good and successful companies, but is very small. Under present conditions, it might be expected that a small number of companies will continue to emerge and develop to a level of some success. However, these will develop as isolated individual companies rather than as an industry segment as a whole (i.e., there will be minimal synergy among the technical and market development efforts). Furthermore, their overall impact on the Canadian construction industry will be low. At this rate, Canadian construction IT is likely to be in a class below the leading countries in this field.

There appears to be enough activity in the newer areas of construction IT, with no major structural barriers, that the potential exists for a more significant construction IT sector on par with world leading countries. This would likely require the types of communities of practice for construction IT that exist in some other countries.

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Lean Construction and IT principles, tools and applications in a South American Precast Concrete Industry

S. Scheer & A. Santos
Civil Engineering Research Centre, Federal University of Paraná

J.R.S. Quevedo & J. Mikaldo Jr
Construction Engineering Graduate Program, Federal University of Paraná

ABSTRACT: During the precast concrete structures production process a challenging task is integration of the supply chain and the various departments within company. It is necessary to handle uncertainties related to the assembling process at construction site. The distance to the construction location, topography, weather conditions and other factors affect the level of these uncertainties. The challenge is to produce with reduced waste, high quality and on a synchronized fashion where every resource gets on exact time and quantity required by the production process. In order to achieve that situation the flow of design and engineering information plays a key role in order to enable a lean flow of materials. The present research investigated this issue on the largest factory of pre-fabricated components in the South of Brazil where the required information and the IT aspects that enable a lean material flow were studied. The emphasis was to look on process transparency and information flow among the design office, the factory and construction site. The paper presents key issues for improving integration of the automation islands in the whole process from design to component manufacturing and construction, like a web collaborative environment as a solution to enhance information flow transparency.

1 INTRODUCTION

A significant change has occurred in the last two decades concerning the importance of the production function within the construction organization. The production function used to be relegated to a second plan in many companies when compared to other organization functions such as planning, finance or marketing. It is now playing a far more pro-active role within construction companies. Taking this into account, the paper begins with a small review about production and its business role looking for a construction industry viewpoint. In the sequence it deals with 'lean thinking' concepts and implications for IT application. With these concepts in mind, a precast concrete plant case study developed in the South of Brazil is described. The analysis of the prefabricated elements production was made with respect to behavior, sequence, waiting, transportation, inspecting and controlling in order to understand the actual information flows and problems. Finally, based on this research tools and techniques of lean production and IT were proposed to collaborate in the search for problem solutions.

2 NEED FOR INTEGRATION

Galbraith (1986) argued that organizations are "packages of mosaics" in which all the pieces must fit together. In line with this, coherence of decision-making between production and other organizational functions, specifically concerning the business process, is a fundamental requirement for achieving a company's strategic objectives. Internal fights within a company, to satisfy fragmented objectives, are counterproductive and only lead to sub-optimization and waste of resources.

Production managers risk being affected by "cognitive nearsightedness" if they do not get involved in strategic planning. Short-term decisions may sacrifice a long-term strategic advantage. Bowman & Asch (1987) define "cognitive nearsightedness" as the tendency to pay more attention to physically observable, quantitative and immediate factors, at the expense of intangible dimensions of a problem that are remote in time and space. In other words, production managers may place too much emphasis on direct operational decisions and give little attention to their implications on the business strategy.

In this context, the production function may opt for one of the following strategic postures with

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respect to business needs (Hayes & Wheelwright 1984; Schroeder & al. 1986; Adler & al. 1992):

– *Internally neutral*: production that is simply reactive to the internal business demands. The function has few links with the rest of the business and makes a minimal contribution to increase the company's competitiveness;
– *Externally neutral*: production that is able to meet the standards imposed by the major competitors. It responds to problems encountered in the rest of the business, but never establishes its own long term strategy;
– *Internally supportive*: production that is tailored to the specific business strategy. In this case, the production function generates many new ideas and has a long term strategy, but it may not be well tuned to other functions needs or expectations;
– *Externally supportive*: production that aims to be as good as any other competitor in the world. In this case production supports both the current business priorities, and other organizational functions, thus, creating new opportunities for increased competitiveness.

Unfortunately, production is often found playing only an internally neutral role in many organizations. Production's usual response to competitive pressure has been a simple directive to "cut costs" which, in turn, results in the decision to reduce capital investment, minimize research and development, cut back preventive maintenance and to lay off workers (Wisner & Fawcett 1991). In some instances, production managers try to transfer and adopt the same "best practices" of other successful production systems. However, Mills & al. (1995) argue that "*the implementation of the best practices alone is unlikely to develop the production function ability to create and understand its own strategy*".

According to Skinner (1969), one of the main barriers for moving the production towards a more strategic role is the lack of a leadership that understands and accepts the idea of developing strategic thinking in the production function.

Hill (1992) adds some other reasons for the poor participation of production at the business strategic debate:

– The production manager's view of themselves: strategic implications of the production decisions are not fully understood even by the production managers themselves;
– The company view of the production manager's role: business strategic decisions are formulated assuming the production manager has few strategic contributions to give;
– Production managers are late into the corporate debate: very often production managers have their first contact with the content of the strategic decisions only after they have already been defined;
– The "can't say no" syndrome to orders: a result from the fear of losing face or being accused of incompetence in relation to other functions within the company;
– Lack of language: production managers rarely understand the language and practice at the corporate level because of their operational background (the lack of strategic management in the curriculum of undergraduate courses is also often a serious gap in higher education in this field);
– Functional goals and measures: the link between production goals and actions in the business performance is not always clearly made.

Hammer & Champy (1994) credit to Henry Ford this fragmentation approach to management where the business processes are broken up in tasks and services. A monumental effort is necessary to reconstitute the fragmented work, particularly on large companies. Davenport (1992) presents the theory of process management against these called functional structures. The idea is simple and looks for results in a linear way based on a continuous flow of actions through an enterprise structure without barriers. The result is an integrated process, transparent and without loss of visibility in the main focus (Gianesi & Correa 1994).

3 FLOW CONCEPT

This research used as a main theoretical framework the principles presented by Shingo (1989) and Koskela (1992) regarding lean thinking. "Flow" was key concept from lean thinking investigated in this research. According to the 'flow model', production is a flow constituted of processing, waiting, inspecting and transporting activities (Gilbreth 1911, Koskela 1992). Within this model, processing activities are the only ones that can add value to the customer and, therefore, waiting, inspecting and transporting are considered non-value-adding activities and should be eliminated from the main process flow.

Based on this model, a production system could be further described as a network of process flows and operations flows, lying along intersecting axes. A process flow is the designation for the flow of materials (or information) and represents the pathway in which raw material is transformed into semi-processed components and then into a finished

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product (Shingo 1989). In car production, the 'process flow' can be further divided into the flow of components to the workstations, and then flow of the car body through the assembly line. In industries such as construction, an additional process flow may occur with the movement of material within and across workstations (Birrel 1980, Koskela 1999).

An operations flow is the designation for the flow of humans or machines that carry on the work over each stage of the process flow. Operations are very diverse and dynamic in terms of content and position in time and space. Thus, in order to facilitate the analysis of production systems, operations can be further classified as (Shingo 1989):

– Set-up operations: preparation of the workstation before and after the principal operations (e.g. installing a scaffolding);
– Principal operations: actions which actually accomplish the essential operation (e.g. launching concrete on the formwork) and, also, those actions that help to achieve the essential operation (e.g. loading and unloading material);
– External operations: activities indirectly related to the principal operation, or common to a number of different operations (e.g. lubricating);
– Personal allowance: activities that serve the needs of the worker in terms of fatigue and biological needs (e.g. rest, drinking water).

4 PRACTICAL IMPLICATIONS AND APPLICATION IN CONSTRUCTION

The strategy to improve performance in the flow model sharply contrasts with the conversion model where the focus is on the replacement of human labor with new technology (Koskela 1997). In the flow model the aim of production managers and workers alike is different and aims to eliminate the inherent non-value adding activities (inspecting, waiting and transporting) and improve the efficiency of value adding activities (processing) (Koskela 1992).

The aim of the flow model is, therefore, to obtain "lean production systems", with little or no waste of resources. Therefore, identifying and eliminating sources of waste is a constant preoccupation on the minds of people using this paradigm in their every day activities. According to Imai (1997) and Shingo (1989), sources of waste are classified according to seven main categories:

– Overproduction: this type of waste results from "getting ahead" with respect to production schedules. Here the required number of products is disregarded in favour of efficient utilization of the production capacity;
– Inventory: final products, semi-finished products, or parts kept in storage do not add any value. Even worse, they normally add cost to the production system by occupying space and financial resources and, also, by requiring additional equipment, facilities and manpower;
– Repair/rejects: rejects interrupt production and, in general, require expensive rework. Moreover, they may end up discarded or damaging other equipment or generating extra paperwork when dealing with customer complaints;
– Motion: any motion not related to adding value is unproductive;
– Transport: although sometimes this activity seems to be an essential part of production, moving materials or products adds no value at all;
– Processing: this waste happens when the use of inadequate technology or poor design results in inefficient processing activities. Sometimes this waste may appear as a consequence of a failure to synchronize processes, where workers achieve performance levels beyond or below the requirements of downstream processes;
– Waiting: this waste occurs when the hands of a worker are idle such as when there are imbalances in schedule, lack of parts, machine downtime or when the worker is simply monitoring a machine performing a value-adding job.

This classification could extend further with the inclusion of vandalism, theft and other sources of waste. Koskela (1999) proposes the inclusion of a type of waste that occurs frequently in construction when production operates under 'sub-optimal conditions'. Congestion of a workstation in small places, work out-of-sequence and excessive stops in the flow are examples of these conditions that lead to production having sub-optimal performance (Ballard & Howell 1998, Koskela 1999). Formoso & al. (1999) adds that on building sites it is possible to find waste due to 'substitution'. This waste happens when, for instance, there is a monetary loss caused by the substitution of a material by a more expensive one or when the execution of a simple task uses over qualified workers.

Another important aspect of the flow model is the importance of the differentiation between 'process and operations flow', particularly for those searching for improvements in production systems. 'Process flows' (material/information) should always receive top priority in improvement activities within production systems. For example, and conventionally, most people simply think that improving transport efficiency refers to the adoption of forklifts or installing conveyors, etc. However, within the process/operation model, improving

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transport can also mean reducing or even eliminating the transport altogether. It is only after this broader analysis has been carried out in the entire ‘process’ that improvements should be devoted to the actual operation of “transport” (Shingo 1988, Edward & Peppard, 1994).

In the case of ‘operations flow’, the objective of managers/workers involved in the analysis of production should be to reduce the amount of set-up, external and personal operations involved or interfering in the principal operations. At the same time, the analysts should attempt to increase the efficiency of the principal operations. Activities such as adjustments, rest or lubrication, for instance, should be moved out of the main process flow in order to allow a smoother and faster process cycle time.

There are many techniques available to analyse and improve production systems using the flow model as the conceptual base. They allow the analyst to understand actual behavior, sequence, proportion and variability of inspecting, waiting, processing and transporting activities. Many of them were invented in the early days of Scientific Management School, such as time-lapse video recording, work sampling and flow charts.

From an Information Technology (IT) point-of-view the flow concept has profound implications. Henderson & Venkatraman (1993) point that one of the difficulties for the companies in getting profits with the implantation of IT relies in the lack of ability to co-ordinate and to line up the business strategies with the IT strategies. Various authors like Laudon & Laudon (2003) agree with it confirming that the most difficult part of an information system project is to efficiently understand the actual problem that should be considered. From a lean production point of view the problem that IT could tackle is straightforward: it could contribute on the reduction of all waiting, transporting and inspecting/controlling activities that interfere on the material/information flow.

5 RESEARCH METHODOLOGY

The chosen research method was the case study supported by bibliographic review. The case study was carried through structured direct observations within the precast plant and interviews with objective of knowing and understanding the actual process and operations flow.

Based on the principles of the lean production, the research team made detailed comments on the transformation processes from raw materials to finished products. A detailed description of all operations to accomplish the processing activities was obtained at the end of the data collection, following traditional approaches used to obtain standard processes. A photographic survey, video recording, document analysis was also carried out in addition to the direct observation and interviews.

A workshop between researchers and company representatives was set in order to increase internal validity of the data and analysis. The company representatives were the team leaders and the people actually in charge of the production system. This workshop adopted the "brainstorming" as a tool to instigate the participants to put their views on the problems and solutions related to information flows that support production.

5.1 Company characterization

Precast concrete is a significant contributor in many building types, including commercial, like shopping malls and supermarkets, and parking garages. Precast concrete plants usually serve limited geographic regions, restricted by the distance over which pieces can be economically transported. Although many companies operate more than one plant, the industry remains somewhat fragmented (Eastman & al. 2003).

The elements most commonly produced for the Brazilian building construction are double tees, hollow-core slab elements, inverted tee and ledger beams, spandrels, columns and façade panels. Like other countries, there is no standard for element dimensions. For example, each company produces double-tees with varied basic dimensions.

This study case is based on data and analysis related to the largest precast industrial plant in Brazil. The same company has another four plants in Brazil. The visited plant has a nominal capacity for 200 cubic meters per day of diverse products. The actual production is about 160 cubic meters. More than a half is of hollow-core slabs and about 60 cubic meters of beams and columns. The inverted tee beams has a non-uniform production and is less than 20% of the production.

The production system within the case study was divided in five main bodies: slabs, roof beams, foundation piles, columns, and beams. In each of these cells there was two main activities: to prepare steel armors and to launch the concrete for the elements. There was a "steel central office" and a "concrete central office" providing all information and resources related to steel and concrete to all production cells.

Each precast element remains in its place until the concrete achieved the required rigidity. This phase usually last around one day and, after that, the concrete elements were transported to a storage area. A subcontracted company transported the elements to the construction site and another team carried out the assembling process.

The main departments involved in this process were: “general management”; “personnel”; “fi-

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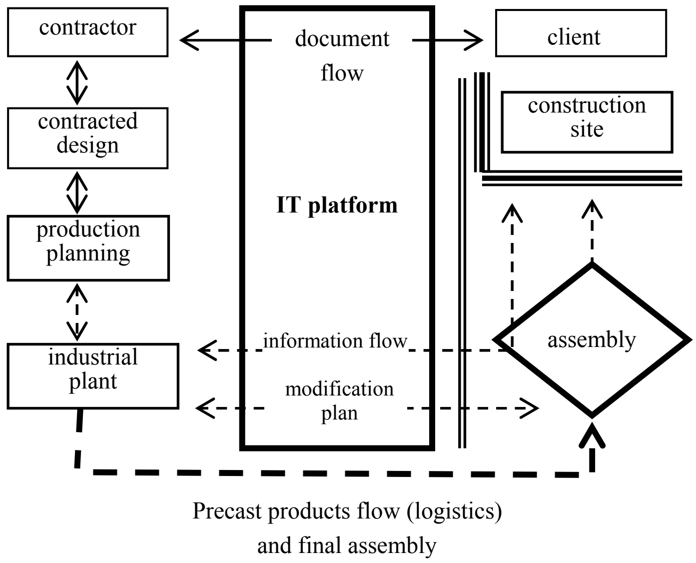
nance" and "accounting"; "purchasing" and "marketing"; "technical/engineering"; "supply management"; and "production". The manufacturing leader in the precast industrial plant had direct communication with the board of directors. In fact, the researchers have identified only one hierarchical level between the director board/management and the manufacturing plant. Taking into account these organizational aspects of the production function, the present research investigated the required information and IT applications that could help this company to enable a lean material flow, with emphasis on the increase of process transparency.

6 MAIN IDENTIFIED INFORMATION FLOWS

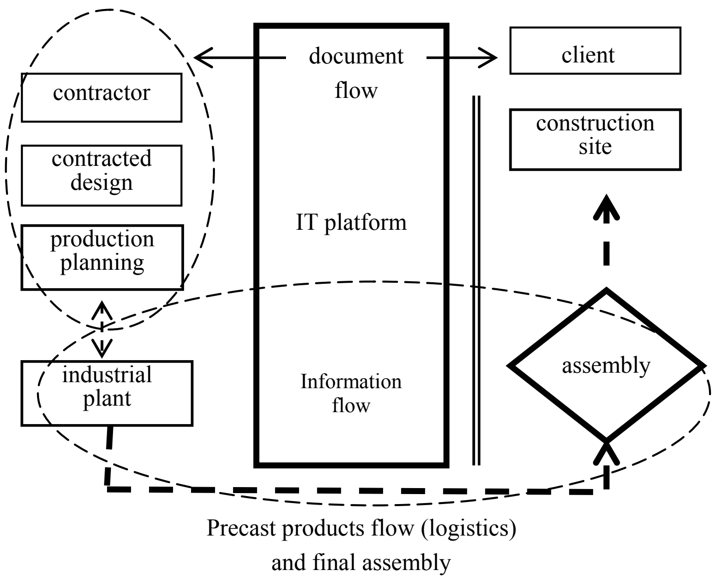
The analysis of data collected on the factory and during the workshop with company representatives allows the identification of ten major production problems that could receive a positive input from IT support:

- variation in the production productivity;
- reduced commitment from employees in relation to business goals;
- no effective communication between teams (factory x designers x construction site);
- losses due to design integration (hydraulic, structure, etc) and lack of standardization;
- losses with storage due to delays on the cutting process of precast element like roof beams and, also, delays on the concrete launch;
- process unbalancing particularly on the concrete launch;
- cure of the concrete as a key bottleneck in the production process;
- excessive time spend on activities such as formwork cleaning, demould and stretching of steel cables;
- losses due to overproduction (production without confirmed client orders with the solely intent of keeping production personnel "busy");
- deficient layout planning: excessive transportation distances and lack of transparency.

One of the main problems pointed in brainstorming was the lack of commitment of the employees regarding the production goals established by the company. This can be attributed to the lack of clarity in the communication which could be observed between the members of a department and between different departments. It can be understood as "noise" during the communication processes, i.e., interferences that make difficult to have clarity in the information reception. Another relevant aspect is the lack of feedback culture between the receiver and the sender of a message or command. It was also identified a deficient communication between the company and its customers and between professionals involved in the architectural design and the assembling team. Such communication problems resulted in poor design standardization and sub-optimized design solutions (Fig. 1).



(a) Original information flow



(b)Possible transformation of the information flows by IT and collaborative environments

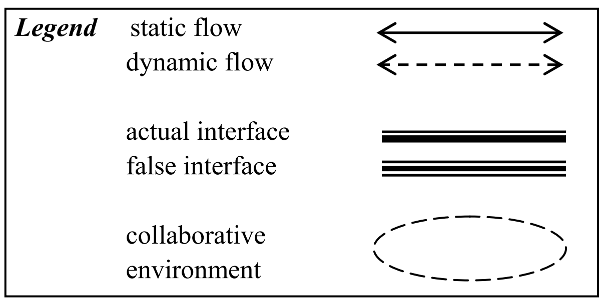


Figure 1. Information flow: original and modified flow

The research observations disclosed that there are lacks of synchronism between the actual flow of the construction site execution and the production flow

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in the precast industry floor plant. This significantly increased the time wait in the assembly of components and in the allocation of people and machines.

Production flexibility, both in terms of volume as product mix, was a major issue to change this scenario. Such flexibility implies in the implementation of devices for increase the speed of setup operations. Therefore, information availability was a key aspect to enable higher flexibility of the workstations.

The first part of Figure 1 shows the reported situation with the disconnected, fragmented and naive sequential use of the information technologies without a real information system characterization. In the second diagram of Figure 1 it is presented a solution approach with the information flow reorganization through web collaborative environment that permits the data sharing for the product characterization and customization: owner demands, manufacturability and constructability, costs and history of the firm. The data sharing provides stronger team commitment and better management decision support. In the case, the suggestion was for a convenient adoption of two different collaborative environments: one for the product design process and one for the product manufacturing.

7 INFORMATION TECHNOLOGY CONTRIBUTIONS TO SOLVE CASE STUDY PRODUCTION PROBLEMS

Current Information Technology solutions are capable of providing solutions to the problems presented above. As described earlier, the process should be tackle first (flow of information/material). Once it has been exhausted there is a number of IT solutions that could be installed like mobile phones, faxes, webcams, desktops, notebooks, handheld computers, and radios and contribute to actually reduce waste in this case study. However, because this company operates in a large geographical area the researchers concluded that it was necessary the use of systems based on local area networks, world-wide area networks (Internet), satellites, magnetic waves and others.

Table 1 summarizes some of the main information problems and proposed tools and techniques of lean production and IT identified.

Currently, it is possible to use different technologies generated under the Internet and the World-Wide-Web development like e-mail, web sites, document servers, chat, business-to-business (B2B) applications and peer-to-peer (P2P) systems (Issato & Formoso 2004). In this scenario, the solution devised to tackle the problems identified in production was to establish the communication between the involved ones by means of an extranet.

Table 1. Information problems, lean production and IT applications.

Information Problem	*Lean Production Principle*	*Lean Production Tool*	*IT Application*
Excessive storage of slabs and piles	Pulled production	Just in time Kanban system	To promote more agile communication with construction sites Extranet and webcams in the construction sites
Excessive timeloss to prepare formwork, demould, etc.	Flexible production	Celular manufact. Quick setup Multi-task workers	Time accounting, dairy schedule and tasks control, production reports, discuss variations
Lack of project standardization and production program without previous plan	Leveled production	Quick setup Small lots Production synchronization	Establish standard procedures; forecast variations; promote feedback culture; promote online meetings; adopt collaborative engineering practices
Lack of commitment with company goals; weak communication with team leaders	Adequate use of human resources	Multi-task workers Kaizen Training	Establish communication channels between departments; small team meetings with self-leadership
Lack of information about solved problems and other fails	Visual management	"Andons" Light panels Call-lights systems	Promote transparency through information panels with goals; more participation of workers in problem-solving routines; videoconferenc. and web cameras
Layout problems: excessive movements for people and transportation; frequent/repeated bottlenecks	Continuous flow of production – Process intervention	Layout in harmony with process Waste elimination	Online communication in the bottlenecks; search for team 'spirit' and results sharing; give visibility and transparency to whole process

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According Pakstas (1999), extranet is based on the Internet infrastructure (servers, e-mail clients and web browsers). Extranet is defined as a business-oriented technology that consists of a private network that involves various organizations that may act in a cooperative way. An extranet needs a server that could be a local hardware or a virtual server. Through this server the information will be controlled and storaged in real time as efficient IT system.

The use of extranets as the communication and exchange of information method can bring good results in this case. However, according to Nascimento & Santos (2002), it must be considered some barriers, that can make difficult the implantation of the system:

- professional staff with little IT training;
- resistance to the change of some involved personnel;
- lack of physical structure and technical staff;
- lack of standardization in the communication as a complex process;
- lack of training adjusted to the system in use;
- necessity of high-speed (broadband) connection to the Internet (availability, cost).

8 CONCLUSION

Each segment of the market demands specific systems that take care of its necessities. Companies such as the one investigated in this research need to establish an IT strategic plan for the development of these systems. In this plan it should be defined which hardware, software and ways of transmission to use. The company needs to define the managerial guidelines for the IT professional who will develop the IT plan: Which is the amount of capital to invest in IT? Which are the necessities that the system will have to take care of? Which are the speed of transmission of information? And so on.

First, it is necessary to define the different departments or external customers that will exchange information. After this definition, with the available amount of capital for IT investments, the IT staff will define hardware, software and transmission (communication) alternatives to use. In the case study, the communication must happen between the customer, the commercial department, the technical/engineering department, the floor production plant and the assembly team. And, the commercial department needs an open channel with all the integrants because it is responsible for the follow-up of the schedules and the relationship with the customer.

In this case study it was verified that it is crucial to have accurate information and at the right moment so that the system of pulled production reaches its full effectiveness. All lack or accuracy of information immediately generates unnecessary supplies that only increase the cost. The production teams with lack of information start to produce more than necessary, looking to safe margins. In this context IT assumes a strategic position in the production flexibility. IT acts directly in the external environment of the company verifying consumption trends and surveying purchasing speed, as well as the products that present bigger acceptance.

In order to achieve full transparency the production system must implement IT solutions along with all visual management practices like visual controls.

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Awareness and Adoption of Information and Communication Technology (ICT) by Architectural, Engineering and Construction (AEC) Industry Educators in Nigeria

O.S. Oyediran

Quantity Surveying Unit, Department of Building, University of Lagos, Lagos, Nigeria

ABSTRACT: The adoption of the ICT in the construction industry has been very slow for Information and Scientifically Underdeveloped Nations (ISUNs), as compared to the wonders of ICT in business and the construction procurement process in the Information and Scientifically Developed Nations (ISDNs). This study set to gather and analyze baseline information about awareness and adoption of ICT in the AEC industry educators in Nigeria. In a stratified sampling survey design research using Nigeria educational institutions offering construction education, it was discovered among others, that majority of the educators are on either stage three or four of IT adoption, with proficiency in word processing packages and at lower level of proficiency on other industry specific packages. The study observed the quest by the younger cadre of educators to acquire training informally. It was recommended that a programme of training the educators through a centrally pooled ICT centre might provide the necessary ICT capacity base for the AEC industry.

1 INTRODUCTION

Oyediran and Odusami (2004) examined the state of the art of computing by QSs in Nigeria at the turn of the last century and observed that there is the need to examine the capacity of the industry educators as a necessary input in designing relevant policy strategy for the industry's IT take-off. Noble (1998) believes that training is central to the adoption of IT and to overcoming the difficulties that may arise as a result of its adoption. Rebolj and Menzel (2004) were right in observing that an important reason for not using IT in construction effectively is education related. They further pointed out that graduated students are powerful agents of change in the industry and agents of technology transfer. A major factor in IT adoption in the construction industry is the inadequacy of human resources and experiences. The industry need highly educated professionals who posses relevant knowledge and understanding of the systems and processes. A shift in education system is not only overdue (Stallings, 2001) but an examination of the IT incapacities of the institutions is indispensable. This will require auditing of both physical and human resources.

There is dearth of industry-wide information about how the ICT technologies are being imported and adopted to build up the capacity level of the AEC professionals in the ISUNs, particularly in Nigeria. The ISUNs are primarily users and consumers of ICTs, while the ISDNs are the primary inventors and developers of these technologies. The developed world has made tremendous progress in application of the technologies in commercial, industrial and educational processes, the less developed countries. The less developed world where the countries in Africa falls are just waking up to the reality of adoption and application of the technologies. However, there has been some rapid progress in the application of ICT in commerce particularly in financial services, of late. This is because of the seamless communication nature of ICT. The construction industry has been sluggish in adoption of ICT despite the amenability of its process to IT operations.

This sluggishness can be traced to conservativeness of the industry, high degree of fragmentation in both the procurement process and production systems, absence of management driven IT strategy (Cartidge, 2002) and low capacity building through education (Oyediran, Odusami, 2004; Rebolj & Menzel, 2003). Rivard (2000) noted the continual demand for upgrading and greater know-how required for IT adoption. This demand for upgrading and know-how underscores the importance and criticality of training at tertiary educational institutions and at continuous professional development (CPD) levels.

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Research in construction IT (Sidewell and Cole, 1988, Doherty, 1997, Howard 1998, Rivard 2000, Samuelson, 2002, Rivard, et al 2003; Love et al, 1995, Hua, 2005, etc) has carried out surveys on ICT wage in most developed (ISDNs) nations. It appears in these studies that capacity development of the AEC industry educators have been taken for granted. Reboly and Menzel (2004) reported that several research projects have seen the issues of educating the practitioners and bringing results closer to the practice as the way forward in making the industry use the IT solutions proffered. However they believed that an important reason for not using IT solutions proffered in construction effectively lies in the current education practice. Stallings (2001) also shared similar views when he submitted that a shift in education system is overdue in his argument for the adoption of the virtual university for education in the 21st century.

This study set to gather and analyze baseline information about awareness and adoption of ICT in the AEC industry educators in Nigeria. It sought to understand the resource constraint prevalent among the educators with the aim of determining the policy directions that will promote better rate of IT adoption that will facilitate the performance of the industry particularly with the globalization challenges threatening the developing economies. It is to further discover the challenges faced by the professionals by examining the factors affecting the use and adoption of computer.

2 METHODOLOGY

The research is designed to obtain information from those involved in teaching/research in construction related fields in tertiary institutions in Nigeria. The sampling technique employed is purposive. The data generated were analyzed using mean item scores to generate ranking of the variables of interest using the following formula as commonly used by some researchers in the construction management field (Odeyinka, 2003; Egbu & Botterill, 2002, Kukulanga, Kuotcha, McCaffer & Edun-Fotwe, 2001; Ling, Khee& Lim, 2000; Wang, Tiong, Ting & Ashley, 2000).

$$I_u = \sum_{n=1}^{5} k_i n_i / n_x k$$

where ki = Rank of event i. and ni = Frequency of event i., I=Index of the specified event.

The events measured are: the awareness of the use of various ICT tools, the of adoption of tools and packages as well as the level of deployment of computer in teaching and research and the factors affecting computer usage.

The modal age of respondents falls in the 41-50 years category, while the respondents spread across the professions in the built environment .The average teaching/research experience of respondents is about 11 years, while majority are in the middle lecturership grade. The respondents were drawn from five categories of educational institutions, categorized by ownership.

About 94% of the respondents indicated that they have been using computer/word processor in connection with their academic work, while about 47% claimed to have been using computers in the last five year, and only about 19% have been using computers over ten years ago. Their use of computer is mostly in the office (89%), at home (49%) and in cyber cafe (40%). About 71% indicated that they use computer every day. Access to computer is predominantly through personal purchase (78%) while the office accounted for about 13% access. Institutional Ownership of computers is very poor. The surveyed average computer ownership by the institution indicated that there are about five computers per respondents. About 29% of the respondents have intercom facilities while about 20% have Intranet access. The intranet and video conferencing facilities are very low. The local area Network facility (LAN) is below 10% (Table 2).

3 RESULTS ANALYSIS AND DISCUSSION

Table 1 itemizes some of the communication facilities of ICT and the mean awareness index of the educators.

Table 1: Awareness of the Information Technology Software

Computer Packages	Mean Awareness Index	Ranking
♦ Electronic document data transfer i.e. floppy disk	3.91	1
♦ Internet (www)	3.90	2
♦ Voice mail	2.93	3
♦ Video conferencing	2.51	4
♦ Intranet communication	2.07	5
♦ Extranet communication	1.78	6
♦ Average Mean Awareness Index	2.85	

0 =Very unaware, 1 = unaware, 2 = aware, 3 = moderately aware, 4 = very aware, 5 = highly aware

Four of the facilities (Electronic document transfer, Internet, Voice mail and Video conferencing), while they indicated that they are not aware of intranet and extranet communication. It should be noted that they are on a high scale of awareness for electronic document transfer facilities, such as floppy disk, flash disk, CD Rom etc, and the Internet. They however indicate a moderate level of awareness for voicemail and video conferencing.

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Do the departments to which the educators belong have ICT facilities to use in operating the ICT product? Table 2 lists the ICT facilities possessed by the departments. Eleven of the items were listed they indicated that they do not possess or own on line databases and interactive video. However, they claimed to have intercom within the institutions and Internet access. Both accounts for about 55%, the average percentage of department possession of these ICT facilities is about 18%. It is not compulsory for a department to have all these facilities.

Table 2. Possession of IT products facilities by the departments

Facilities	Possession	%
♦ Local Area Network	5	7.35
♦ Internet Access	18	26.0
♦ Intranet	1	1.47
♦ Video conferencing	1	1.47
♦ Reprographic machines	6	8.82
♦ Tele-fax technology	2	2.94
♦ Globile system of Mobile	7	10.29
♦ Intercom within the institution	20	29.41
♦ Voice mail	2	2.94
♦ On line data bases	0	0
♦ Interactive video	0	0

The five essential of these facilities are Intercom within the institution, local area network, Internet access, Internet and video conferencing, having an average percentage of departmental possession of about 24%.

Table 3. For functions for which departments originally acquire the computer(s)

Purpose of computer acquisition	Frequency	Percentage
♦ Word processing	40	58.80
♦ Student records	38	55.88
♦ Designs and Drafting training	12	17.60
♦ preparation of Muliti-media teaching resource	11	16.18
♦ Database management	8	11.76
♦ Estimating	1	1.47
TOTAL	110	

It is further expected that the purpose for which the department of the educators acquired their computer systems (which form the hardware base of the ICT) can partly indicate their awareness of their ICT. As indicated in table 3, two functions form the bulk of the reason why the hardware was acquired. These are to carry out word processing and student records functions. These two broad functions account for over 50% of the respondents. The other technical and industry specific functions and teaching functions account for less than 20% of the respondents.

3.1 *ICT Adoption Thresholds of AEC Industry educators*

Three measures were used to ascertain the ICT adoption threshold of the educators. They are the stages of adoption (table 4), the proficiency level of the educators (table 5) and the level of deployment of IT in teaching and research table 6.

Table 4. Stages of IT adoption

STAGES OF IT ADOPTION	Responses	Percentage
Stage 1: Awareness	2	2.94
Stage 2: Learning the process	4	5.88
Stage 3: Understanding and application of the process	19	27.94
Stage 4: Familiarity and confidence	19	27.94
Stage 5: Adaptation to other contexts	13	19.12
Stage 6: Creative application to new contexts	7	10.29
No stage indicated	4	5.88
Total	68	100

As expected, respondents (about 3%) are still at the lowest stage of IT adoption. Majority are either in stages three (about 28%) or four (about 28%). These stages are the understanding and application of the process and familiarity and confidence. Fewer educators are on the adoption to other contexts' stage and the creative application to new contexts stage.

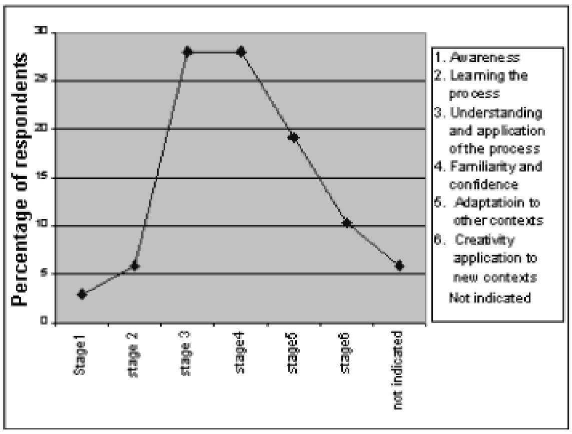

Figure 1. Stages of IT adoption by AEC educators.

The mean proficiency index, constructed on a 6-point Likert type scale of the educators proficiency on software packages 2.5 indicated on table 5. The average mean proficiency index is about 1.75 on a scale of 5. This indicates a moderately proficiency level. Decomposing this to groups of software shows varying levels of proficiency for each of the groups. The educators exhibit, comparatively, highest proficiency, (about 2.53) in the use of computer based communication media software. This is followed by the proficiency level in general-purpose software and then database management packages.

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Table 5. Proficiency level in the use of computer packages

Computer Packages	Mean proficiency index	Average mean proficiency index
Word Processing packages (e.g. MS Word)	2.99	
Presentation Packages (e.g. MS PowerPoint, MS Publisher	2.03	2.51
Database management packages		
MS Access	1.44	
MS Excel, Lotus 1-2-3 or MS Lotus 1-2-3	2.72	2.08
Computer Based Communication media		
E-mail	3.38	
Internet	3.51	
Intranet	0.69	2.53
Design Packages (Auto CAD, Archi CAD etc	1.75	
Quantity Surveying software packages	0.49	
GIS packages	0.96	
Project Management software	1.04	
Property and Facilities Management software	0.85	
Programming languages (Basic, Virtual Basic, Fortran, e^{t++}).	0.90	
Average Mean proficiency Index		

0 = cannot use at all, 1 = not proficient, 2 = moderately proficient, 3 = proficient, 4 = very proficient, 5 = very highly proficient

Their proficiency level in programming languages, and other industry specific software is very low (average mean proficiency index for industry specific software is about 1.02), indicating no proficiency.

Table 6. Level of deployment of IT in teaching and research process

Teaching and research process	Mean develeopment Index	Ranking
♦ Surfing the Net for research information	4.03	1
♦ Research data analysis	3.44	2
♦ Processing student results	3.34	3
♦ Communicating using E-mail	3.25	4
♦ Managing student records	2.99	5
♦ Direct Instruction to students	2.34	6
♦ Preparation of slides	1.71	7
♦ Communicating with students on-line	1.41	8
♦ Average Mean Deployment Index	2.81	

0 = not existent, 1 = very low, 2 = low, 3= moderate, 4 = high, 5 = very high

Table 6 shows the level or degree to which the educators deploy ICT in their teaching and research process. On the average, the mean deployment index of about 3 indicates a moderate level of overall deployment. It is apparent that communication component of ICT is the more prominent areas of deployment of ICT by the educators (Average mean deployment index is about 2.90). They also deploy ICT to research data analysis, process student results and managing student records at moderate level. Evidence of little or no use of ICT facilities in teaching is indicated by the low mean deployment indices for preparation of slides and communicating with students on-line.

3.2 *Factors impeding the deployment of ICT tools in teaching and research process*

All the respondents weakly agree that the eleven listed factors (Average MII = 2.95) table 7 limit or impede the extent of deployment of ICT tools in the teaching and research process. The high cost of hard and software however is indicated as being a leading inhibiting factor.

Table 7. Factors limiting the deployment of IT tools in the educational and research process in institutions

Factors	Mean Index of Inhibition	Ranking
♦ High cost of hard and software	3.71	1
♦ Inadequate telecommunication network	3.28	2
♦ Computer illiteracy among staff	3.19	3.5
♦ Ineffective telecommunication network	3.19	3.5
♦ Attitudes of staff to IT deployment in construction education	3.09	5
♦ Inadequate relevant software	3.04	6
♦ Inertia of senior academics	2.85	7
♦ Lack of interest by the management of the institution	2.79	8
♦ Computer literacy level among students	2.76	9
♦ Personal contact is considered more effective	2.50	10
♦ Reliance on IT seen as disempowering	2.01	11

0 = not sure, 1 = strongly disagree, 2 = disagree, 3= weakly agree, 4 = agree 5 = strongly agree

They disagree that reliance on IT is seen as disempowering and as such it does not constitute attitudinal belief that is capable of weakening the resolve to digitalize teaching and research process. This result seems not to agree with Babajide and Bolaji's (2003) result that observed that the respondent lecturers of pure and applied science related disciplines in the tertiary institution studied seems not to believe in the use of ICT communication media for dissemination of knowledge. At best this may be a tempo-

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rary position, as unfolding events in ICT advancement will make such belief unpopular.

4 DISCUSSION OF FINDINGS

Results indicating the level of awareness of the AEC educators show that they are moderately aware of the ICT operating software. This result agrees with Oni's (2003) findings, which indicated that the AEC industry professionals in Nigeria are moderately aware of electronic mail, electronic document transfer and Internet communications. This seems to indicate that the awareness level of educators in Nigeria is not higher than that of the industry practitioners. They seem not to be ahead of the industry unlike in the developed economies where researchers have not only indicated high level of awareness, but have come up with solutions reflecting the extent of use, adoption and application of these facilities to peculiar construction industry contexts (Rebolj & Menzel, 2004; Kalay, 2004; Rivard & Bedard, 2004; Lindemann, et al, 2004; Mangini & Pelli, 2003; Bacblom et al, 2003).

The departmental possession of the ICT facilities is very low. For the most essentials ones needed for training the students, the average percentage indicating departmental possession is less than one-quarter. Various government organs have seen the need for integrating IT culture into the educational system in the country. However, this aspiration has not been met with required implementation seriousness. Busari (2003) has noted that most teacher trainers in tertiary institutions in Lagos State of Nigeria have gotten little or no ICT support from their employers. There has been much rhetoric about ICT deployment in teaching and research and less of reality.

The purpose for which the computers acquired by the departments of the educators also indicate that the educators are operating on general and popular ICT awareness and less of awareness of the industry specific functional specification of ICT needs.

Following the report of Mohammed and Ekpunobi (2003) that ICT has developed in the Nigerian University System through academic computer science departments and computer centers, then the AEC educators who did not go through such academic programme is left with the option of private on-the-job training or self-taught training. Busari (2003) has reported that about 77% of the tertiary education teachers have acquired their capacity level in ICT through self-taught on-the- job training. The preponderance of the self-taught training by educators requires self-motivation on the part of the learners so as to overcome learning struggles without abandoning the learning process. However, it is apparent that self-taught learners, as usual will have to pass through various stages of awareness. While some may overcome the learning struggles and move to advanced stages of awareness and adoption, many may be satisfied with the basic knowledge and be operating at the periphery of ICT knowledge, use and adoption. Formal ICT training for the AEC educators may therefore become imperative if their products will be able to meet the expectations of the ICT-driven industry and global economy.

Proficiency, according to Jacobsen (1998), is the degree to which an individual is relatively measured on the level of expertise in the use of the specified computer software and tools. It can be used as a measure of the threshold of ICT adoption. While the educators specify their stage of adoption, the proficiency measure indicates what level of expertise they can be said to have attained on the specified expertise item.

There appears to be progress in the stage of adoption. Majority are at the middle point of the adoption stages. This corresponds with the proportion that claimed that they have been using computers since the last ten years, cumulatively. The prospect for rapid progress is high since the modal age of respondents fall within the 41-50 years age group. This is still within the age group of those that Jacobsen (1998) found to be integrating computer technology for teaching and research in higher education.

Of all the industry specific software, the design packages (AutoCAD, ArchiCAD, etc.) have the highest mean proficiency index, which indicates moderate proficiency. This is followed by project management software. These low mean proficiency indices for all the industry specific software indicate not only the proficiency of the educators, but the capacity in terms of the number of proficient educators that can train the would-be industry professionals. In reality, most of the AEC industry graduates leave school without any training in these packages. They therefore rely on the employer to provide the training or they acquire it privately so as to be employable in the industry.

5 CONCLUSION

The study has examined the level of awareness and adoption threshold of the AEC industry educators in Nigeria. The results obtained have indicated a moderate level of awareness of the various ICT tools currently available. The awareness level of the educators has been found to be almost at the same level with the industry practitioners.

The departmental possession of ICT facilities and tools is very low. The management of the institutions is to provide such facilities through sufficient budgetary allocations and implementation of relevant IT policy. Management must move from policy formulation to implementation.

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It is apparent from this study that AEC educators lack ICT facilities that can integrate IT culture into the educational system of the AEC industry graduates. This is bound to have effect on how the graduates adopt and adapt to ICT in the industry, and consequently the industry is worse of for not having the capacity to deliver value in the project procurement process. This ultimately will affect the capacity of the industry to compete globally.

The proficiency threshold is average. Majority of the AEC educators are already able to understand and apply ICT to the teaching and research process and as well able to use ICT with familiarity and confidence. There is need for acquisition of further expertise so as to be able to move to later stages of ICT adoption.

The expertise level measure in proficiency terms, for the industry specific ICT tools is below average. While the expertise level for design packages is the highest it does almost not exist for other equally relevant packages being in use in the project procurement process.

Cost of hard and software has been singled out as having significant impact in limiting or inhibiting the deployment of ICT tools in teaching and research process. Other factors that show some level of significant inhibition to ICT deployment are inadequate and ineffective telecommunication network, computer illiteracy among staff, attitudes of staff to ICT deployment in construction education and inadequate relevant software.

The AEC industry educators must have ICT knowledge-edge over the industry applicators of ICT tools. This is necessary to provide necessary leadership in education and in research into applications relevant for the use of the industry practitioners. The study hereby advocates the creation of a Construction ICT Centre in any of the tertiary institutions that have infrastructure base and the minimal human capacity for ICT training. The Centre will pool existing and available human resources from various institutions offering AEC industry related courses or programmes.

The Centre is to primarily serve as training the educators (TTE) Centre as well as develop to a center of excellence in construction ICT research and development. The Centre can seek and assess any nationally and internationally available financial resources and as well network with other similar institutions in developed and developing economies of the world. Attaining a high level of ICT awareness and expertise coupled with capacity to keep on the cutting edge of ICT development is a must for the AEC industry educators, in developing economies, if the industry will be able to deliver value to the society.

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An exploration of design systems for mass customization of factory-built timber frame homes

M. Lapointe
CIBISA and FOR@C, Université Laval, Canada

R. Beauregard
CIBISA, CENTOR, CRB, Département des sciences du bois et de la forêt, Université Laval, Canada

S. D'Amours
FOR@C, CENTOR, Département de génie mécanique , Université Laval, Canada

ABSTRACT: Demographic trends are forcing the homebuilding industry to speed up the industrialization process through mass customization. Our survey of companies in the sector of factory-built timber frame homes shows that data processing for the prefabrication of houses and their structural components comprises many iterations which generate a bottleneck at the technical design function. Companies must generate considerable agility in their design function to deal with repeated change in orders and to coordinate multidisciplinary information, while controlling costs, delays and quality. In order to develop mass customization of factory-built timber houses, our study proposes a design system framework, taking advantage of a product platform based solution. The framework aims at integrating functional requirements and constraints in house engineering and manufacturing. Such conceptual work is an initial step towards emulating a multi-agent based method capable to provide proper coordination through proper data exchange required for the processes of the homebuilding value creation network.

1 INTRODUCTION

This paper addresses some of the technological challenges of manufacturing system for producing engineered wood systems for housing including roof trusses, floor joists and wall panels in consideration of the ongoing industrialization of the North American homebuilding industry. It focuses on manufacturing of panelized housing systems as opposed to modular houses. A trend towards panelization is developing in high volume homebuilding which means that builders are taking steps to streamline building and lower job site costs (Schuler & Adair, 2003). Non-volumetric panel systems are easier to transport than modular systems giving it more potential for large distribution and exportation.

These same authors see the increase in the prefabrication of residential buildings in the U.S., mostly as a result of an aging population and a consequent labor shortage on building sites. With prefabrication, a majority of wood frame components are manufactured in a factory and delivered to building sites for assembly.

The Science and Technology Council of Quebec (CST, 2003) reports that, contrary to what happened in Japan and Sweden, factory-built residential construction systems in Quebec (Canada) have so far been unable to exceed conventional site building methods. The complexity of the building construction process inherent to the multitude of needs that the end-product must satisfy appear to be a major hurdle to standardization in factory-built housing and to high production volumes being achieved. On the other hand, CST (2003) cites new market conditions appearing favourable to greater development of prefabricated systems. These include a need for enhanced productivity, a growing demand for warranties of quality and sustainability, skilled manpower shortages in industrialized countries, and the opening of growing export markets.

The ongoing consolidation in the housing industry of the United States, Canada's biggest export market for softwood lumber, is leading larger builders towards a more systematic approach to homebuilding. Design for rapid construction, efficiency and gains in productivity paves the way to the use of structural components.

In their study of the U.S. homebuilding markets, Poliquin *et al.* (2001) estimate that factory built roof systems (i.e. with engineering of trusses and assembly) were use in 60 to 70% of the housing starts, and flooring systems was used around 30 à 40%. Following the broad acceptance of manufactured roof and floor systems by stick (on-site) builders, prefabricated walls are gaining market share. For the U.S. markets, Robichaud and Fell (2002) estimated that prefabricated wall panels were used in 18% of the housing starts. They are predominantly used by large builders and in the northern parts of the U.S.

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Such demands for factory-built components open the door to industrialization in residential construction, allowing it to benefit from improvements in terms of quality control, services and costs. Competitive advantages of industrialization can be expected through increased standardization of components, processes and information, as it may provide more efficient control tools and improved process coordination. In a number of industrial sectors, a similar combination of standardization and prefabrication have led to the adoption of new manufacturing techniques to develop and introduce new types of equipment leading to enhanced productivity and quality (Barlow *et al.*, 2003).

2 MASS CUSTOMIZATION AND VALUE CREATION NETWORKS

As will be shown, the reorganization of the homebuilding industry involving high-volume prefabrication is tied to the development of mass customization strategies through value creation networks. Mass customization is a strategy aimed at designing products and a manufacturing system capable of delivering on demand a broad range of products fitted to the specific needs of each client and at the same time maintaining high production efficiency.

Adoption of mass customization is based on three basic trends (Da Silveria *et al.* 2001). The first factor relates to the level of flexibility allowed by novel manufacturing and information technologies, which makes it possible to supply, with greater agility, an increased product variety at a lower production cost. The second factor is a growing demand for product variety and customization, as seen in housing by Schuler & Adair (2003). This forces producers to identify narrow market niches rather than to rely on conventional mass market segments. As a third factor, shorter product life cycles and increasing competition in a global market environment have caused the demise of various mass production industries, reinforcing the need for customer-focused production strategies.

The transition from conventional manufacturing to mass customization can be achieved in two different manners. In the first approach, used in the automobile industry, mass manufacturers customize products by involving customers towards the end of the manufacturing process. In other approaches, used by customized businesses, customers are involved upfront at the design and production stages, but reliance on modules and similar methods allows for delivery times comparable to those of mass producers (Pine, 1993). This latter approach is believed to be the model for factory-built construction.

Pine (1993) suggests five methods to achieve mass customization:

– customize services relating to standard products and services;
– develop products and services that can be customized;
– allow for customization at delivery point;
– shorten value chain response time;
– develop modular components to customize products and services.

Such generic approaches to mass customization may need to be adjusted to the actual industrial sector at study. According to Barlow *et al.* (2003), Japanese house prefabricators have adopted build-to-order techniques which involve standardization, prefabrication and management of the value chain such that houses can be provided with a high level of customization. With their approach, these prefabricators are able to meet the needs of individual buyers and specific market segments without incurring the costs of traditional customization. Figure 1, the value creation network as seen in high volume homebuilding involves specific actors providing certain activities and products. The ongoing consolidation and the reach of high volumes in some homebuilding networks in North America will probably have a substantial impact on distribution networks because the power of large builders as the main industry clients will increase, enabling them to impose their perspective (Schuler and Adair, 2003). The buying power of large builders may result in smaller margins and additional services, including engineering, prefabrication and installation of components.

> *"Large pro dealers are less likely to offer traditional uncharged services to larger builders than they are to offer them to smaller builders that offer larger gross margins. This may be because large builders do not value these services. On the other hand, large pro dealers are more likely to offer prefabrication and installation services to large builders than to small builders, either due to customer demand or due to the dealer feeling that there is more potential margin (and less competition) in offering services than in merely distributing products." (Abernathy et al., 2004)*

The movement toward consolidation in the value creation network for homebuilding in North America shows adoption of mass customization principles and may contribute to changing the rules of competitiveness towards "network against network" competition. It has yet to be determined whether these consolidated groups will develop cooperative business practices through electronic commerce like some recent alliances suggest. A major change in client-supplier relations could very well push them in that direction (Lefaix-Durand, 2003).

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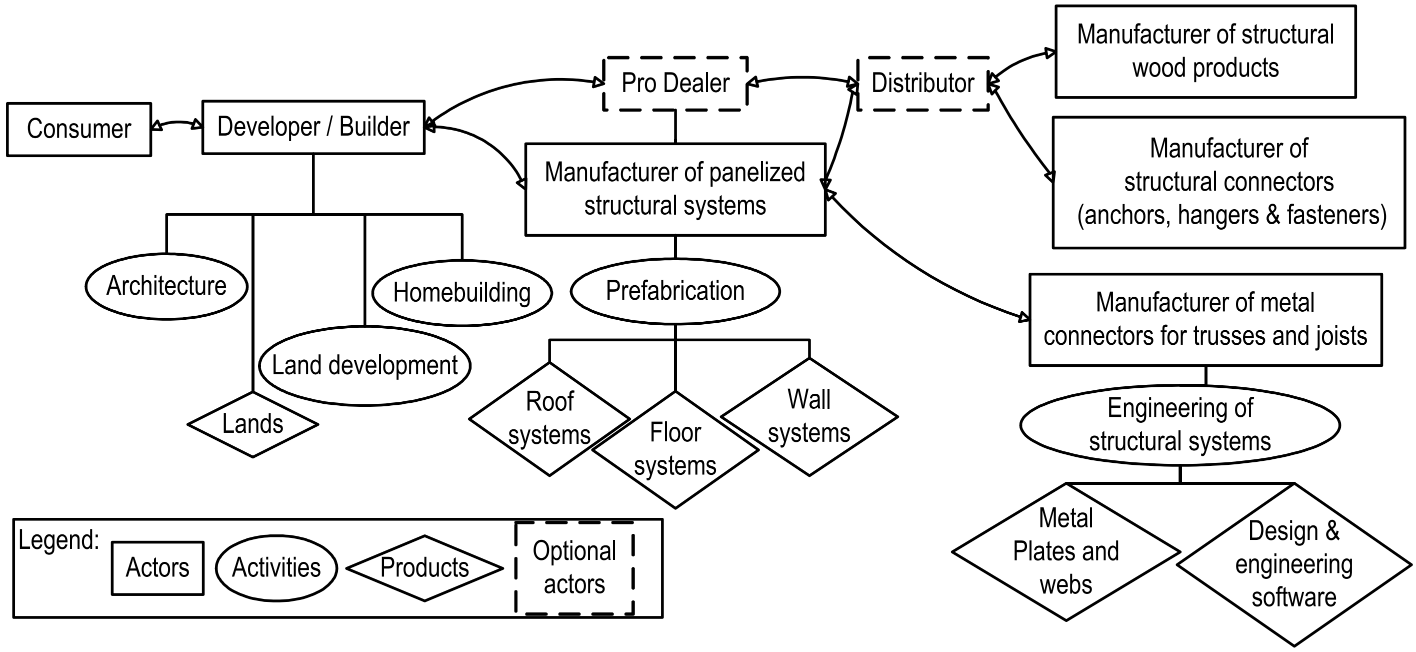

Figure 1 Prefabricated structural systems in the high volume homebuilding value creation network

"Business relations between companies are traditionally characterized by strong competition rooted in transactional issues (costs, product specifications, quality, deadline, performance, etc.). Such practices foster within value creation networks (business networks) inefficiencies in the form of accumulated stock, redundant activities, non-compliance with specifications, delays, etc."

"For more than a decade, some companies have realized that their ability to meet the needs of their clients and therefore profitability are subject to the performance of the business network as a whole (distributors, suppliers, sub-contractors, service providers, etc.) Those companies have therefore started to work differently with those partners by sharing certain information, training them, making them responsible for certain processes and trusting them." (Translated from Frayret et al., 2003).

Mass customization depends on a balance between three factors: unique features, cost and execution. In order to strike that balance for mass customization, three technical challenges were identified by Jiao and Tseng (1999): common features, product platform and integrated product development. Relating closely to the domain of engineering design, the first two challenges correspond to the development of coordination by standardization, as opposed to coordination by plans, and the third corresponds to business conducted through collaboration networks.

Considering these technical challenges, this paper proposes to analyze the current design process of 13 enterprises in the business of panelized structural systems in order to provide a coordination model necessary for its integration in a homebuilding value creation network involved in mass customization.

3 SURVEY OF TECHNOLOGIES IN THE FACTORY BUILT HOUSE INDUSTRY

Our project initiated a survey of current design practices in the prefabricated house and engineered wood systems industries, looking at the integration of design with other corporate functions in terms of software usage. Semi structured interviews were conducted in 13 companies of Central and Eastern Canada producing either modular houses, panelized houses or panelized structural systems. Products and markets varied a lot across companies, it is thus difficult to compare volumes traded. Three companies sold panelized house kits to builders (structural systems), three sold panelized house kits and three others sold modular houses to consumers (structural systems and interior design), one sold panelized wall systems and two were selling metal connectors and engineered wood products to structural systems manufacturers. All companies prefabricating structural systems relied on strong regional markets for their business development. One manufacturer of panelized house kits had nation-wide distribution as did the providers of metal connectors. The interviews aimed at identifying actual design practices in the factory-built house sector, and to determine how design functions are integrated with other company functions with respect to software utilization. The interviews were conducted with managers and technicians capable of discussing the design constraints (consultation, architecture, civil engineering, industrial engineering, equipment manufacturers, shippers, etc.) and needs related to the integration of de-

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sign with other management functions in their companies and value creation network.

Results of the study are grouped under three headings: sales; design and production; and planning. The following sections describe how software programs are currently used in these three groups of functions, as well as some integration issues.

3.1 *Sales*

To sell their products to consumers, manufacturers often rely on paper or electronic catalogues, from which customers can design their houses by selecting features from the various options and components available. Two manufacturers of modular homes were using a basic architectural design software program to develop their clients' selections. Only one of them transferred this rough design into an electronic file for later use in technical design. Manufacturers of panelized housing selling to builders were reported to receive clients' orders in many different ways, from vague drawings on a piece of paper to complete architectural drawings.

Any salesperson needs to process clients' drawings into price estimates and delivery schedules. According to all manufacturers consulted, fast pricing is a major selling point. Most companies used a homemade program based on a electronic spreadsheet (e.g. MS-Excel). Two house manufacturers indicated that their pricing software was accessible on the Internet, which made it easier to circulate updates. Pricing data were updated on a weekly basis to reflect variations in material and service costs, as well as fluctuations in production capacity. Updates were provided by managers who were also responsible for generating production schedules, following up on them. They mostly entered all the data manually.

Several design and engineering software for prefabricated housing components included cost calculation modules. Only one of the panelized housing manufacturers participating in the survey used the costing module attached to their engineering software for pricing orders. The main reasons suggested for not using these costing modules included frequent wood price changes, frequent modifications to technical specifications and the excessive amount of work involved when performing too much engineering before costing. Access to databases available in design and engineering software programs is limited, as these are proprietary solutions often linked to proprietary building materials. Consequently, only suppliers are able to update data on materials. In a context of limited control over such updates, manufacturers are unable to ensure connections with other applications using materials data. This is a typical example of the problems involved in integrating the various manufacturing functions. In the factory-built housing sector, this is a frequent problem in all functions using materials data.

For complex orders, the need for validation by the engineering department during the sales process leads to repeated iterations between engineering and the client. All companies make use of electronics for internal data transfers in this situation, but many of their communications are still on paper, particularly technical drawings. Standardization of drawing symbols is minimal, and they vary with internal methods and practices. For this reason, companies prefer re-entering drawings from outside sources to ensure that all details are properly covered for production. Housing manufacturers with a large distribution network rely on various methods to simplify the integration of changes to design and submissions, and to increase their use of electronic communication.

3.2 *Design and Production*

The production of factory-built houses requires extensive manufacturing flexibility, as it involves customizing products to clients' preferences, but it does not allow for mass production unless companies achieve a high level of CAD/CAM integration. Implementation of the latter being costly, it requires significant sales. Among the roof truss manufacturers surveyed, only those producing an estimated 500 or more units a year were found to operate integrated and automated systems (including CAD/CAM). Only one of them used an automated system for walls. For all others, the housing component production system was handled manually in most aspects. As for floor joists, they are mostly manufactured on a large scale by major forest products companies, and production is usually automated. As regards floor systems, we observed a broad range of design approaches, with some companies providing a complete floor system, including engineering, while others provided only components and engineering, integration of the components being left to the house manufacturer.

Engineering software programs designed for roof trusses have reached a high level of CAD/CAM integration, from drawings to assembly. They start from architectural roof profiles and slopes, from which the structure is automatically generated, taking into account manufacturing parameters and structural design standards. Following technical validation, a cutting bill is generated; part production schedules are optimized and transferred to automated saws for cutting to precise dimensions. The parts are organized into numbered lots and moved to assembly tables, where a laser system projects the various profiles, numbers and part positions, ready for assembly. Technical validation includes consideration of the codes and standards applicable in the jurisdiction where the building is to

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be erected. Similar trends can be observed in the wall manufacturing sector, but to a less advanced degree.

To design their floors and roofs, all manufacturers use proprietary software from their I-joist and metal plate suppliers. CAD-generated data for the design of structural subsystems provide a link between the geometrical shapes to be built, the structural analysis and the definition of the elements required to manufacture the product. The development model of a link of this type is complex and costly. Whether owned by metal plate connector providers, automated equipment suppliers, prefabricated building manufacturers or even software developers, these programs are a strategic element of the prefabricated building manufacturing system. All manufacturers use them in isolated design units so that data used by several systems need to be re-entered. Only manufacturers using a CAD/CAM program combining a family of equipment from a single supplier are in a position of being able to implement data sharing and interoperability. Even then, such integration applies only to subsystems such as roofs, floors or walls. We failed to find a single manufacturer using proprietary solutions in such a way as to group and integrate all manufacturing units.

For these independent centers to operate, they have to be organized into repertories of multiple subsystems developed under various software environments to allow for re-utilization. All manufacturers manage these repertories and CAD-generated documents in accordance with specific procedures. Three of the manufacturers surveyed had developed a formal management system for documentation and archiving.

This same issue regarding independent automation centers was raised by Bouchard *et al.* (2002) in connection with manufacturing systems for wall panels:

> *"A study of software used in the manufacture of wall panels shows that integration with architectural drawings is very limited, even though the programs allow for various levels of integration with management and production. In addition, many software programs do not provide engineering calculations or validation against building codes. As a result, these have to be based on data included in databanks containing design values for the components."*

3.3 *Planning and Control*

Among the manufacturers participating in the survey, production management methods focused on material supply management tools (Material Requirements Planning - MRP) and Just-in-Time delivery. The planning of production processes generally uses internally developed systems based on office software, but one modular housing company was in the process of adopting a program of the Enterprise Resource Planning (ERP) type. One of the issues still requiring attention relates to the integration of production planning tools, sales tools and product design tools.

Process performance indicators vary from one company to another. Process improvements are adjusted based on in-house staff expertise, and we heard no mention of any optimization programs being applied to support process re-engineering in regards to improving production efficiency. However, manufacturers using CAD/CAM integration have access to an integrated monitoring tool for the various production functions, which they can use to track orders and work in-process in real time in addition to tracking some production indicators. We observed no bar code being used. Only one manufacturer used electronic equipment to monitor labor activities or time spent on specific projects. Quality control was typically entrusted to skilled employees and senior technicians who relied on specification sheets and the standards and building codes applicable to the area where the building was to be erected.

The survey of companies in the prefabricated wood-frame house sector showed that there is some duplication in the exchange and processing of data for prefabricated houses and structural components. There have been many advances, but the technologies used cannot effectively deal with the heavy burden placed on technical design teams. From sketches to architectural, engineering and production plans, companies have to demonstrate a great deal of agility in design in order to handle the demand for changes and at the same time control costs, timelines and quality. Sub-contracting of structural components often adds to the complexity of the design and manufacturing processes. This highly distributed environment, where information is exchanged across business functions and networks, using different data formats and linking interdisciplinary activities, poses numerous challenges in terms of coordination.

4 COORDINATION ACTIVITIES FOR STRUCTURAL SYSTEMS

Structural design involves input from various stakeholders in the value creation network. The architect of the building documents the building concept by identifying the profile of structural components, the structure permanent connections, details of the live and dead loads, and the integration of mechanical, electrical and sanitary systems. He has to design a structure that ensures that the components are not adversely affected by humidity or temperature and that the various component systems are compatible.

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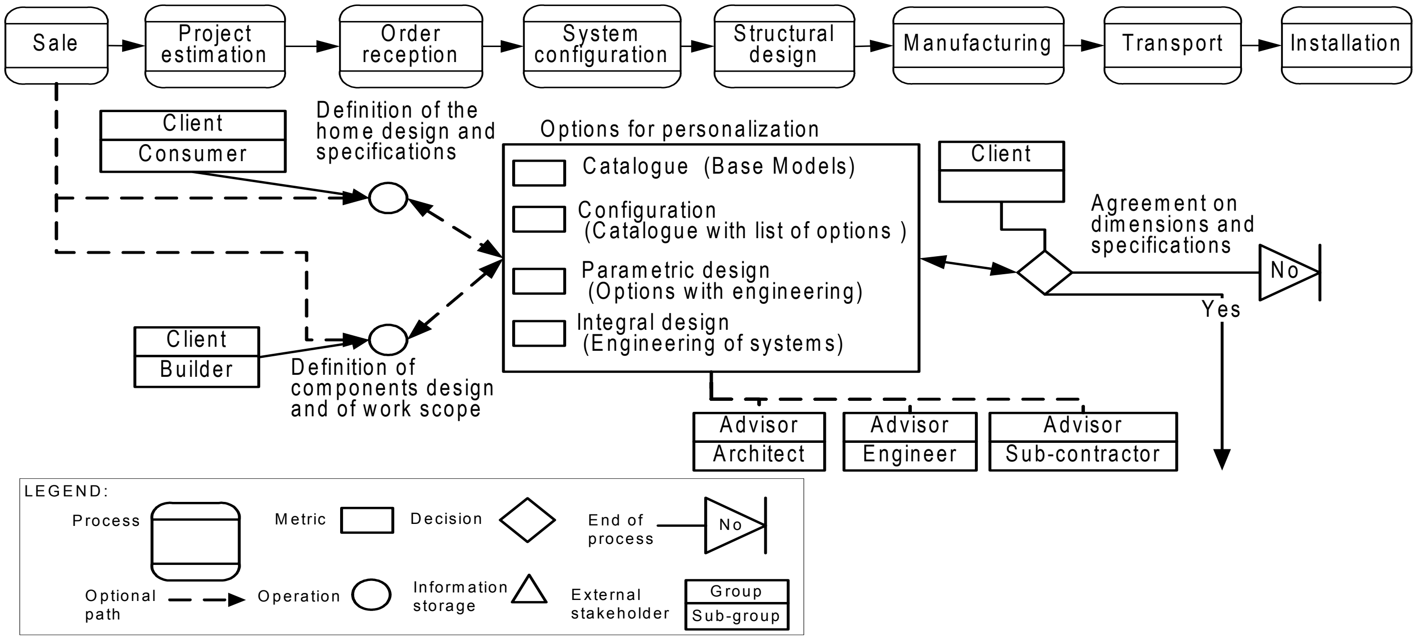

Figure 2. Description of the sale process

Once the design is set, a number of stakeholders are brought together to make the design a reality, and the activities between the players bring to light various coordination needs. Here's where a manufacturer of structural systems is integrated. As we will see, this network primarily uses plans as means of coordination, mostly relying on an intensive design process all the way up to manufacturing.

As shown in Figure 2, the sale process is organized according to the type of clients. Selling directly to the consumer is done by companies producing entire house kits, such as modular homes. It is mainly marketed through catalogues with options. The model variations offered enable changes based on client needs and choices and make it possible to accelerate certain technical validations and subsequent approvals. They also make it possible to refine the specifications submitted to manufacturer.

More frequently, sales are made to builders who want to obtain components. In this instance, they define their design as thoroughly as possible, often using an architectural plan, in order to permit integral engineering of systems

At the time of sale, information exchange becomes intensive. The buyer and the manufacturer go over the plans and review the available options. The objective is to inform the customer about quality, product availability, design options and opportunities for customization. The options and changes chosen by the customer are recorded on the model plans. The plans are reviewed by the manufacturer, who checks a general construction schedule and sends the plans, terms and conditions of sale to the design/engineering division and accounting so that they can do a technical review and costing, respectively for the selected items.

The manufacturer evaluates the difference between the model and the chosen options in terms of cost and feasibility. The project evaluations are sent to the customer so that he can go over the drawings and construction costs related to the desired changes, and if everything is satisfactory, the customer signs an agreement in principle. If more changes are requested, the construction documents are sent back to the engineering division for more revisions and then returned to the customer for approval.

Some component configuration takes place to meet specific technical requirements in addition to standard code requirements. These systems include a series of predefined options that are pre-approved and often meet private certification schemes. A manufacturer's use of these systems consists only of configuring the assembly options for the house to be produced. As presented in Figure 3, these systems are available for both building structure and envelope systems.

For structural design of systems, most work is done by computer with proprietary software under an engineer's guidance and supervision. From the systems configuration and assemblies definition, he will lay out structural elements and connect them. Cross-section properties will be analyzed and adaptations will be made to ensure integrity and stability of the structural system. For complex designs, this process requires feedback to the customer. Finally, at delivery, the manufacturer's shop drawings and assembly plans are provided in compliance with the details supplied by the builder.

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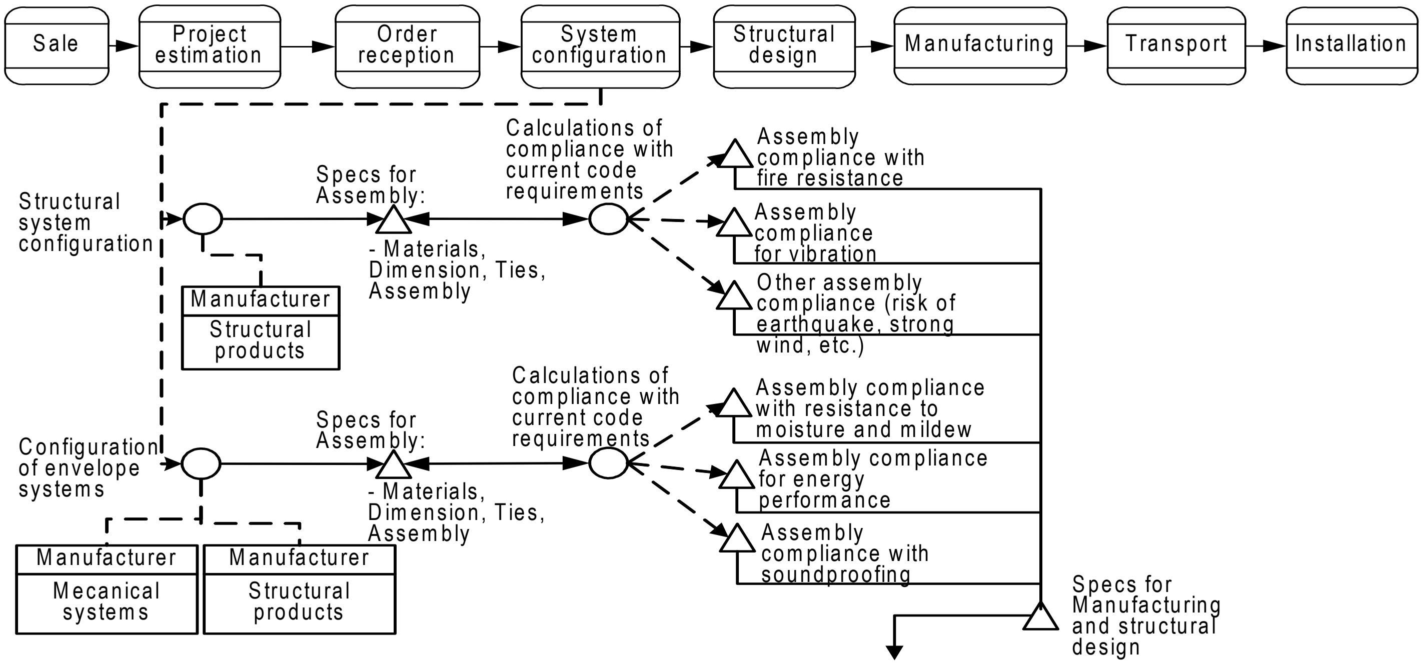

Figure 3. Description of system configuration

5 ENGINEERING DESIGN FOR MASS CUSTOMIZATION

Mass customization requires the establishment of highly integrated processes between product design and production, as the information is critical in ensuring efficient building process and delivery to the client. Faster product development for mass customization requires cooperation both within businesses and throughout the value creation network. The design processes are thus expected to play a key role in capturing, integrating, drafting and disseminating the information required by production teams.

The complexity of design tasks is a problem for mass customization, whereas many processes have to be integrated at the design level and have to be increasingly simultaneous in order to minimize costs and ensure a quick response to demand. The problems are aggravated in environments where a network of several companies has to integrate the downstream activities of planning, production and delivery with the upstream activities of response to market demand and system design. The players in a value creation network have to meet significant challenges in order to coordinate and manage information.

As seen previously, prefabrication of structural systems requires mastery of an entire series of materials, components and technical systems. From these basic steps several business models may arise, each focused on effective handling of technical and commercial constraints.

5.1 *Coordination by standardization*

Mass customization essentially lies in the ability of the product developer to identify and capture market niches and subsequently develop the technical ability to meet the needs of its different customers. Mass customization is accomplished in three ways (Jiao and Tseng, 1999): reaching the market in time, offering a variety of products and achieving economies of scale during manufacture. The first phase of a mass customization process consists in developing model homes based on trends in a market niche and ensuring compliance with the regulatory standards applicable in a particular region. Once the company's catalogue is produced, the designs are gradually modified to incorporate options and new customer trends as well as lessons learned during production to save material and labour and coordination among contributors.

5.1.1 *Common features*

Maximum repetition is essential in attaining mass production efficiency and effectiveness in sales, marketing and logistics. This is achieved by maximizing common design features so that modules, knowledge, processes, tools, equipment, etc. can be reused. Common features are often considered in relation to the physical aspects of the product or manufacturing accommodations. From a mass customization perspective, common features have to be clearly identified in relation to customers' needs or functional requirements. When customers' needs are consolidated, a set of designs can be created to establish a series of product families, which facilitates the link between customers' needs and the company's capabilities (Tseng and Jiao, 1996). This approach is reflected by repetition of structural elements seen in the catalogues of large builders of prefabricated houses; the builders use mirror designs and predetermined roofing systems to fill out their structural catalogue.

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5.1.2 *Product platform*

A product platform is a breakdown of a company's catalogue that identifies common features among families of products and serves as an inventory of knowledge about various products. They are used to incorporate into designs: materials; processes; technologies; and commercial factors. They also make it possible to prevent the proliferation of products for the same customer needs.

The most visible effect of product platforms is the ability to configure variations of models quickly and inexpensively by rearranging the components within a modular design. Modular design creates a clearly defined and relatively stable technical infrastructure. The creation of new products can thus draw on a growing choice of new and improved modular components by configuring product variations. This approach should simplify sales and costing because the new product would be only a variation of known components; technical and operational evaluations would not have to be repeated in order to get an agreement in principle.

6 DISCUSSION

Reaching markets in time by linking execution time through the value creation network depends on integration of the product development process from identification of needs to delivery. From an organizational standpoint, this means expanding areas of intervention and synchronization of the product development cycle. The scope of design has to be extended to sales and service in order to take into account factors upstream and downstream of product creation. Achieving mass customization involves not only integration of the product development process, but also cohesive integration of different views over the product life cycle.

In the context of homebuilding, as in custom manufacturing industries where design is done through a network, it is difficult to optimize design activity when most of the expertise is distributed through the company and its network. Optimal design is hard to achieve because it is dependent on information exchanged between people. However, solutions to construction design problems have been developed using artificial intelligence technologies that make it possible to automate some design phases. Agent technologies might be a way to automate a great deal of design interaction. The interplay between distributed agents results in a dynamic, flexible, adapted and expandable system. Using product platforms as a basis for the collaborative design environments for prefabricated structural systems, agent technologies find valuable applications as proposed by Ugwu *et al.*(2000):

- filter information and retrieve design and project management data;
- customize information in order to be in proper line with users in distributed decision-making environments;
- automate routine design and project management tasks, including negotiation leading to the best design optimization.

This improvement in the communication of knowledge bases means that designers will be able to produce better solutions by anticipating the impact of manufacturing activities on their design decisions. This will in turn reduce changes during production and extra design work for prefabricated structural systems.

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A three level approach for exploring the ICT impact on the building design process applied to a real-life project

A. Moum
Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT: An understanding of how ICT impact on the building design process and the architect's role and contribution within it can be crucial for the building project success. This paper introduces a possible approach of organizing and structuring design process actions and roles, and how ICT impact on them. This approach is based on the definition of three building project levels and could contribute to a better overview of how ICT impact on the building design process and on the architect's role and contribution. The aim of this paper is to illustrate how this approach can be used to explore the ICT impact on a real-life project.

1 INTRODUCTION

A fundamental pillar of a successful building project is a good design process. The future and development of a good architectural design solution depends on complex and iterative processes on several levels and with different actors. Over the years, the ICT impact has led to dramatic changes within the construction sector average working day. Especially the network technologies, such as internet and e-mail, and the development of advanced visualization and CAD systems, such as virtual reality and building information models (BIM) have had and will further have an impact on both processes and role definitions (Wikforss 2003). The participants within the building design process face ICT related benefits and challenges at several levels. The architect has a distinct and important role within the building design process (Gray & Hughes 2001). His skills makes him adaptable for several roles, from being a design specialist, translating the many project constraints into physical form, to being a design generalist; leading, coordinating and administrating the design process as the building design- or even the project manager. An understanding of how ICT impacts the building design process and the architect's role and contribution within it can be crucial for ensuring building project success, due to quality, time and cost.

This paper introduces a possible approach of organizing and structuring design process actions and roles, and how ICT impact them. This approach is based on the recognition of three levels within a building project. The intention behind this approach is not to force aspects of the complex architectural design process into rigid categories, rather it aims to contribute to a better overview of how ICT impact on the building design process in general, and on the architect's role and contribution in special. The paper focuses on four essential aspects of the design process: the generation of design solutions, the communication, the evaluation of design solutions and the decision-making. These four aspects are highly interdependent and iterative, as figure 1 seeks to illustrate. The illustration is among others based on Kalay's description of the communication process (Kalay 2004).

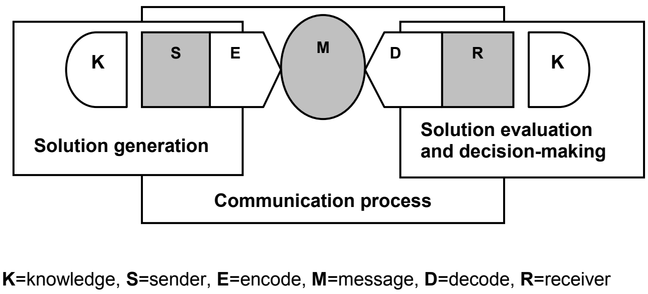

Figure 1. Illustration of the relations between the four selected architectural design aspects

This first outline of the three-level-approach is based on the exploration of recent literature and research within the area. The aim of this paper is to illustrate how this approach can be used to explore the ICT impact on a real-life project. The first part of the paper will introduce and explain the three-level-approach, illustrating the three levels using some

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theory examples. The second part is based on an interview with an architect involved in a housing estate project in Trondheim, Norway, which was completed in 2002. The three-level-approach was both used as a guideline throughout the interview and as a support of analyzing and presenting the interview respondent's perception of the project processes, participants, and the use and impact of ICT. Based on the very first and tentative impressions such an interview can give, the approach's adaptability on this specific real-life project and the challenges for further development will be discussed. This paper and the three-level approach contribute to a framework for further inquiry about the relation between ICT and the architect's role and contribution within the building design process.

2 INTRODUCING THE THREE-LEVEL-APPROACH

Three levels of operations and actions can eventually be recognized within the building design process. As a first overview of the three levels: the micro-level comprises individual and cognitive processes, based on what is going on in the head of the individual. The meso-level covers the mechanisms within a group and the macro-level comprises the mechanisms on overall organizational or sector level.

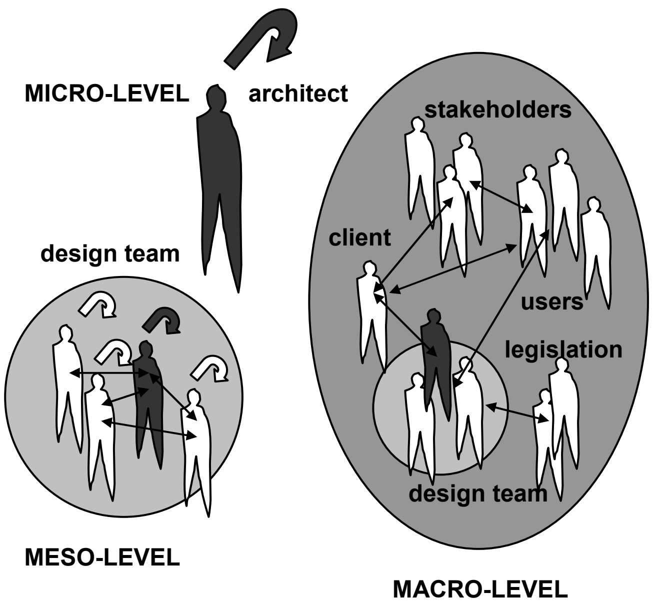

Figure 2. Illustration of the three levels within a building project

Different types of theories, as for instance individual theories (micro-level), group theories (meso-level) and organizational theories (macro-level) can be used to illustrate the processes on the different levels.

Many individuals are involved in a building project, each communicating, making decisions and taking actions based on "something going on in their head". Each of these individuals is himself a micro-level, as the client, the architect, the mechanical consultant and the manufacturer. However, at the same time, every individual operates within one or several contexts. The client is an individual operating within his own organization (meso-level) and within the overall project context (macro-level). The three-level-approach could thus be applied on different situations with focus on different individuals. The chosen individual can be the filter for defining the other levels. In this case, the chosen individual and the filter is the architect. Thus, in this paper, the micro-level is illustrated by the individual architect generating his ideas, the meso-level by the design team in which the architect interacts and the macro-level by the overall building project context and frame around the design process.

The architect could be seen to have different roles and contributions on the different levels. The creative processes in the head of the individual architect, take place on a micro-level. Within a meso-level context or the design team, the architect has to interact with other designers and consultants, as a design specialist and a hierarchical equal participant, or as a design generalist, with responsibilities within coordination and leading of the group. On the macro-level, the role and "visibility" of the architect depends on his function on the two other levels.

In an unpublished paper written for the CIB Symposium "Combining Forces" in June 2005, a literature based exploring of ICT related benefits and challenges within four essential aspects of the design process: the generation of design solutions, the communication, the evaluation of design solutions and the decision-making, was presented. An ICT impact matrix, based on the three level approach, was introduced as a frame for summarizing and gaining overview of the theoretical topic explored (Moum 2005).

2.1 *The micro-level*

The micro-level is in this paper illustrated by the architect's individual development of design solutions. According to Lawson (1997), the design process is a simultaneous learning about the nature of the problem and the range of the possible solutions, with no clear distinction between problem and solution, analysis, syntheses or evaluation in the design process. The designer juggles with several ideas at the same time, without forcing a premature precision or decision (Lawson 1997). Schön (1991) describes the design practice (e.g. sketching) as a conversation or reflective dialogue between the designer and the design situation or design issue (Schön 1991). The designer conversation with the design situation allows a fluid thinking process

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without constraints like disturbing accuracy. The designer's conversation with the drawing, or what Kalay (2004) calls ideation or an intra-process role of communication are examples of micro-level processes.

Figure 3. How do ICT impact on micro-level?

2.2 The meso-level

The group processes within the design team illustrate actions on the meso-level. Heavily based on collaboration and communication, taking into account different constraints set for the project, the primary idea develops within a group context into something that can become the conceptual fundament of the building project.

The importance of collaboration is growing, as globalization and increasingly complex technique and products require more teamwork, and the complexity of the problem becomes unmanageable for one individual. Barrow (2000) introduces the term Cybernetic Architecture, which he explains as a "collective" body of knowledge and specialty skills found in many individuals (Barrow 2000). The focus changes from the individual to the collaborative design process, and this introduces a challenging dimension in the idea finding process: the interaction between the individual and the group (Lawson 1997).

Successful teamwork is among others based on shared understanding. If the group participants have similar background and a common base of experiences, with the opportunity to learn about each other over time, to communicate, share information, and to develop a team spirit, this will be ideal conditions to ensure a shared understanding of goals and tasks (Hinds & Weisband 2003). Within a design team, much of these will not be the case. The actors come from different companies and organizations, have different interests and experiences, have often never worked together before and will perhaps never work together again. However, the project team consisting of specialists with different competences, as architects and consultants, has a long tradition, especially by middle-sized and large projects. Hence, handling team processes and communication is nothing new for the building process participants. The degree of shared understanding as the basis for a good teamwork can on the one hand be seen to depend on the skills of the manager, such as the facilitating and monitoring of information exchange and interpretation (Cramton & Orvis 2003). On the other hand the informal "rules" of how to structure the building process, partly defined in different professional guidelines as the German HOAI (Honorarordnung für Architekten und Ingenieure) or the Norwegian AY (Arkitektytelser), contributes to establish routines and an understanding of the work to be done.

Figure 4. How do ICT impact on meso-level and the architect's role and contribution within it?

2.3 The macro-level

The design team is a part of an overall context, the macro-level. The building project comprises many organizations, representing different interests. The client organization, the users, the building authorities and the contractors are some of the actors, which establish the overall building project frame and the constraints and requirements influencing the design process. Decisions are made on all three levels. The architect will on the micro-level make his decisions about which design solutions are worth being put on the paper. But on the macro-level the client will be responsible for the crucial decisions regarding which proposed concept should be developed further.

There are several challenges due to decision-making within the field of architecture. The building design process is in addition to the measurable, quantitative and conscious based on the qualitative, intuitive and tacit (Kiviniemi 2004, Lawson 1997). Explicit knowledge can be articulated and is thus accessible to others while tacit knowledge cannot be articulated (Griffith et al. 2003). Wittgenstein's language game theory is one illustration of this problem area (Lundequist 1992). The crucial question within evaluation of design solutions is how to measure or judge the qualitative, tacit and intuitive aspects? "Is it possible to say that one design is better than another and, if so, by how much?" (Lawson 1997, p.62). The client's understanding of the qualitative aspects depends

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essentially on the communicative skills of the architect and the design team.

Failed communication can cause conflicts and misunderstandings, negatively influencing the building project if not recognized and solved at an early stage. As illustrated in figure 1, the sending and receiving of a message (e.g. design solution) depends on the competence, knowledge and previous experiences of the participants in the communication process. The architect must encode the design solution in the form of some symbolic language, which is then transmitted, through a suitable medium (e.g. paper drawing scale 1:100), to the client, which must decode the design solution to understand it. Both the client and the architect decode and encode information based on their knowledge, or frame of reference (Kalay 2004). If the client does not know the symbolic meaning, or the level of abstraction used, he will not understand what the architect or the design team tries to communicate.

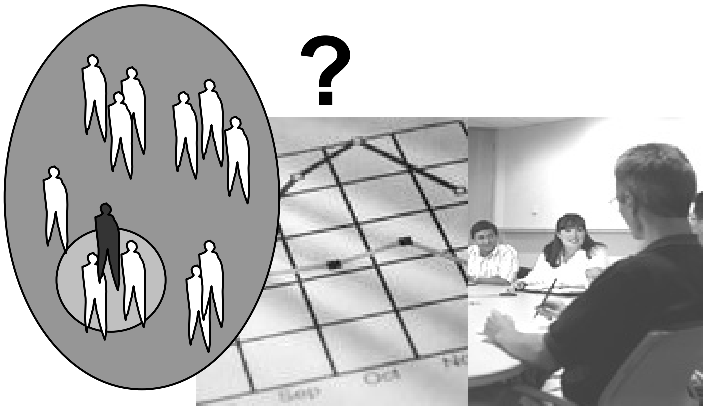

Figure 5. How do ICT impact on macro-level and the architect's role and contribution within it?

These were some theoretical key points related to each of the three levels, which seems to inherit different challenges and difficulties to be handled. Processes and actions on all three levels could be seen to impact on the successful design process and the generation and development of good design ideas.

3 THE THREE-LEVEL-APPROACH APPLIED TO A REAL-LIFE PROJECT

The three-level-approach was applied in different ways within the exploration of the real-life project. A matrix (Table 1) established a frame for exploring the relationship between ICT and the four design process aspects on each level. This matrix was intended to guide the interview and to structure the questions to be asked. Further, the three-level approach and the matrix were used to analyze and structure the interview material, with the intention to present an understandable overview of the key points concerning the project design process and the ICT used.

Table 1. Outline of the ICT impact matrix.

	Micro-level	Meso-level	Macro-level
Generation of design solutions			
Communication			
Evaluation of design solutions			
Decision-making			

3.1 Background and context of the real-life project

Trondheim is a middle-sized old university town in Norway. On a site directly by the waterfront, the development of a housing estate, including a home for elderly people, was started in 1998.

Figure 6. Housing estate project "Ilsvika"

The client, a professional organization, offered services within project development, real estate, contracting and module manufacturing. These different client departments played different roles during the building process. This client commissioned in 1998 a middle-sized architectural company from Trondheim to do the introductory negotiation with the building authorities, resulting in a development plan, and the following building design. This paper focuses especially on the building design process. The housing project was divided into four stages of construction, in the size from 850 to 6400 square meters usable area (total 22,000 square meters). The design of the first construction stage started in 1999, the whole project was completed for sale in 2002.

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One of the main requirements from the client was to use a prefabricated modular system, which made the short construction period of two years possible. In addition, there were influential design constraints based on the legislative regulations, regarding e.g. environmental-, noise- and day-light conditions to be handled. Both together established a narrow frame around the design, and had a distinct impact on both process and result.

3.2 Actors, processes and the use of ICT on micro-level

Within the design process, the construction stages had own groups of architects, and an internal design manager coordinated each of these groups. The interview respondent was the internal design manager responsible for two of the four project stages, in addition he kept the overview of the project in total to ensure the transfer of experience between the different construction stages.

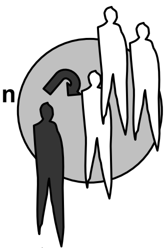

Figure 7. Micro-level actors

Each of the architects working with the design used the VektorWorks CAD program as a 2D tool. A specialist within the company developed the 3D models. In the beginning of the design process, the architect was sketching with pen and paper. But very soon the hand-sketches had to be transformed into computer-generated drawings. According to the respondent, there were several reasons for this. The project was to be built up of several identical units of accommodation. In addition, a modular system was to be adapted also on e.g. facades and construction system. Thus, as soon as the sketch of one unit was put on the paper, its potential as a repetitive element had to be tested. The computer was a valuable support within this task. Furthermore, the solutions should as early as possible be transferred to the module manufacturer, which controlled the usability and adaptability of the suggested components. In addition, the architects consequently used computer-generated drawings as basis for communication and discussion with other participants. ICT was in this project more a tool for evaluation as a partner supporting the creative processes. The respondent perceived the time available and used for sketching and modeling by hand as too short, and according to him, this could negatively have influenced the quality of the design solutions.

The applied CAD system did not allow more than one person to work with one file at the same time. This made it difficult to delegate tasks and, according to the respondent, led to a less efficient working day.

3.3 Actors, processes and the use of ICT on meso-level

In the beginning of the design process, there were not many participants within the design team. Only structural, acoustics- and fire-technical consultants supported the architects with the outline design stage. The architectural company offered itself the traditional mechanical and electrical services until later in the process. As the mechanical and electrical consultants finally joined the process, both as planner and as manufacturer of the technical systems, the main design concept was almost fixed. Thus, there was little activity around collective design solution generation at the meso-level. The respondent emphasized several times the drawback of this situation, since the knowledge of these participants would have been a valuable contribution within the generation of the design concept. The independent design manager joined the design process first at the end of the scheme design, and at this time also the formal design team meetings started, coordinated and leaded by this independent design manager.

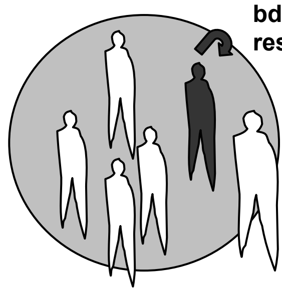

Figure 8: Meso-level actors

Originally, the client wanted to use a project-web system for documentation and file exchange, which would have been quite unusual and innovative at that time in the Norwegian AEC industry. These plans were stopped as the main person behind this idea left the client organization. Instead more “traditional” ways of documentation and information exchange were used. The information, which was not exchanged face to face within the regular meetings, was communicated using telephone, fax or e-mail. The consultants were working with AutoCad as CAD system, and all file exchange was based on e-mail using dwg-format. The respondent mentioned the tendency that some participants, after receiving the files from the architect, redrew the computer-generated drawings from scratch with their own

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CAD system, which meant double work and inefficiency.

According to the respondent, the use of ICT in this project did not lead to central advantages due to accelerating the processes in the first stage of the construction. But as the design team started with the further parts of the project, ICT supported the possibility to reuse solutions and experiences in a most efficient way. Especially since the project was based on modular systems. The previous experiences were used as basis for improving the solutions. Thus, according to the respondent, the processes behind the later building stages went without most of the problems characterizing the first construction stage. This improved the quality of the design. However, another essential issue for reuse of knowledge was that the main participants remained the same throughout the whole project. This made it easier to build up a common knowledge and understanding of the project and what was to be done, which again supported the collaboration and the transfer of knowledge from one building stage to another.

3.4 Actors, processes and the use of ICT on macro-level

From the very beginning there was a very close collaboration between the architect and the client organization. The main actors within the outline design process and the design generation was thus the client and the architect, but also the building authorities and the module manufacturer indirectly or directly influenced this early stage of the planning. Thus, most of the processes due to idea-generation, evaluation and decision-making were taking place at this macro-level.

For communicating their ideas to the client, the architect used mainly 3D models, QuickTime movies and flyovers, all made with VectorWorks. The exchange format was pdf-files. The respondents experience was that this kind of illustrations supported the effort of making the qualities of the design solutions better understandable and visible to the client. The architect used this way of presenting ideas deliberately to influence the client's decisions. The same CAD system was used to simulate daylight conditions in the area, as this issue was seen to be critical from the side of the building authorities. The 3D models were made only from parts of and not from the whole project. The architect did not participate on the main client decisions and there was no forum or meetings around these decision processes. The decisions made were given further to the architect and the design team as new requirements or green light for further action. Because of this, the possibility to visualize the project in a convincing way without the support of verbal explanation was crucial for the architects' indirect influence on the client's main decisions.

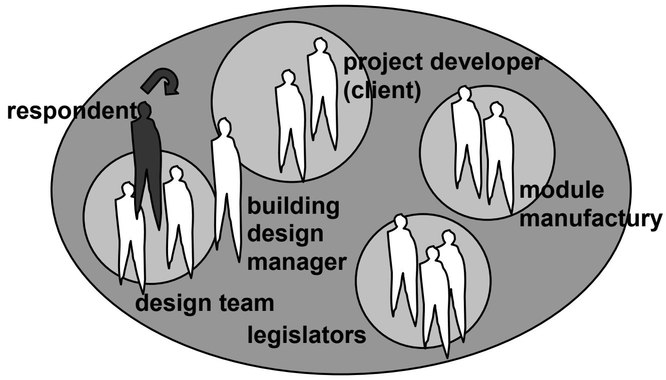

Figure 9. Macro-level actors

Another essential action on this level was the collaboration and communication with the modular manufacturer. As already mentioned, the client's requirement to use prefabricated modular systems directly influenced on both the design process and -product. The manufacturer participated already in the design process, and the communication with him was mainly based on the exchange of dwg-files. This made the architects digitalizing their ideas on a very early stage. The manufacturer controlled the files and gave feedback on the constructability of the suggested solutions. The ICT made it thus possible to integrate the production very early in the process. The only communication problem general within this building project was inherited in this contact, since the areas of responsibility for the design was, informally, not clearly defined. According to the respondent, these problems could have been more efficiently solved if the manufacturer and the architects have had more face-to-face contact.

3.5 Actors, processes and the use of ICT: summary

The project studied is not especially innovative due to the use of ICT, it is rather a typically example of a building process in Norway today. Of course within every project there are "specialties" which impact on both processes and the built result. In this case, such "specialties" are the late appearance of central consultant services, and an outline design process, taking place on the macro-level. The traditional design team and meso-level activities appeared as the main concept of the project already was fixed. Another specialty was the rigid design frames due to building authority constraints and the client requirement of using prefabricated modules, which impacted the design process on several levels, from the individual design generation to the overall communication structure.

These "specialties" could in fact be seen as independent of the use of ICT. But ICT was in this project used to handle the emerging challenges

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resulting from these “specialties”. In summary, ICT influenced especially four main issues. At first, ICT was used in the individual architect’s design generation to test the ability of the hand drawn and tentative idea to fit into a total modular system. Within the matrix, this impact could be placed on micro-level design solution evaluation. Second, ICT supported the communication and exchange with the manufacturer, and made it possible to integrate production aspects already in the design process. This led to a blurring of the boarder between planning and production, and the border between the designer’s and the manufactures responsibility. Within the matrix, this could be placed both on macro-level communication and design solution generation. Third, ICT contributed to the reuse of experience and solutions from one construction stage to another, which can be seen as both meso- and macro-level communication. And fourth, the ICT supported the architect in his effort to convince the client of the qualities of his suggested ideas. Within the matrix, this could be situated within macro-level evaluation, communication and decision-making.

Since the main consultants and the independent building design manager, who was a civil engineer, joined the process later on in the design process, there were not any participants “between” the architect and the client. The respondent regarded the architect’s influence on the design process as high, especially on the meso-level. At the macro-level, the architect’s influence and role was as strong it could be, taking in account the narrow frames of design and the client’s overall control of the processes. The respondent further emphasized that the influence on the building concept was higher in the beginning of the building process, as changes did not cost much time, money and effort. The architect was commissioned for only doing the planning, not the production. Thus, the architect could not influence on the decisions made on the building site.

Today, the architectural company has changed from using VectorWorks to Archicad as main CAD device. The respondent gave two reasons for this. In the first place, Archicad offers the possibility of parallel working with the same file. Secondly, Archicad offers the possibility to work with IFC and product models, which could become relevant within other projects. Till now, this has not been the case.

4 THE THREE-LEVEL-APPROACH AND THE ADAPTABILITY ON PRACTICE – FIRST IMPRESSIONS

This first step into the real world has given some tentative feedback concerning the adaptability of the three-level-approach on a specific building project. In the interview situation itself, it became clear that using the matrix as a direct guideline as intended was very problematic. It was difficult to separate between the four design process aspects, especially due to the partly unconscious cognitive processes on the micro-level. There was also challenging to spontaneous handle all the “specialities” and the irregularities within this specific project. Both resulted in a freer interview form, leaving the more structured interview guide beside. However, the three-level-approach itself helped the interviewer to keep the big picture and not to get lost. Thus, to use the three levels as orientation points during the interview situation functioned very well, especially as the respondent himself easily recognized that he was working on different levels. It should be emphasized that the respondent gave answers reflecting his attitudes, experiences and interpretation of a situation, process or action, which can deviate from how something really happened. Still, as he was working both as a designing architect and an internal building design manager, he could give a good overview of processes and actors on all three levels.

However, within this case the main support of the three-level-approach was in the analyzing and presenting of the key points of the interview. In this case it was not quite clear on which level the actions within the group of architect’s should be seen. It can be found arguments for both. In this case, the respondent gave information about how the architects, including himself, were working with ICT as individual designers, which led to the choice to place these actions on the micro-level.

5 CONCLUSION

This paper has illustrated how the introduced three-level-approach can be used to explore the ICT impact on a real-life project. The tentative impressions of the approach’ adaptability on practice, is the potential as support for both guiding the collecting, analyzing and presenting the empirical data. Within the project presented in this paper, the approach helped keeping overview of actors and processes, and which role and influence the architect had on the different levels. There are of course still several aspects to be further developed and clarified, especially regarding the definition of the levels and the understanding of the interactions between them and the four design aspects. In a next step, this approach could be applied to a case study of a large project using more “up to date” technology than the Ilsvika project. Within such a project, several architects working within different levels could be interviewed to get a more detailed impression of how ICT impact on their work and role. Interesting interview respondents could be an architect working on macro-level as a project

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manager, an architect being responsible for the design-team (architect as design generalist) and an architect developing design ideas (architect as design specialist). Such a case study could give further impressions of the three-level-approach and the matrix' adaptability on practice, and throw light on how ICT impact on different architects' working day within a developing building project.

6 ACKNOWLEDGEMENTS

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Model based cost and energy performance estimation during schematic design

V. Bazjanac
Lawrence Berkeley National Laboratory, University of California, Berkeley, USA

ABSTRACT: The U.S. General Services Administration (GSA) may require the submission of an IFC based Building Information Model (BIM) at the end of schematic design in the foreseeable future. The driving force behind this possible requirement is GSA need to obtain much more frequent and reliable cost and energy performance estimates from building design projects they fund. This, and similar initiatives that may be forthcoming in the U.S. and elsewhere, will force architectural and engineering firms to use model based CAD software in their work. Cost estimating and building energy performance simulation and analysis, done with interoperable software tools, will draw some of the data needed for its work directly from a BIM.

Direct import and reuse of building data will inevitably cause process change in practice. Some design decisions will have to be made (much) earlier in the design process; greater emphasis will have to be given to multi-disciplinary work earlier in a project. A need for new skills will arise in practice. A "new generation" of software tools will be deployed and project staffs will have to learn how to use them competently and effectively.

This paper describes the process of data import from an IFC compatible BIM for cost and energy performance estimating, and what is possible with currently available software. It discusses anticipated effects on architectural and engineering practice in North America, and action to be undertaken to make the use of IFC compatible building information modeling with "downstream" applications a reality.

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1 INTRODUCTION

In a memorandum to PBS Assistant Regional Administrators dated December 23, 2003 (Moravec 2003), the Commissioner of the U.S. General Services Administration (GSA) instructed them to "Prepare Design Deliverables and As-Builts using Standardized IFC based Building Information Models: Cost overruns and claims can be reduced on our construction contracts by improving the quality of our design product. New technology now affords us the opportunity for quantum improvement in design quality by building our buildings virtually before building them physically. … This technology is now available to the construction industry in the form of interoperable building information modeling using Industry Foundation Classes (IFC). Interoperable object model technology also allows automated standards checking and cost estimating to better control project scope and cost. ... The goal will be to provide IFC based building information models in support of all national office concept reviews on projects receiving design funding in FY 2006 and beyond." The memorandum also states the Commissioner's concern with sustainability of GSA buildings and directs the "… implementation of specific OCA design initiatives [such as] LEED certification, …" The memorandum establishes the goal of using IFC based building information models in GSA project reviews and the objectives of automated standards checking, cost estimating and LEED rating.

Early assessment of LEED rating level classification the building design may achieve is meaningless without considering the evaluation of the designed building's energy performance (LEED 2005). For LEED classification purposes that evaluation is based on "whole building" annual energy performance simulation. HVAC equipment and systems designed for the building are a vital component of the simulation, and account for a significant portion of the building cost (usually around 20% or more). Early assessment of LEED rating potential and calculation of more accurate early cost estimates require the use of building energy performance simulation at the same early stage of building design.

Different individuals and groups interpret Building Information Modeling differently (Laiserin 2002). The definitions are continuously evolving and it appears that every newly formed group with interest in interoperability coins its own definition. A Building Information Model (BIM), the *noun*, is defined here as an *instance of a populated data model of buildings* that contains multi-disciplinary data specific to a particular building which they describe unambiguously. It is a *static* representation of that building (i.e. it uniquely defines that building in a section of time) – it contains "raw" data that define the building from the point of view of more than one discipline (Bazjanac 2004).

It is impossible to store *all* data related to a building in a BIM. The shear volume of data related to a building would render such a BIM impossible to manage, navigate, query and share; such a BIM would be useless. The IFC data model was designed to contain only the fundamental static data from which other data can be derived. Derived and time based data are stored externally – a BIM contains only references and/or links to locations where such data are stored.

Even so, the IFC data model defines many more data types and formats than any single software would need or could create. Consequently, a fully populated IFC based BIM contains much more information than any cost or energy estimating software needs to exchange or make use of. Data sets which are pertinent and are subject to exchange among software applications that serve a particular industry discipline or service a specific set of tasks are defined in specific "views" of the IFC model. Current "views" of the IFC data model include the architecture and coordination "views" (these mostly define data types and formats that populate a BIM with building geometry and geometry related data), the quantity take-off "view" (that defines data types and formats for cost estimating), and the thermal "view" (that defines *passive* performance data types and formats for energy performance estimating). IFC compatible software typically represents a particular "view" of the IFC data model; its IFC interface maps to the software's own data structure only those IFC data type and format definitions that are identified in the particular "view" and *ignores* all other.

Creating a BIM makes sense only if software is available to populate the BIM with data that can be reused by other software, and only if software exists to extract and import data from a BIM. Thus the primary purpose of BIM is to facilitate reuse of reusable data.

This paper discusses typical tasks encountered in the process of generating early cost and energy performance estimates. It defines types of software interoperability and identifies directly and indirectly IFC compatible (interoperable) software currently available in North America. It identifies and groups software per task – BIM authoring, cost and energy performance estimating. It also identifies "target" software that, as a group, can perform all tasks necessary to generate cost and energy performance estimates.

The paper also reviews data types that must be populated in a project BIM. These are data types that are required for successful deployment of cost and energy performance estimating software in schematic design. It then assesses the availability of such data and identifies data types that are exchanged among "target" software and thus should be contained in the BIM. Some data types that are necessary cannot be exchanged and are thus kept in external data bases.

Interoperability and IFC compatibility assessments are limited to those relative to the IFC2*x*2 version of the data model, as this is the only version of IFC that supports *all* data types that are subject to exchanges among "target" software. Interoperability and IFC compatibility based on IFC2x and prior versions of the data model are noted as appropriate. All software assessment is based on software versions, their characteristics, functionality and status as of March 31, 2005. Software not usable in schematic design, proprietary software used in schematic design but not on the market, software that "will be released soon" and software that is "just about to be released" is not considered here. Software targeted for foreign language markets (such as Japanese and French) and not available in North America is not considered either.

2 SOFTWARE AND SOFTWARE ISSUES

Surveys of AEC industry software on the market today (see *2.2 CAD BIM authoring software* below) show that only *one* BIM authoring tool is currently capable of populating a BIM with *all* building geometry definitions that are necessary to operate other tools engaged in the delivery of automated or semi-automated cost and building energy performance estimates. The same vendor provides an integrated cost estimating tool which is the only cost estimating software in North America that can make use of *all* necessary information contained in an adequately populated IFC based BIM. Surveys of AEC industry software also show that only *one* energy performance simulation tool on the market today (see *2.6 Energy performance simulation and analysis software* below) is IFC compatible, capable of importing building geometry needed for the simulation from an IFC based BIM, and capable of adding HVAC equipment and systems definitions and schedules to an IFC based BIM.

While several software tools (often employing own proprietary data models of buildings) may be individually able to perform single tasks in the process of populating a BIM and generating cost and energy performance estimates, as of this writing the actual choice is limited to only a few tools that are IFC

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compatible. In order to create a valid, fully populated IFC based BIM and IFC based cost estimate, one *currently* has to use a single vendor's integrated BIM authoring and cost estimating tool, and the single publicly available building energy performance simulation tool (in addition to any indirectly interoperable tool of choice – see below). This applies to every project, regardless of what BIM authoring tool(s) the design team may be using natively. As other vendors' tools, including other cost and energy performance estimating tools, become directly IFC compatible, the choice of usable tools will increase.

2.1 *Software compatibility with IFC*

An IFC based BIM is essentially a data base for a given building with data formats and internal organization that follow the rules defined in the IFC data model of buildings. If these rules are the rules defined in IFC2*x*2, the BIM is IFC2*x*2 based. An IFC based BIM has a form of an IFC file. If the exchange of information in that file is accomplished by "physical file" exchange, software engaged in the exchange must be compatible with the particular version of IFC in which the BIM was created. Otherwise it cannot import the IFC file or write to it. If a BIM is resident on an IFC model server and is accessed via web services, the IFC version is irrelevant as long as there is no data format incompatibility among the IFC versions in question.

Software compatibility with IFC is obtained with a mapping interface between the software's internal data model and the IFC data model that translates the relevant IFC definitions into software's own data model formats and/or translates the relevant software's data model definitions into IFC format. Software that has an IFC2*x*2 interface is *directly* IFC2*x*2 compatible (Figure 1). Software that does not have such an interface and cannot perform the necessary data translations is not IFC2*x*2 compatible, is *not directly interoperable* with IFC2*x*2 compatible software, and cannot be used to *directly* write data from/to an IFC based BIM.

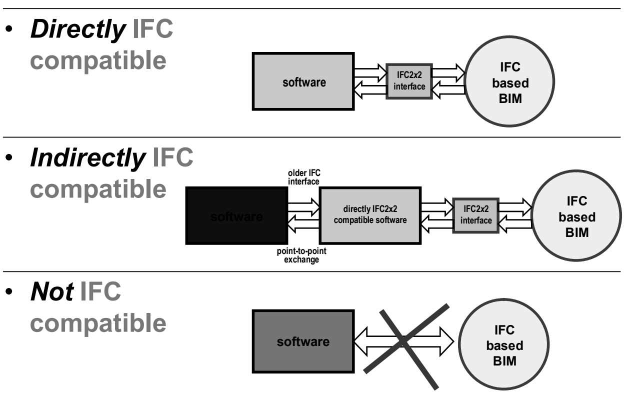

Figure 1. Types of software compatibility with IFC

Some IFC interfaces are based on older versions of the IFC model (prior to IFC2*x*2, such as IFC2x or IFC 2.0) and can populate a BIM only partially: They can populate a BIM only with information that was exchangeable and definable on the basis of the particular version of IFC. Software with such interfaces is *indirectly* IFC2*x*2 compatible – used as necessary *in conjunction* with directly compatible software it can participate in adequate population of a BIM. If data exchange with a BIM is of the "physical file" kind, the BIM can be populated with data from indirectly compatible software only through an "intermediary:" directly compatible software that also has an IFC interface in the version of the particular indirectly compatible software's IFC interface (Fig. 2). In that case the directly compatible software can read the file submitted by the indirectly compatible software, resave it in IFC2*x*2 format and populate the BIM. Directly compatible software can also extract the data from a BIM and then write it in IFC format that is readable by indirectly compatible software.

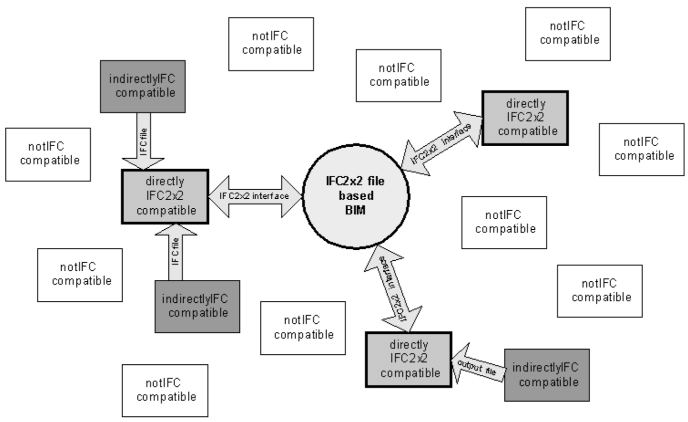

Figure 2. Path from indirectly IFC compatible software to an IFC2*x*2 based BIM via "physical file" exchange

Some software has no IFC interface whatsoever, but has an export data format or utility that allows it to export its building model data to directly IFC compatible software; the IFC compatible software can then populate a BIM with data originally defined by such fundamentally IFC incompatible software – such software can thus be used as *indirectly* interoperable software to provide data for a BIM.

If a BIM is resident on an IFC file server, indirectly compatible software may be able to access it directly (Figure 3). In that case such software may be able to import data from and write it to a BIM itself, without the need for "intermediary" software.

Published lists and reviews of software that is currently used in building design, construction and operations abound. Some of the lists and reviews specifically identify BIM authoring software, or software that is used in cost or energy performance estimating. These include software reviews and analyses published monthly in Cadence (a widely distributed AEC industry CAD magazine), reviews in LaiserinLetters (Laiserin 2005), the Newforma White Paper (Howell and Batcheler 2005), the Geo-

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praxis Green Building Studio web survey of AEC design practice (Geopraxis 2004), a list of minor special purpose cost estimating software (OzGrid 2004), the Building Energy Software Tools Directory from the U.S. Department of Energy (U.S. DOE 2005), the BEST list from the University of Hong Kong (Hui 2005), an informal survey of IAI end users by the IAI Technical Advisory Group (TAG 2003), and more. A review of these sources identifies software that is or can be used early in the building design process and specifically in schematic design.

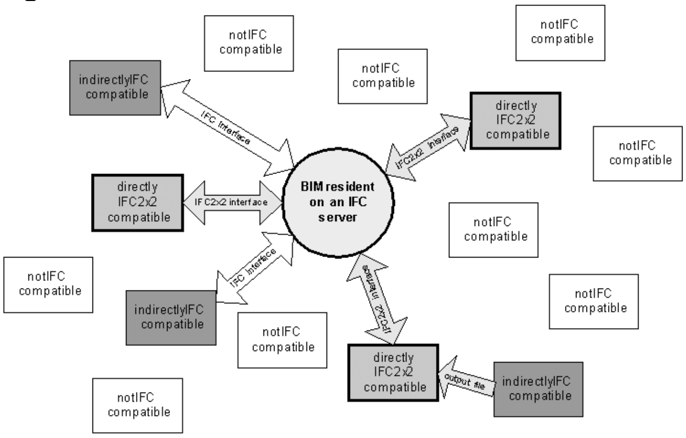

Figure 3. Path from indirectly IFC compatible software to an IFC2*x*2 based BIM residing on an IFC server

2.2 *CAD BIM authoring software*

The only *directly* IFC2*x*2 compatible BIM authoring tool on the market *today* is ArchiCAD 9 from Graphisoft. It is a sophisticated CAD tool designed to primarily serve the architectural design community. Compatibility with the IFC2*x*2 data model is achieved via ArchiCAD's IFC2*x*2 Utility. Besides IFC2*x*2 files, ArchiCAD 9 can read and write files in IFC formats that preceded IFC2x2, such as IFC 2.0 and IFC2x.

A number of BIM authoring tools have interfaces to previous versions of the IFC data model. The Geopraxis' web survey (Geopraxis 2004) shows that such tools most frequently used in North America are Architectural Desktop (ADT) 2005 from Autodesk and Microstation Triforma from Bentley, with some market presence by Allplan from Nemetschek. None of these tools are currently IFC2*x*2 compatible. To populate an IFC2*x*2 based BIM with these tools one must first import the IFC file generated by such a tool into ArchiCAD 9, then save it in IFC2*x*2 format. This makes these tools *indirectly* IFC2*x*2 compatible (Figure 1).

SketchUp from @Last Software is a different kind of *indirectly* interoperable tool. SketchUp has no IFC interface whatsoever, but generates output files that can be imported via a third party plug-in into ArchiCAD 8.1, resaved as ArchiCAD files and moved into ArchiCAD 9 for saving in IFC2*x*2 format. In that way one can populate an IFC based BIM with building geometry data that was originally created with SketchUp.

Visio 2002 Professional from Microsoft is yet another *indirectly* interoperable tool that has only an IFC 2.0 interface. The tool has limited functionality: It can only model building designs for which the third dimension can be *completely* extruded vertically from 2-D floor plans. One can import an IFC 2.0 file generated by Visio into ArchiCAD 9, add to it or modify it if necessary, save it in IFC2*x*2 format, and populate an IFC based BIM with data some of which were originally generated with Visio.

Most of the other "3-D" CAD tools on the market today do not even qualify as BIM authoring software – they create 3-D definitions of surfaces (mostly for visualization of some kind) but do not associate any other buildings related information with them. If their internal architecture is object oriented, their objectivity is mostly limited to drafting; their objects do not carry any kind of "buildings" intelligence. Obviously, none of them can be IFC compatible.

A notable exception among previously *non IFC compatible* CAD tools is Revit 8 from Autodesk. This is a true BIM authoring CAD tool, even if the BIM it populates is based on a proprietary building data model, not IFC. The recently released Revit 8 includes an IFC2*x*2 "*export only"* interface that could not be properly tested on non-trivial buildings at the time of this writing (because one cannot import such test files with the current interface). With a properly working interface one will be able to populate an IFC based BIM with data generated in Revit 8. This will make Revit 8 a directly IFC compatible CAD BIM authoring tool.

2.3 *BIM checking and verification*

Solibri Model Checker (SMC) from Solibri can "spell check" an IFC based BIM to find and report inconsistent and conflicting, as well as required but missing definitions in a BIM. Different types of checks are defined as "constraint sets." These can perform a variety of standard BIM checks that include checks for typical modeling problems, for inconsistent component properties and profiles, for different kinds of component interference, and more. SMC provides exceptional "see through" visualization that makes it very easy to locate a reported problem in the building model. Solibri also distributes the Constraint Set Manager (CSM) which allows end users to write custom constraint sets that are then executed by the Model Checker. SMC is *directly* IFC2*x*2 compatible and can read and check any BIM that is based on any version of the IFC data model. It is the *only* tool in the category of model checking software on the market today.

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2.4 *Cost estimating software*

While most cost estimating tools can perform quantity take-off or import quantity take-off data, all cost estimating software requires the use of associated and/or additional data bases that contain unit costs and other industry data needed to prepare an estimate. Data in such data bases often require regional or localized adjustments; cost estimating can seldom be fully automated when initially used in a project.

No standalone cost estimating software available in North America today is *directly* IFC2*x*2 compatible. IFC compatible software, such as ToCoMan from TocoSoft (a Finnish vendor) or CI Estimator from CRC (an Australian vendor), need adaptation to North American construction practices, prevalent classifications systems, manufacturer data, unit system and more before they can be widely used in North America.

Constructor and Estimator from Graphisoft are a special case of interoperable cost estimating software. They are two of several Graphisoft tools that use the Graphisoft "virtual building" model as the building data model and repository of information; ArchiCAD 9 is an integral part of that group of tools. Constructor and Estimator are linked directly and operate as a fully integrated pair. Constructor uses ArchiCAD 9 as its user interface and to supply and/or modify building geometry, and is fully integrated with it. Since ArchiCAD 9 is a *directly* IFC2*x*2 compatible tool, Constructor inherits all interoperability features from it and can itself be considered *directly* IFC2*x*2 compatible.

Graphisoft's Estimator in itself is not IFC compatible, but since it is integrated with Constructor (and thus also with ArchiCAD 9) it can use data contained in an IFC based BIM. The data flow from an IFC based BIM is one-directional, however: Graphisoft's IFC2*x*2 Utility cannot at present write original data generated by Constructor or Estimator to an IFC file. Thus Constructor and Estimator cannot populate an IFC based BIM themselves.

PrecisionEstimating from Timberline is *indirectly* IFC compatible, though the indirect compatibility in this case is "reverse:" It has an IFC 2.0 interface that allows it only to import building geometry from an IFC 2.0 file. This requires intermittent use of a separate directly IFC2*x*2 compatible tool that can extract data from an IFC2*x*2 based BIM and save them in IFC 2.0 format for reading by the Timberline IFC 2.0 interface. PrecisionEstimating contains several integrated modules, including CAD Integrator that manipulates building geometry.

The North American AEC industry uses a variety of other cost estimating tools, such as WinEst, US Cost, CPR, and more. Not one of these tools has an IFC interface of any kind and thus none are IFC compatible.

2.5 *Thermal zoning and space boundary definition*

The simulation and analysis of a building's energy performance are based on the building's thermodynamic behavior and require a "thermal" view of the building. "Thermal" view is quite different from "architectural:" Individual architectural spaces (or rooms) that have the same thermal behavior are agglomerated into thermal zones. This agglomeration is a necessary step in the modeling of energy performance of any building. Performed manually, it amounts to redrawing the building, which is very laborious and resource consuming, and is a major deterrent to automating the simulation and analysis of building energy performance. ArchiCAD's IFC2*x*2 Utility allows one to create new IFC zones in the building model's "object tree" and drag-and-drop appropriate spaces/rooms found in the tree into the newly created IFC zones. This facility saves many hours of labor and eliminates possible drawing mistakes.

State of the art building energy performance simulation and analysis software also require proper definition of thermal "space boundaries" in the input of building geometry. Figure 4 visually explains issues related to "space boundaries." A construction like a wall or a slab is defined in CAD BIM authoring software as a single instance in its full length (long wall in the left image in Figure 4). That construction has two sides, each of which may be shared by more than a single space or zone. To properly account for thermal transmission through the construction, the originally single construction must be segmented into areas that uniquely belong to each space or zone. The segmentation will increase further if the unique construction segments do no coincide on both sides of the construction. In the example in Figure 4 four zones share the same wall (two on each side of the wall). Proper allocation of "space boundaries" divides this wall into three segments (right image in Figure 4): one wall segment is uniquely shared by zones 1 and 3, another segment by zones 2 and 3, and yet another by zones 2 and 4. Any definition of building geometry for energy performance simulation and analysis software must include resolved "space boundaries."

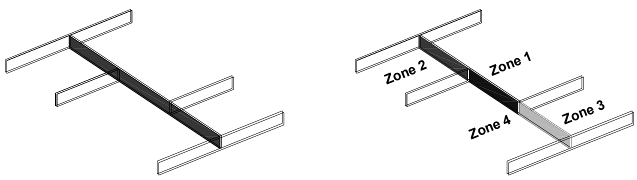

Figure 4. Definition of "space boundaries" for thermal modeling

Manual definition of space boundaries for non-trivia building designs is very tedious, resource consuming and error prone. To be useful, any automated or semi-automated generation of energy performance

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estimates must employ software that generates proper space boundaries *automatically*.

ArchiCAD 9, via its IFC2*x*2 Utility, is currently the only BIM authoring software on the market that can properly accomplish this task. This, and the currently unique facility to drag-and-drop space objects into IFC zones, makes ArchiCAD 9 a currently necessary and unavoidable element in automating the estimation of building energy performance. It explains why it is necessary to import building geometry from an IFC based BIM and "re-work" it with the ArchiCAD IFC2x2 Utility before loading it into energy performance estimating software when the BIM was populated by another CAD BIM authoring software.

2.6 *Energy performance simulation and analysis software*

Building geometry, as defined with CAD BIM authoring software, is full of detail that "downstream" software does not necessarily need. A BIM must contain such "rich" definition of geometry because some "views" of the model and related software (including cost estimating) need it. Models of building geometry employed by most energy performance estimating tools are fairly simple: They define only the length, height, width, and location of *planar* surfaces relative to a coordinate system. Any additional geometry data contained in a BIM are redundant to such tools. Thus geometry contained in a BIM has to be simplified for use in energy performance estimation, a task suited for middleware.

EnergyPlus from the U.S. Department of Energy (DOE), a tool in the public domain, is the only building energy performance simulation and analysis software that is *directly* IFC2*x*2 compatible. It is a "state of the art" energy simulation tool designed to simulate energy performance of buildings of any type and complexity, in any location, for any period of time. The tool uses BS Pro COM Server middleware from Olof Granlund OY (a Finnish vendor) and its EnergyPlus client from LBNL (IFCtoIDF) to simplify building geometry imported from an IFC based BIM. While BS Pro can currently write six specific parameter values to an IFC file, neither BS Pro nor IFCtoIDF can export new data to a BIM. However, EnergyPlus has an IFC HVAC interface from LBNL that makes it possible to import HVAC definitions and building use schedules from a BIM and/or populate a BIM with the same.

EnergyPlus cannot write *results* of simulation and analysis to a BIM *by design*. Each energy performance simulation generates enormous volumes of data – a project BIM could not possibly contain all those data and still be navigable, searchable, and generally manageable and useful. Instead, SMIET (another interoperable tool from LBNL) places references and/or links to external files that contain the results of simulation and analysis, or contain all simulation input data necessary to recreate the simulation and analysis into IFC2*x*2 based BIMs. SMIET – a *directly* IFC2*x*2 compatible BIM authoring tool for HVAC equipment and systems definition – can extract from and/or populate an IFC2*x*2 based BIM specific data related to energy simulation that are not an integral part of EnergyPlus simulation and thus cannot be imported or exported with the IFC HVAC interface for EnergyPlus. Such data include manufacturers' product information, maintenance information that is not time based, and more.

Surveys show that a substantial portion of building energy performance simulation and analysis in North America is still done with DOE-2 (a predecessor of EnergyPlus) and its various commercial or public domain derivatives. None of these has an IFC interface of any kind. However, DOE-2.1E and DOE-2.2 input can be at least partially translated into EnergyPlus format with an EnergyPlus utility. This makes DOE-2 and all of its derivatives a special case of *indirectly* IFC2*x*2 compatible software, similar to SketchUp (see above).

Other currently available energy performance estimation tools do not have an IFC interface of any kind and are thus not IFC compatible. These include TRNSYS, HVAC Solution 3.0, and others from North America, and ESP-r and TAS (two tools from U.K. with some presence in North America). Some of these tools can import (simplified) building geometry from CAD files generated by directly or indirectly IFC compatible software, (such as gbXML, which imports building geometry and includes it in the input it creates for DOE-2 or EnergyPlus), but none can export information back to BIM even through an "intermediary."

2.7 *HVAC design software*

Unlike energy performance estimation software discussed above (with which it has many common aspects), HVAC design software is used specifically to design HVAC systems that serve a building. Surveys show that such software is used by virtually all HVAC designers; it is not coincidental that the two most prominent design tools of this type come from HVAC manufacturers (Trace from Trane, HAP from Carrier).

Unfortunately, none of the HVAC design tools used in North America, such as Trace, HAP or the Right-Suite Commercial suite from Wrightsoft, are directly or indirectly IFC compatible. None have an IFC interface or any ability to have data they generate added seamlessly to a BIM. A couple of European tools are either directly (such as DDS from Norway) or indirectly IFC compatible (such as MagiCAD from Finland). Both are primarily ducting and piping design tools, and neither has a presence on the North American market yet.

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The lack of interoperable HVAC design software poses a serious issue in BIM authoring. EnergyPlus (not a primarily HVAC *design* tool) provides the only way to populate a BIM with HVAC data; to do that one has to enter data describing HVAC equipment and systems, possibly already defined by an HVAC design tool, manually into EnergyPlus before those data can be placed into a BIM via the IFC HVAC interface to EnergyPlus.

3 DATA AND DATA TYPES

Software manipulates data. For software to run and generate results, its user must "input" data. Interoperable software obtains some of the data it manipulates seamlessly (i.e. automatically or semi-automatically) from other interoperable software or data bases. Other parts of input data sets it manipulates come from external sources (i.e. from software or data bases that are not interoperable, or from information available to the end user that is not in electronic format) and are entered by the end user. Some data are yet generated by the software itself.

If a particular (required) datum is not found in a BIM, interoperable software is still useable. It merely means that this particular datum is provided from another source. That in fact is how all interoperable "downstream" software operates today. Interoperable cost and energy performance estimation software draws building geometry and some other data from a BIM. The rest of the data input content is completed with data from data bases contained in computer files (such as those that contain task libraries and/or input data for previous projects), manuals and catalogues (such as those that contain manufacturers' product and/or performance data) and information that comes from end user's training, knowledge and experience. If the end user provides input information that links the software to external electronic data bases (as is the case for weather data in energy performance estimation), the software automatically fetches the needed data. Otherwise, the remaining data are entered by "copy-and-paste" or manually.

Most sophisticated "downstream" software has a mechanism to protect it from missing data that are mandatory for its operation.

Table 1. Data types created in schematic design and used by cost and energy performance estimation software

Discipline	Data types that define	IFC2*x*2 BIM authoring tool(s)	Determined in schematic design	Data source(s) for software
Architecture	Building geometry	IFC compatible CAD software	Sufficient	BIM
	Construction materials	None adequate	Preliminary	External data base
	Manufacturers' components	None adequate	Preliminary	External data base
Structural engineering	Frame	Geometry: IFC compatible CAD	Preliminary	BIM, experts
	Load bearing walls	Geometry: IFC compatible CAD	Preliminary	BIM, experts
	Columns	Geometry: IFC compatible CAD	Preliminary	BIM, experts
	Beams	Geometry: IFC compatible CAD	Preliminary	BIM, experts
	Slabs	Geometry: IFC compatible CAD	Preliminary	BIM, experts
	Foundations	Geometry: IFC compatible CAD	Insufficient detail	Experts
MEP	HVAC equipment & systems	EnergyPlus	Preliminary	EnergyPlus input
	Ducts & pipes	None (in North America)	Insufficient detail	Experts
	Electrical equipment & systems	None (in North America)	Preliminary	Experts
	Wiring	None	Preliminary	Experts
	Fire safety equipment & systems	None	Insufficient detail	Experts
	Lighting equipment & systems	Geometry: IFC compatible CAD	Preliminary	BIM, experts
	Utility rates & schedules	None	Sufficient	Local utility
Civil engineering	Excavation	None	Insufficient detail	Experts
	Hauling	None	Insufficient detail	Experts
	Grading	None	Insufficient detail	Experts
	Drainage	None	Insufficient detail	Experts
	Irrigation	None	Insufficient detail	Experts
Landscape architecture	Landscaping	None	Insufficient detail	Experts
	Planting	None	Insufficient detail	Experts
Construction management	Methods	None	Preliminary	Experts
	Resources	None	Preliminary	Experts
Building operations	Occupancy schedules	EnergyPlus	Sufficient	EnergyPlus input
	Internal loads schedules	EnergyPlus	Preliminary	EnergyPlus input
	HVAC systems schedules	EnergyPlus	Preliminary	EnergyPlus input
	Plant schedules	EnergyPlus	Preliminary	EnergyPlus input

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Some software has "default" values for such data types built into its code; if the input data set fails to include a particular required datum, the software uses the default value for it. (End users have to be aware of that default value to fully understand the results the software generates.) Other software interactively reminds the end user to input the datum and may not proceed until a value is entered.

The list of needed and used data types also depends on project type. Software supporting the design of a new building may need a full set of data it can manipulate. Even so, at a particular stage of a project design decisions may emphasize a particular set of issues related to a discipline (e.g. the building structure), leaving other issues (e.g. building envelope or electrical systems) for future consideration. In that case software will use only data related to the particular area of emphasis (i.e. structural design). In renovation projects (such as HVAC equipment and systems upgrade) some areas of the building may never be considered (e.g. foundation design) and "downstream" software (such as cost estimating) will not receive any data pertinent to those area, will not include them in its work and will not calculate any results pertinent to them.

Input sets provided by end users also vary depending on what information is available to end users at the time, and end users' knowledge, experience and skill in the use of the particular software. Everything else being the same, two users are not likely to prepare identical input data sets; yet both are likely to obtain valid results from the software, at least in their own minds.

3.1 *Data types manipulated by cost and energy performance estimation software*

Table 1 shows data types that are used in cost and energy performance estimating. It also shows types of IFC compatible software that can populate a BIM with (some of) those data, and sources of data used in the operation of "target" software. Data types in the table are organized by industry discipline that is expected to participate in or provide information to design decision making during schematic design. Within industry discipline, data types are organized by building component type.

In absence of a tool capable of placing data of a particular type in a BIM, such data must be supplied to the software from external sources. In some cases BIM authoring tools can populate a BIM with only a segment of data used by "target" software; in that case the remaining data are also provided to the software from external sources. "External sources" may include electronic or printed data bases, product catalogues and manuals, previously defined relevant data (defined for other projects), or information selected or supplied by experts. Information from experts may result from experts' knowledge of the particular project, subject and/or software, from experience in the use of software in similar projects, and/or experts' specialized training.

Design decisions in schematic design result in data for software that are defined at different levels of detail and confidence. Some data types can be defined sufficiently. Other data are typically defined only in preliminary form: Definitions may be incomplete, may not contain much detail, and/or may change as design progresses. Yet other data are defined in form insufficient to use with "target" software, or are not defined at all.

Some of the data types are defined insufficiently or not at all because those who are expected to define them do not participate in schematic design for the particular project (they typically join the project and contribute their data later). To improve the accuracy and quality of cost estimates during and at the end of schematic design, the project team should include members from the top six (of seven) disciplines listed in Table 1 and should *start work of these disciplines already during schematic design*. To improve the accuracy and quality of energy performance estimates, MEP work during schematic design should include specific building systems designs and sufficient knowledge of building operations for the building that is being designed.

The absence of sufficiently defined data does not necessarily prevent the use of "target" software. Discipline experts and/or software use experts can reform data or supply data that are meaningful for the project and enable "target" software to operate and produce sought results. *That is how industry software is used in most cases today.*

3.2 *Minimum data sets*

From a technical point of view, the definition of a "BIM minimum data set" primarily depends on the software that uses data extracted from a BIM in its operation. Currently, "minimum" data sets for cost and energy performance estimating "views" should include all data types (a) that are used by the single vendors' cost and energy performance estimating tools discussed above, (b) that are also defined in the IFC2*x*2 data model, and (c) that can actually be populated with project information. Data used by these tools are explicitly defined in the Input section of each respective Users Manual. The respective tools' IFC interfaces determine what data can be populated and exchanged. From a practical point of view, minimally "required" data sets should be determined individually for each project on the basis what data are required to obtain the sought results.

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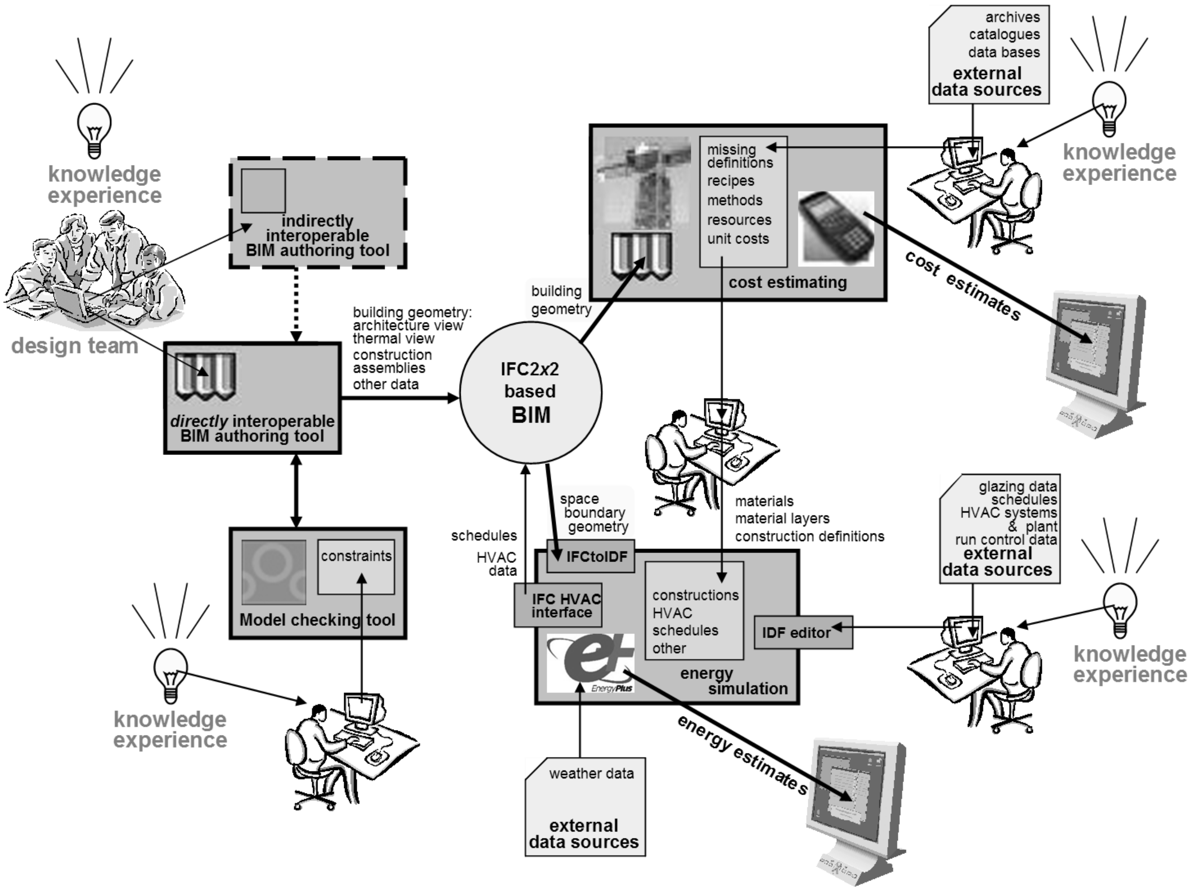

Figure 5. Data generation and flow in current cost and energy performance estimating

4 GENERATION OF ESTIMATES WITH DATA FROM AN IFC BASED BIM

The process of generating an IFC based BIM and cost and energy performance estimates using data from that BIM, as possible today, is diagrammed in Figure 5. The design team defines the building geometry and composite construction types in ArchiCAD or in an indirectly interoperable CAD BIM authoring tool, such as ADT, Microstation Triforma or other software (see the discussion of indirectly interoperable software in *2.2 CAD BIM authoring software* above). If the former is the case, the model of the building is saved in IFC2*x*2 format. If the latter is the case, the model of the building is imported into ArchiCAD and then saved in IFC2*x*2 format. A qualified member of the design team defines the thermal "view" of the building geometry with ArchiCAD's IFC2x2 utility (i.e. groups rooms/spaces into appropriate thermal zones). The IFC2*x*2 file thus becomes the BIM that contains building geometry and the basic definitions of construction materials for the designed building.

The content of the BIM is checked for errors, omissions, interference and contradictory definitions with SMC. In most cases this first requires selection of "constraints" that define the rules and subject of checking from available constraint sets; in some cases the definition of new sets with CSM may be required. If SMC detects problems, the model of the building is corrected in ArchiCAD and the IFC2*x*2 file is resaved to be further checked with SMC. This feedback process continues until no further problems are detected in the BIM.

The user of the cost estimation tool (Constructor and Estimator) imports building geometry and the associated basic definitions of construction materials directly from the BIM. Constructor is an application that runs "on top" of ArchiCAD: It is integrated with ArchiCAD, so the import of data from the BIM is actually done with ArchiCAD via its IFC2*x*2 utility. To create cost estimates, the end user must next import or define "recipes" and "methods" of construction from external data sources, assign construction "locations," and specify resources and unit costs for each instance of a construction element identified in the building geometry. This requires expert construction and cost estimating knowledge. Seamless import of data from a BIM in this process is limited to the import of building geometry and the associated initial basic definitions of construction materials, and does not include definitions of HVAC equipment and systems. The rest of the process is "hard core" cost estimating facilitated by the rules, procedures and requirements of Constructor and Estimator.

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The user of the energy performance estimation tool (EnergyPlus) can currently import only building geometry from a BIM. This is accomplished via the IFCtoIDF tool which incorporates BS Pro and imports building geometry as defined in the thermal "view" of the building, simplifies it and translates into EnergyPlus input syntax. The simplification of building geometry includes simplified definitions of slabs, walls, windows and doors, omission of beams and free standing columns, incorporation of other columns into walls, and omission of interior walls defined entirely within the same thermal zone. Definitions of HVAC equipment and systems, as well as occupancy, plug load and operating schedules, can also be imported via the IFC HVAC interface to EnergyPlus *if* they exist in the BIM.

Since no HVAC design tool in North America is currently IFC compatible or indirectly interoperable (see *2.7 HVAC design software* above), EnergyPlus is the only tool that can populate a BIM with such data. Thus the user creates HVAC definitions, schedules and all other data that are necessary to execute the simulation manually or from external data sources using the IDF Editor (a native input tool bundled with EnergyPlus). It is important to note that seamless import of building geometry from a BIM can reduce the effort and the time needed to prepare input for EnergyPlus by 70-80% (Bazjanac 2001), but that it currently works properly only for buildings that do not have complicated or unusual geometry features. (Work to make this process more robust is currently in progress.)

While BS Pro can extract simple and composite constructions from a BIM, IFC interfaces to EnergyPlus currently cannot translate these into appropriate EnergyPlus input format. Nor can they automatically define material properties as required for EnergyPlus. These are all added manually. "Recipes" for cost estimating are usually the most accurate source of information for detailed definition of composite constructions.

Multiple simulations typically result in partial redesign and/or resizing of HVAC equipment and systems. While the IFC HVAC interface can populate a BIM with the original HVAC data and subsequent updates, such data cannot be seamlessly transmitted from the BIM to Constructor.

Tools used in this process are sophisticated and very complex. Their *proper* and effective use, and the generation of *meaningful* results require substantial skill, knowledge and experience. The process requires the participation of highly skilled individuals from different disciplines who are also skilled in the use of specific software. Tasks such individuals perform cannot be successfully done by members of typical A/E project staffs, except for transcription of construction materials and assemblies needed for EnergyPlus.

5 WHAT IS NEEDED IN THE NEAR FUTURE

The process depicted in Figure 5 still involves a significant amount of end user manual intervention that should be automated. With such improvements, a more semi-automated process of generating cost and energy performance estimates using IFC based BIM is depicted in Figure 6.

Reaching the status of the process depicted in Figure 6 will require a few new interfaces as well as enhancements to several existing software applications and interfaces. CAD BIM authoring tools will have to be able to define and write external shading surfaces as such to a BIM. At least one HVAC design tool will have to become IFC directly or indirectly compatible to enable IFC based BIM population with original HVAC design data. This will also make the use of such HVAC design tool much more productive, as its users will be able to seamlessly import building geometry that such tools require and that is currently recreated manually. Constructor and Estimator (and other future IFC compatible cost estimating tools) need an IFC interface that will export detailed materials and constructions data to a BIM and import HVAC equipment data they use in cost estimating. Interfaces to EnergyPlus (and future IFC compatible energy performance estimating tools) will have to be able to import materials definitions and rich composite constructions from a BIM, as well as geometry definitions that specifically describe external shading devices.

Pilot projects are the best mechanism to make the AEC industry in general aware of successes and pitfalls in the deployment of new technology. In this case a pilot project demonstrates how cost and energy performance estimating software can be used to improve design decision making for building designs that are not trivial, and how a BIM can make the use of such software faster and more efficient. While a few such pilot projects have been already completed and a few more are in progress, many more are still needed.

A/E staffs in general do not have the necessary skills to create a BIM and use the "target" software by themselves – few A/E firms have tried this in real, commissioned projects. Only a few software tools in North America qualify as "target" software. This currently leaves A/E firms with virtually no alternative choices in the selection of in-house software that can participate in the process of creating semi-automatic cost and energy performance estimates that draw data from an IFC based BIM. Some of the available software itself is still buggy and sometimes cannot model unusual or complicated features of a building; its use often requires direct technical support from its vendor. The AEC industry software vendor community overall will have to do more than it has traditionally done – it will have to offer more robust products with more functionality and more IFC interfaces.

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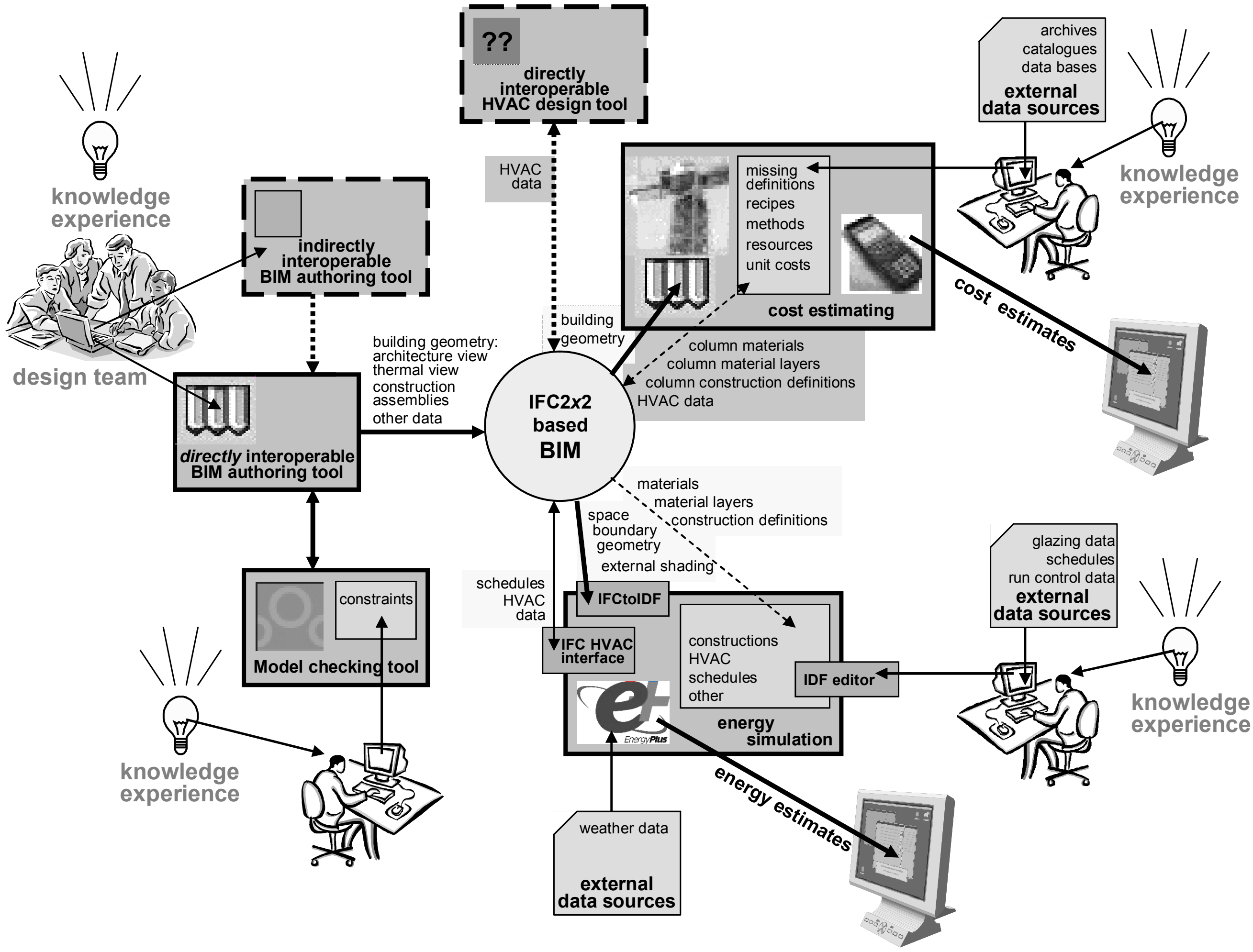

Figure 6. Data generation and flow in a more semi-automated cost and energy performance estimating software environment

A/E firms and their staffs will need immediate, quick and direct help when they encounter problems. That help is already available from the few existing knowledge centers. A knowledge center – at times called a Virtual Building Environment (Bazjanac 2004) – is a place one can go to in order to obtain expert help in the development of an IFC based BIM and in the use of "target" and other industry software. It is also a place where one can test new interoperable software and specialized hardware before acquiring it, witness efficient and effective use of "target" software, learn how to use sophisticated features in software, obtain "work-around" solutions when software cannot do something directly, obtain immediate support from software vendors' technical staffs to fix bugs or provide "special case" solutions, get leads to proper "external" data sources, be informed about "default" values built into software, and much more. In addition, a knowledge center can provide another important service: "neutral source" validation of IFC based BIMs and of cost and energy performance estimates generated with "target" software.

In principle, three such knowledge centers already exist in North America – one is at Stanford University (Center for Integrated Facilities Engineering, or CIFE), one at LBNL (in its Building Technologies Department), and one at the Georgia Institute of Technology (the AEC Integration Laboratory) – and one in Finland (the first formal Virtual Building Environment center at Tampere University). Another one could fairly easily be started at the U.S. National Institute for Standards and Technology (NIST). More are needed, especially those that are not based at academic or research institutions.

6 CONCLUSION

One can generate meaningful cost and energy performance estimates using data obtained directly from an IFC based Building Information Model (BIM) *today*. A BIM cannot, and probably never will, contain *all* data possibly used in generating these estimates; it *does* contain important *reusable* data that can be fetched from it or added to it by *IFC compatible* software.

LEED rating and the quality of cost estimates depend a great deal on the design and performance of energy systems and the building as a whole. Cost

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and building energy performance estimating based on information directly obtained from a BIM can be accomplished only by a handful of "single-source" software tools. Vendors of other tools will have to provide IFC interfaces to their tools before these tools can participate in IFC BIM based project data exchange.

Not everyone will be able to use these "new generation" tools immediately, but there *are* some who already can. The tools are very sophisticated and their use requires skills and knowledge not commonly found in the industry. Their use in real life industry projects will initially require the participation of experts who can provide to project staffs the necessary skills and knowledge.

Work remains to be done before A/E firms and their staffs industry wide can readily create a BIM or fully utilize interoperable software. Some of the currently available software needs prompt fixing. Multiple pilot projects should be launched in the immediate future (a few have already started). Initial support should be provided to existing and new knowledge centers.

To provide the necessary information for meaningful cost and energy performance estimating, some design decisions traditionally made later need to be made during schematic design. Systems like foundations, MEP, electrical, fire safety, security, landscaping and others need to be outlined early enough in sufficient detail to provide meaningful and usable information needed by the estimating and simulation tools. In the future, project consultants who provide such design services should be contractually bound already in schematic design, and contractually required to provide the necessary design information in support of cost and energy performance estimating in that phase of design.

7 ACKNOWLEDGMENTS

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The use of Virtual Reality in a large scale industry project

T. Olofsson & R. P. M. Jongeling
eBygg – Center for Information Technology in Construction, Department of Civil & Environmental Engineering, Luleå University of Technology, Sweden

S. Woksepp
NCC Construction Sverige AB and eBygg – Center for Information Technology in Construction, Department of Civil & Environmental Engineering, Luleå University of Technology, Sweden

ABSTRACT: LKAB, a large mining company in Sweden, has decided to invest in a new pelletizing plant in Malmberget, Sweden (MK3). The total expenditure will amount to €280 million and the new plant is expected to be operational around the turn of the year 2006-2007. Contractors are expected to employ about 250 in connection with the construction of the plant, while some 150 consultants and engineers are engaged in the design phase. Since time to market is a crucial factor for LKAB, the contractual agreements for cooperation in the project support collaborative working methods such as concurrent engineering, open information flow and introduction of innovations in the design process. The complexity of the project, the number of actors involved and the desire to involve end users such as industrial workers responsible for the future plant operations in the design makes VR an excellent enriched source of communication in the review process.

1 INTRODUCTION

1.1 *A document based information process*

Communicating, coordinating and maintaining up-to-date construction information is very difficult to achieve since the information process in typical construction projects is based on documents. Even if the introduction of computers in the construction industry has radically changed the design and planning work the full potential on project level is yet to be reached. A great number of paper and reports emphasize the need for change in order to increase the effectiveness of the AEC industry (e.g. Egan 1998; Koskela et al., 2003). Changing the industry does not necessarily rely on the introduction of new advanced information technology (IT), however, many of these systems have proven to be very efficient in other sectors. For example, results from the EC project ESPRIT CICC (1999) indicates that an efficiency increase of 30 % is possible by exploiting the possibilities of different IT tools. But to be able to act as a facilitator the IT systems have to be adapted to the business processes (Björnsson, 2003).

The business processes the construction industry is using today are developed to produce documents and 2D drawings, these procedures also have to change when implementing model-based design methods.

Several European Information Society Technology (IST) projects have taken the challenge to introduce new IT tools and model based methods in the construction industry, e.g. OSMOS, eConstruct, Divercity, ISTforCE, eLegal, GLOBEMEM, etcetera. The results from the ICCI project (ICCI, 2004), where one of the objectives was to improve the coordination between these IST projects, revealed that there is also a need to overcome social and technical barriers. Some of the recommendations of especially importance are:

- Improvement of trust and social cohesion between all stakeholders involved in the construction process and product lifecycle.
- Changing the attitude and perceptions of the industry towards Information and Communication Technologies (ICTs)
- Improvement of reliability and security of data and information exchange, as well as their underlying ICT systems.

However, we need to find enough incentives in order to justify the introduction of new model-based working methods. The report “Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry” (NIST GCR 04-867, 2004) by the National Institute of Standards and Technology (NIST) indicates that the cost for inadequate interoperability in the U.S. Capital Facilities run up to $15.8 billions annually. This report contributes to creating an increased awareness about interoperability-related issues, not only for owners and operators in the capital facility industries, but also for the construction industry at large. This might not be a technical-related problem at first hand but rather a consequence of the

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reluctance to share information and knowledge between the stakeholders in a construction project. Basically the lack of trust, but also, the lack of adequate tools for communication is the two most important factors for information losses in traditional construction projects (Blokpoel, 2003 and Blokpoel et al., 2004). The pragmatic communication in construction today is often based on traditional media where the breakdown of the project and its presentation can only provide some basic information transfer between the stakeholders of the project (Kähkönen, 2003).

1.2 Virtual reality for review and coordination

One way to approach the challenge of providing a good understanding of the construction and its facilities would be to exploit the potentials advanced visualization techniques such as Virtual Reality (VR) provides. VR is a spatial and communicating medium well suited to facilitate collaboration and understanding about the construction and the processes needed to erect it (Wokseep et al, 2004). Even though VR today primarily is used for visualizing the final product (Woksepp, 2001) there is also a great potential to use it as a universal interface to all design applications (Aouad, et al., 1997; Issa, 1999). It might seem that we are evading the issue of "lack of trust" by suggesting a technical solution, but the fact is that VR has proven to promote collaboration in e.g. the design process through its ability to allow team members to create a design and evaluate it simultaneously for function, cost and aesthetics (Issa, 1999). Actually, some of the major business drivers for VR identified by lead users are just coordinating design and design reviews (Whyte, 2002), which also leads us to the possibilities to facilitate effective processing of client requirements.

1.3 Aim and scope of the case study

Given the fact that VR still constitutes an unexploited resource within the construction industry makes it particularly interesting to study how it can be used in a large and complex construction project as the MK3.

Our aim is to describe a practical approach to facilitate decision-making, and coordinate and communicate client requirements in the design review process via a number of collaborative VR prototypes of the construction and its installations.

The impact will only be measured qualitatively since it is difficult to estimate the impact on economy and time in a project as MK3. We will instead estimate the effect by evaluating how the client and the other stakeholders have been using VR as an alternative form of communication and also provide the readers with some good examples.

2 THE MK3 PROJECT

2.1 Background

The Swedish state owned mining company LKAB has recently initiated the design and planning process of a new pelletizing plant (MK3) in Malmberget, northern Sweden. The plant is planned to be operational by October 2006 and involves an investment of €280 million. It will be complementary to an existing pelletizing plant for the purpose of increasing the production capacity. The Center for Information Technology in Construction (eBygg) at Luleå University of Technology is closely monitoring and studying the design, planning and construction process of the plant as it involves the application of advanced IT systems, such as process-plant design software and VR walkthrough environments.

The client's three key goals in the MK3 project are to obtain a plant with required *Capacity* in *Time* within the *Investment frame.*

2.2 Project characteristic

Discussions whether a construction project can be classified as unique or not often leads to different standpoints. Nevertheless, one can certainly assert that the MK3 project is carried through based on a combination of conditions that all together have an effect on the project performance in a way that separates this project from other similar projects.

The time period from the decision of investing in the construction of a new pelletizing plant to its completion is limited to two years. This put great demands on the project organization and project performance. Also the preliminary study as well as the preliminary design, which both formed the basis for the investment decision, was carried out during a very short period of time.

Normally, the spatial needs govern the preliminary plan in a construction project. However, the design in the MK3 project is affected by the following parameters:

1 The design of the manufacturing process
2 The plant layout (the plant and its surroundings)
3 The construction of the plant

This leads to a situation where the focus is on the assembling and functionality of the machinery in the plant instead of the actual building. All separate design processes including construction, HVAC, electrical installations, process, etcetera occurs simultaneously in a concurrent design approach.

The project has also employed a number of retired local staff who has experience from the existing pelletizing plant constructed during the 1970s. Otherwise, lack of local competence could have been a problem considering that the plant is being built on a remote and sparsely populated place.

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2.3 *Contractual form*

Because of the complexity of the project the contract was based on incentives to meet the client's requirements in function, time and costs. This contractual form is called *Partnering* and is used to form an open collaborative environment. The involved partners can make a lot of deals in order to improve the working climate and trust in order to find prerequisites for a closer cooperation. This facilitates problem solving and shift focus from the individual goals for the involved partners to the overall project goals. Partnering often involves cost reimbursable forms (transparent) for remuneration either with some incentives or without. The incentive is often based upon sharing savings and overflows of the target price. In the MK3 project the incentives are based on a combination of the three project goals to make all major stakeholders focused on the overall project performance. It was also decided to use model based methods (3D and VR) in the design and planning process of the project to enhance the communication and reduce the risk.

3 THE DESIGN PROCESS

3.1 *Modeling tools and work process*

The VR system used in the MK3 project is a low-cost approach that consists of commercial software, PC computers, servers and projectors. The VR software being used is Walkinside™ that is compatible with the most of the major CAD formats. An independent VR consultant is especially appointed to work full-time managing the VR model and the information that is passing through.

Most of the information that makes up the VR prototypes of the plant originates from 3D CAD models developed by groups of multidisciplinary design teams. These teams work together with a common goal to fulfill the client's design intents of the pelletizing plant. The cabling are modeled in 2D and later remodeled into 3D CAD path for the electrical installations.

Apart from forming the base for the VR prototype, the 3D CAD models are also being used for other purposes such as: spatial planning, extracting 2D CAD drawings and further processing in order to extract more detailed 2D CAD drawings as well as for updating 2D CAD drawings. The 2D CAD drawings are only used for production.

The design teams who also extract chosen parts of the models to be included in the VR prototypes are responsible for the development of the 3D models. These are then transferred into a common FTP server that works as a hub for exchanging and storing all visualization information. Every design team has their own dedicated folder with assigned authorization to facilitate the exchange administration and also to secure those parts of the information that is, for example, protected by patent. It is also common that the designers do not want to share all the information they create (Staub et al., 1999). They simply want to share the relevant information for a particular situation (Liston et al., 2001). The design teams are also responsible that the latest updated version should always be available.

The modeling is carried out in 3D CAD software such as, Solidworks, AutoCAD, Tekla Structures, Microstation (where most of the mapping of material and textures is done) and Intergraph's PDM system. The common exchange format is primarily DWG.

After a new set of 3D CAD models has been transferred to the FTP server they are converted into VR format by the VR consultant. Large models are converted independently, optimized and integrated with the other models in the VR prototypes. Smaller models are converted in groups. The aim is to present updated versions every week, however, the reality is that this occurs every two weeks or when some big change has been made. To smooth the progress of integration, all 3D CAD models are modeled using the same coordinate system. The total amount of information describing the VR prototypes of the palletizing plant is extensive, including the construction (prefabricated and cast in place concrete, and the steel structure), its installations (machinery, HVAC, electrical installations, etcetera) and its surroundings.

The VR prototypes are considered to be reliable because they origin directly from the design teams 3D CAD models and not regenerated via some supporting 2D CAD drawings.

After the transfer, storing, converting and optimizing have been completed, the VR consultant then produces different VR prototypes for different purposes, for example, design reviews, construction site planning, production, mounting, working environment, presentations, exchange of experiences, etcetera and transfer them back to the design teams folders in the FTP server. Focus is also on producing suitable VR prototypes for the customer to use for e.g. spatial planning, understanding the construction and its machinery, training of workforce, reconstruction, new work activities, handling hold-up in production, etcetera.

All demonstrations of the VR prototypes are done with computer monitors or projectors (2D). Screenshots and movies are also produced and distributed via the FTP server. Besides overview and detail examining, the VR software is also used for ocular clash detection (automatic clash detection is being carried out in the 3D CAD software by the design teams themselves), distance measuring, user positioning (via XYZ coordinates or marked on a gen-

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eral map, updated in real-time), turning objects on/off via layers, gravity, impenetrable objects, avatars, etcetera, see Figure 1. An especially practical functionality of the VR system is that the user can mark areas within the VR prototype and write notes in a separate text entry window that is connected to the marked area but logged in a separate text file. The text and its connection can later be resumed by clicking the notes. A number of people can also interact collaboratively in the VR environment over the network.

Figure 1. A screenshot extracted from a VR prototype showing the avatar inside one of the main facilities in the pelletizing plant.

3.2 *A concurrent design process*

Figure 2 outlines the iterative design process in the MK3 project. The client is responsible for the overall design process while the design teams, here denoted 1 to n, is responsible for the design of the subsystems in the plant, i.e. process equipment, building structure, installations etcetera. All design teams is also responsible for providing correct and updated input data to the "VR database". An independent VR consultant working for the client manages all the VR data and also makes updated and corrected VR prototypes accessible for everyone to use in the project.

The provided VR prototypes, denoted VR1 to VRn, are also used in the design review meetings that take place once every fortnight. Errors discovered during these design review meetings are immediately delegated to the design teams concerned. All errors that have been attended to are logged and later confirmed in the next following meeting. Decisions on major changes in the design are taken after conducting a risk analysis on the three goals in the project; the capacity, the time and the economical impact. These decisions are always taken in the risk management group consisting of the client and the main subcontractors in the Partnering contract. However, the greatest value for the customer comes from the ability to supervise, interact and provide input to the design teams in the design reviews during the entire design process.

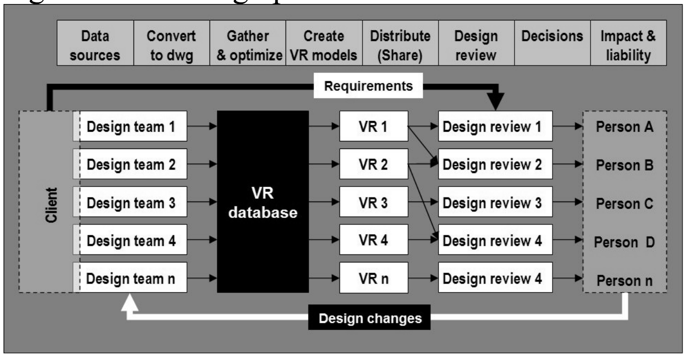

Figure 2. An iterative design review process with specified VR models in a concurrent and multi-disciplinary design situation.

‘Informal’ design review meetings are also conducted continuously throughout the design process. These informal meetings main objectives are to function as a complement to the formal meetings and to speed up the design process. One of the drawbacks of using VR as a communication platform has been that the access to the VR software and the computing power to visualize the growing VR prototypes been limited. Therefore most of the information in these informal meetings has been based on 3D models, extracted 2D paper drawings communicated through emails and telephone meetings. However, the lack of VR has not impacted the information sharing, since theses informal meetings occurs between the regular design reviews where the coordinated VR prototypes are presented. The partners in the Partnering group have encouraged these informal meetings between the different design teams and sharing of information.

4 DECISION-MAKING

4.1 *Introduction*

Howard et al. (1984) defined the term decision analysis as the discipline comprising the philosophy, theory, methodology, and professional practice necessary to address important decisions in a formal manner. They continues to argue that the term includes the procedures, methods, and tools for identifying, clearly representing and formally assessing the important aspects of a decision situation.

Decision-making in the MK3 project is a delicate procedure, especially for the client where the decisions in the project will have a long-term impact on the opportunity to make revenue on the invested capital. The decision making and the design sequencing can affect the design process negatively. To reduce the risk for negative design iterations Ballard (2000) suggest among other measures; team problem solving, the share of incomplete information and concurrent engineering. Decisions made early in the design process have also a greater im-

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pact on the final outcome. Therefore, by focusing on the preliminary design stage, the greater are the chances to achieve a positive effect on the final costs and quality. This applies to this project as well to most construction projects. In view of the wide range of technical inputs, the client and the designers must provided information so it can be assimilated into other decision criteria, e.g. risks, costs and milestones.

The challenge, according to Kam et al. (2004), is to keep the decision makers (in this study - the client and the design teams) informed of all the options and decision criteria during all phases of the decision-making process, particularly in the briefing phase. It is therefore vital that the design teams prepare the information in a way so that the client can pay attention to what is essential, thus saving a lot of valuable time and reducing the risk for misinterpretations. The design teams themselves need to explore different alternatives by predicting and evaluating the impact on the project as a whole in order to come up with the best solutions.

4.2 Decision-making and capturing the client's requirement in the design review process

The use of VR prototypes facilitates two important processes in the design review; the *Decision-making* and *Capturing the Client needs* and requirements. The decision makers base their decisions on large, heterogeneous and multidisciplinary sets of data (Liston et al. 2001). These data sets need to be effectively coordinated and communicated in design reviews with the multidisciplinary design teams and the client (Christiansson, 2001).

The time-pressure in the project and the use of Partnering as a stimulus to enhance the collaboration between the stakeholders, resulted in a concurrent design process where the use of digital VR mock-ups where selected as the main tool for coordination and communication of client requirements in the design review process.

Today the communicating in most construction projects is based on 2D drawings and paper documents. This is clearly not sufficient as regarding to the requirements mentioned above. The participants need better and more effective tools to share and communicate project information. To support the needs of the collaborative multi-disciplinary design and decision-making process in the MK3 project, the client and the different design teams has used a number of VR prototypes for communication of comprehensible project information. Early in the project the decision to use 3D CAD and VR was taken by the Partner group. The project management foresaw the difficulties of gathering and communicating easily comprehensible multi-disciplinary information.

There are several examples in the MK3 project where the VR prototypes been facilitating the decision-making in the design process. For example, because of the tight time schedule, sometimes the different design teams needs to take quick internal decision often without consulting the other design teams on a regular design review meeting. The VR prototypes have help them to better understand the multi-disciplinary consequences of a decision.

From the client's perspective, the impact of the decision on the manufacturing processes has the highest priority. All other decisions regarding e.g. construction, HVAC, etcetera, is of subordinate significance. Therefore, when the client had chosen the plant process and the machinery and supported the required capacity, it was then possible to define the spatial needs. These needs were describe to the construction design teams using a VR prototype of the plant process design. The construction design teams could then begin to plan the layout of the construction and make decisions about technical solutions, which would later be discussed, followed up and evaluated in the succeeding design review meetings.

Besides making it easier for the client to make crucial decisions, the VR prototypes have also involved the client in the everyday design work. Being able to quickly sort out the information that is relevant for the moment and present it in an easy and comprehensible way to a wider audience such as the plant operating and maintenance staff, have facilitated for the client to concentrate on the actual decision.

4.3 Adding value and minimize waste

Several papers and reports have pointed out the role of IT in facilitating the processing of client requirements (e.g. Kamara, 1996; Worthington, 1994; CIT, 1996). Client requirements and the processing of these involves the communication of needs, wishes and expectations of the person or firm responsible for commissioning and paying for the design and construction of a facility in a format that enhances the understanding and implementation of what is desired (Kamara et al., 1999 and Miron et al., 2003).

As mentioned earlier, the use of VR prototypes in the MK3 project have facilitated for the client to become more actively involved in the design process. However, it is difficult to give an overall estimation of the value added and the waste saved caused by the use of VR in the design process. Here, we will give the reader a few examples on how the technology been utilized to add value to the final design and to minimize the waste in the production phase.

In the analysis of the plant working environment and safety a special designed avatar of ample size (210 cm of height) was let to mimic the behavior of the operational and maintenance staff. This was primarily a spatial analysis where working spaces, es-

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capes routes and risky areas in the plant were investigated. The result of the analysis was forwarded to the involved design teams for redesign of the problematic areas in question.

The second example also concerns a spatial analysis but with a total different purpose. The operation of a highly automated industrial process is to a large extent dependent on the maintainability of the process equipment. Measures to prevent production losses have high priority in such facilities due to the economical consequences. Therefore, to make sure that maintenance could be conducted, the maintenance personal was asked to participate in a spatial analysis using avatars and VR prototypes of the process machinery and layout. Problematic areas from a maintenance point of view could as a result be taken care of in the design phase, see Figure 3.

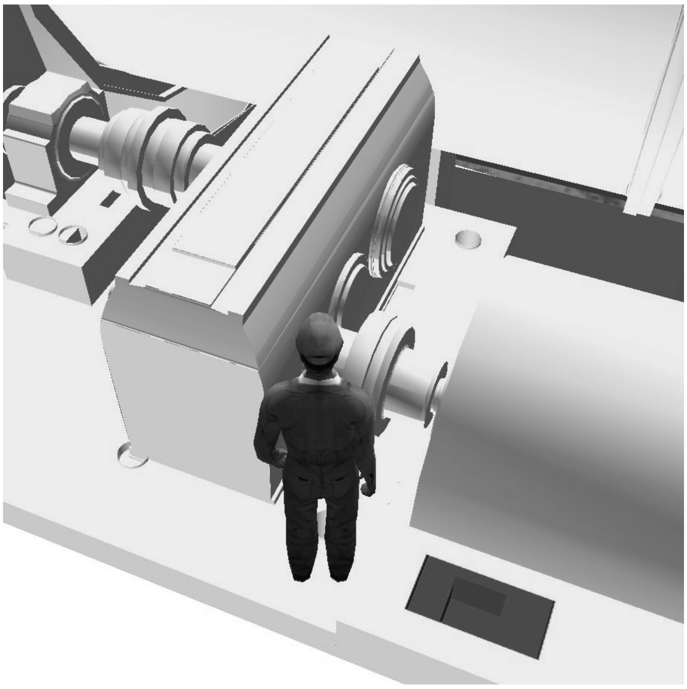

Figure 3. A screenshot showing the use of avatars for investigating the maintainability of the process machinery in the dressing plant.

Many of the non-productive work during the production phase is generated in the design phase. Rework caused by collisions between different objects, such as HVAC and the building construction, is mainly due to incomplete coordination and information flow between different design teams. The use of 3D and automatic collision detection can be a remedy to this problem, but this implies the all design teams should use the same CAD system. Furthermore, in large construction projects containing a huge amount of CAD objects, the use of automatic collision detection generates in many cases too much collision information to be practicable. Instead the same technique of probing avatars was used to detect collisions in special areas of the plant. Since the major risk for collisions occurs in the interface between different design teams, e.g. mainly between installation and construction, a visual detection technique was used. For example the avatar was made to craw inside the ventilation system to detect colliding objects penetrating the ventilation shaft. This last example is also shows how natural/visual interfaces to large data sets can inspire to interaction with the VR system that mimics the strategy that would be taken in the real world, see figure 4.

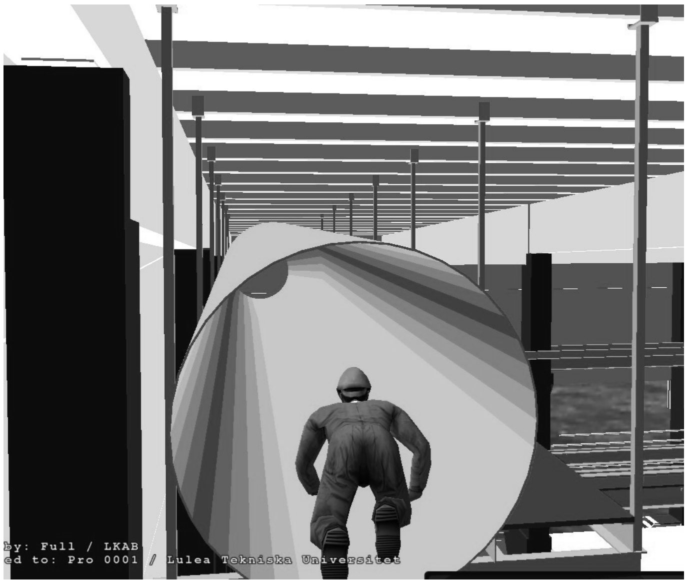

Figure 4. Screenshots extracted from a VR prototype describing how visual clash detections and spatial analyse of the installations with the help of an avatar was carried out.

5 DISCUSSION AND CONCLUSIONS

Howell (1999) pointed out the essential principles of lean construction; to include a clear set of objectives for the delivery process, aimed at maximizing performance for the customer at the project level, concurrent design of product and process, and the application of production control throughout the life of the product from design and delivery. Even if not explicitly evaluated, we still want to stress the correlation between some of the main principles of lean construction, especially the use of VR to facilitate decision-making, coordination and communication in the design review process. According to several interviews the use of VR has increased the reliability in the design process especially in capturing the client's needs and requirements. The reliability has been obtained by continuously updating the VR model using the different design teams' production models.

The rich information environment has facilitated the client and the design teams to focus on 'priority of consideration'. The interactivity has enabled the use of unorthodox methods to test for maintainability, working environment and to minimize waste in the production phase caused by collisions in the design.

The technical interoperability between the different design teams has not been an obstacle despite the

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variety CAD system used in the project. The rather primitive propriety format DWG provided 'enough' interoperability for the users in this project. The technical interoperability has been identified as one of the main barriers in several research project conducted over the last decade. Instead the project management focused on selecting the best designers available using the CAD software of their choice. The interoperability was then a technical matter of selecting the common format and to overcome some of the spurious errors that occurred in the exchange of the DWG files to the VR prototype. Most of these exchange errors could easily be detected, see Figure 5.

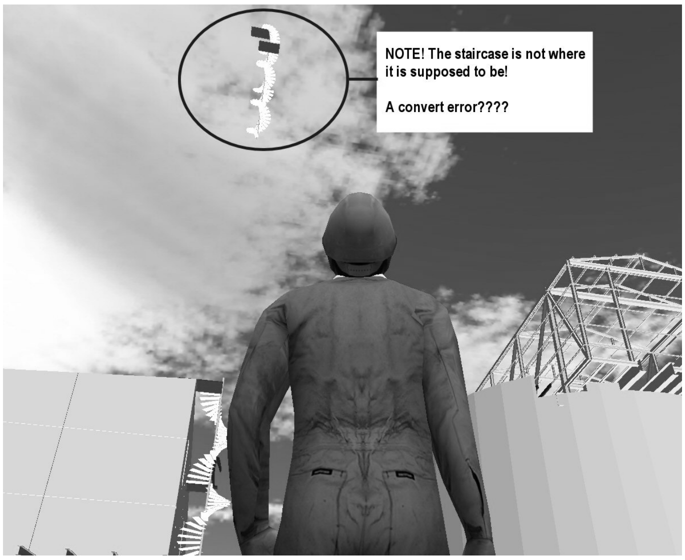

Figure 5. An example of exchange error that occurred between the CAD and the VR software used in the project.

The reluctance to share information is also a major identified barrier in the construction sector. Even though the Partnering contract facilitates the cooperation between the different stakeholders by trust the main cause for the intense information flow and willingness to share has been the time pressure forcing the different design teams to act concurrently.

Based on the experience from the MK3 project, the client LKAB, has decided to use the same contractual concept and working method in the next project – the construction of a new pelletizing plant in Kiruna, Sweden, twice the size of MK3.

6 ACKNOWLEDGEMENT

This paper is based on a field investigation where several people involved in the MK3 project were interviewed. These people represent the client (LKAB) and a number of subcontractors with liabilities within project management and planning, design management, business management and development, technical engineering and VR modeling. We thank them for their invaluable commitment and patience in sponsoring our work and providing access to project data and methods as well as their own knowledge and experiences. We also acknowledge the financial support from the Swedish research fund for environment, agricultural sciences and spatial planning (Formas), the Swedish construction development fund (SBUF) and the European regional funds.

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An application of Artificial Intelligence Planner for bespoke precast concrete production planning: a case study

V. Benjaoran & N. Dawood
Centre for Construction Innovation and Research, University of Teesside, Middlesbrough, UK

ABSTRACT: Precast concrete manufacturers are highly involved in the construction industry through the supply of bespoke products. Their workload is a complex combination of different and unique designed products, which have various delivery dates. The production process from design to manufacturing is complicated and contains uncertainties due to many factors such as: multi-disciplinary design, progress on construction sites, and costly purpose-built moulds. An integrated, comprehensive planning system called Artificial Intelligence Planner (AIP) has been proposed to improve the efficiency of the process by targeting on the production planning as a significant impact to the success of the business. Artificial intelligent techniques are used in AIP to enhance data analyses and decision supports for production planning. A case study for the implementation was conducted on a real bespoke precast concrete manufacturer. The difference between AIP and this factory setting was attended. Data from the studied were reformatted and the AIP configuration was customized. Finally, the successful implementation has showed the adaptability and flexibility of AIP to the real production conditions, and it has given the improvement of the resulted production schedules. The anticipated outcomes are the shortened customer lead-time and the optimum factory's resource utilization.

1 INTRODUCTION

The precast concrete industry is a major supplier of off-site prefabricated components to the construction industry. The construction of a building can be regarded as an assembly of hundreds of bespoke precast concrete components, some of which have different and unique designs and delivery dates. 'Bespoke' precast concrete production has a major distinction from ordinary 'mass' production that is, it constantly requires new product design. Variations in the demand of precast components also create a complexity in the planning of concrete production in terms of efficient resources utilization (Ballard et al., 2002). Since the production is less uniformity, the 'learning curve' is hard to establish and the automation is hardly implemented to assist the process. Therefore, the production planning process requires sophisticated managerial skills and becomes a key of the success of the delivery program, customer lead-time competitiveness, and the effective utilization of purpose-built moulds (Benjaoran et al., 2004).

The aim of this research is to develop an innovative (semi-automatic) planning system to manage bespoke precast concrete production called the '*Artificial Intelligence Planner*' (AIP). The AIP system and the operations of its components are briefly described in the next section of this paper. This paper is mainly focused on the application of the proposed system to a real case study, which is the bespoke precast concrete production of a UK leading manufacturer.

2 ARTIFICIAL INTELLIGENCE PLANNER (AIP) APPROACH

AIP's operations start from preparing input data and finally arranging production schedules. The system adopted artificial intelligence technologies (neural network (NN) and genetic algorithm (GA)) to assist the process of production planning. Figure 1 shows the main components of the system, which are: information inputs, main production processes and information outputs.

Primary information inputs of the proposed system are generated from external sources (project designers and contractors of construction projects). This can be project drawings, product specifications, and construction schedules. The main production process includes product design, productivity estimation, production planning, and manufacturing. Three main AIP components have been developed namely: '*Graphic data Extractor*' (GDE) to assist the product design; '*Processing-Time Estimator*' (PTE) for the productivity estimation; and '*Produc-*

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tion Scheduler' (PS) for the production scheduling (Benjaoran et al., 2004). Also, the AIP system implements data integration technology through the central database to manage historical and current project data. The ultimate outputs of the system can be a high quality production schedule that satisfies short customer lead-time, effective factory resource utilization, and satisfaction of delivery requirements.

2.1 *Product Design with GDE*

The product design is a key task of the bespoke production. It generates unique designs of products. This crucial information then is used by the downstream production process. The quantity taking-off task is considered as an intermediate process that transfers product information from designs to production planning and the task itself is time consuming (Ogunlana & Thrope, 1991). There are some researchers who recognized this problem and developed a system for automating this quantity taking-off task. A study has applied AutoCAD features of organization of drawing elements to retrieve the product information from 2D drawings (Eben Saleh, 1999). Another proposed a new method of modeling 3D CAD product data from horizontal and vertical viewpoint 2D drawings for the purpose of material quantity taking-off (Kim et al., 2002).

GDE is initiated to automatically extract targeted product information regarding products' geometry and material properties from their drawings. Figure 2 shows the operation procedure of GDE. GDE draws on the CAD objects identification technology of AutoCAD and rule-based object recognition that was assimilated from the quantity surveyors' professional knowledge and experience. The methodology is to reorganize all CAD *drawing elements* into referable categories, which the object recognition rules can be applied. This extracted information will be used for the productivity estimation.

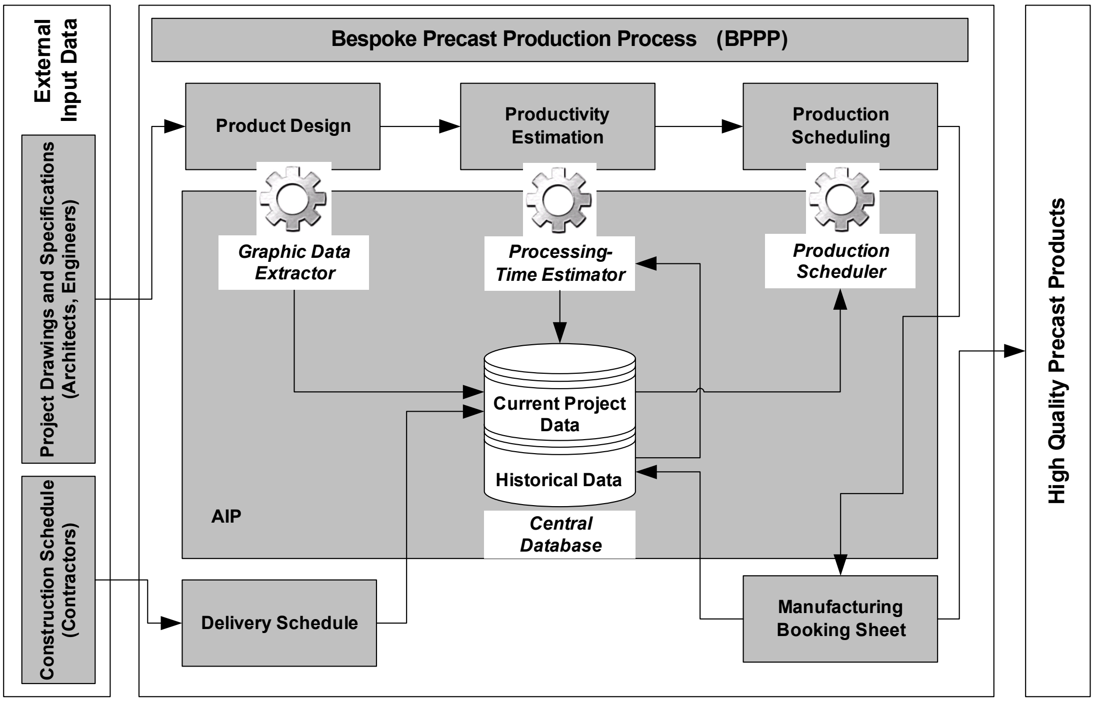

Figure 1: An Overview Flowchart of the AIP System

2.2 *Productivity Estimation with PTE*

The productivity estimation of precast concrete manufacturing routines is a necessary task before being able to arrange production schedules. A large variety of bespoke product designs results in requiring their own different manufacturing time. The current practice of this task relies on estimators' implicit knowledge which is experience and intuition based. It is difficult to share this valuable knowledge within the company. Within PTE, a neural network (NN) has been adopted to formulate a productivity estimation model. The model is used to map the obscure mathematical relationships between the productivity of manufacturing tasks and their own influential factors. These relationships are built upon historical project data and are used to estimate productivity values of the new project. Figure 3 shows the operation procedure of PTE. It is difficult to exhaustively determine all factors affecting labor productivity. Many productivity models that have been proposed by previous literature have different sets of these factors. Previous studies (Sonmez & Rowings, 1998; AbouRizk et al., 2001; Thomas et al., 2003) have proposed their models for the on-site construction tasks considering influential factors largely based on the variation of the working environment regardless building designs.

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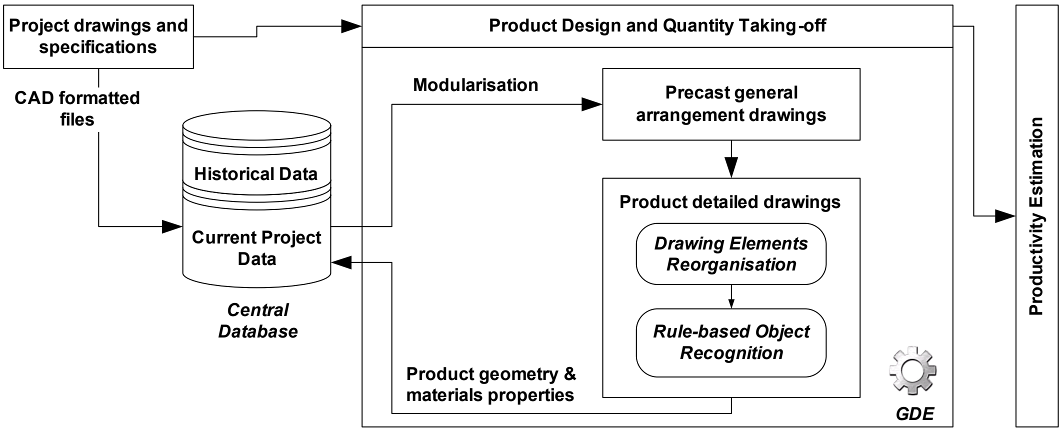

Figure 2: An operation procedure of GDE

However, bespoke precast concrete manufacturing is executed in a more controlled working environment but it has a very large variation of product designs. The difficulties in product designs should contribute important influences. This research study identified influential factors mostly based on the difficulty and variation in their custom designs regarding product geometry, materials, and manpower. The values of these influential factors are already extracted and prepared by GDE as stated before. The outputs are the estimated processing-time values for accomplishing the manufacturing tasks.

2.3 *Production scheduling with PS*

The production planning is very complicated and has a high impact on time and cost of the production program. However, the current practice of production scheduling is much simplified by applying the earliest due-date sequencing rule. Precast concrete manufacturing consists of many repetitive routines and each product is independent without obvious logical precedence. Pioneering researchers (Chan & Hu, 2002; Leu & Hwang, 2001) have proposed scheduling methods for the precast concrete manufacturing using the '*flowshop scheduling model*' and the GA approach for the optimization.

The principle of the flowshop scheduling (Johnson, 1954) has been adopted to formulate a scheduling model particularly for '*bespoke*' precast concrete manufacturing and using a genetic algorithm for the optimization. Figure 4 shows the operation procedure of PS. This model has included mould reuse considerations since types and available numbers of moulds have impacts to the production cost and time. The moulds are costly and purpose-built in a limited number. Bespoke precast concrete products are tied to specific delivery dates which usually correspond to the construction progress on sites. It is important that the production schedule must be attempted to satisfy all product delivery dates.

The directive routines of bespoke precast concrete manufacturing process which are activities associated with the casting procedure are included into the flowshop scheduling model. They are namely mould modification, mould preparation, concrete pouring, curing, mould stripping, and finishing. These routines have their own special characteristics and work logics which are modeled accordingly with a set of complicated mathematic equations (Benjaoran & Dawood, 2004). The GA-based optimization then randomly arranges job sequences and evaluates them with the multi-objective function. This procedure is repeated numerous times until optimum solutions (or near) are found. The optimum job sequences are allocated into a factory's timetable with regard to the existing workload. The outputs of PS are efficient production schedules and a decision support for utilizing factory's resources such as moulds and manpower.

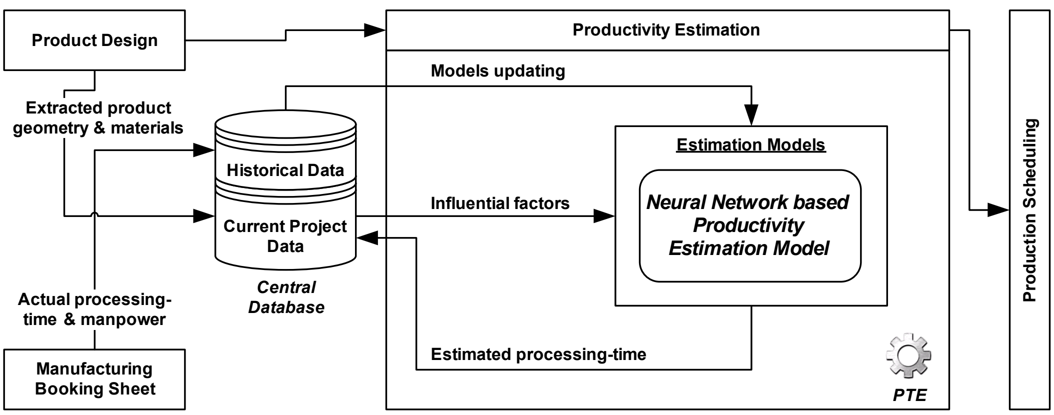

Figure 3: An operation procedure of PTE

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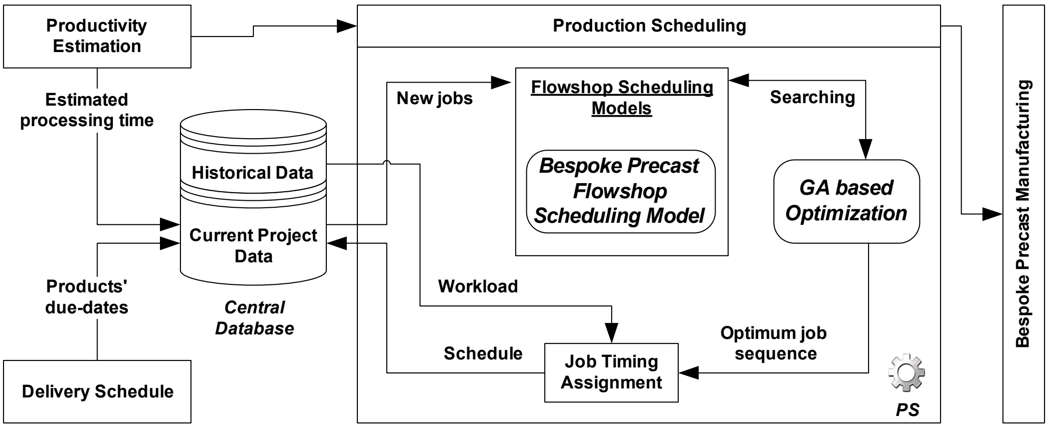

Figure 4: An operation procedure of PS

3 A CASE STUDY OF AIP APPLICATION

A case study was conducted on a bespoke precast concrete company in the UK referred as 'X'. The objective of the case study is to evaluate the possibility of the implementation of the proposed AIP system on this company and to benchmark the system results. The difference between the model assumptions and the real implementation is expected on any development. Therefore, this trial implementation is needed to be conducted. AIP is put to the test here.

3.1 *Background of the company*

Real life production data was collected from company 'X' for being the system inputs. Some adjustments for this case study have been made and described as follows. Company 'X' uses semi-dry cement mix in the casting and therefore moulds can be stripped off their side forms immediately after the final compaction. The cast-units can support their own weight and maintain their shapes. The finishing or surface repairing process will be proceeded straight away. Therefore, the side forms of the moulds can be reused on the next unit and the new casting cycle begins. The manufacturing model of AIP was formulated from the traditional casting process which is using ordinary concrete and requires concrete hardening time. Moulds reuse consideration in the scheduling logic is not applied on this case study because of the advantage of immediately mould stripping. The mould availabilities of all types were set as infinite numbers in PS. The waiting time due to mould occupation is eliminated.

Another area of the differences, the manufacturing model of AIP includes three crews working together to complete the whole manufacturing process. There are six consecutive manufacturing routines that form scheduling logics of the model. In this case study of 'X', these manufacturing routines are reduced to two: mould preparation and casting. They are executed by two crews: joiners and casting workers. These two routines form a working cycle that complies with the flowshop scheduling concept. PS input for the other four routines was left blank. None or simple reinforcement can be inserted in between of the pouring routine so that there is no reinforcement cage installment before pouring. The curing routine which could have taken a long time in the middle of the manufacturing process is not applied in the scheduling logics because moulds are not occupied during the curing routine.

Also, 'X' records their casting crew productivity in term of man-days while PS requires this in term of hours. there is no detail record of each casting routine because any worker completes all the routines individually and continuously. The productivity rates of manufacturing routines are estimated by experience using constant factors to covert job quantities (tons) into required man-day unit. Given their product designs are in general simple shapes, the difference and difficulty of designs which could affect the productivity rate is not concerned. From the historical data analysis (two months period of actual production), the error from this estimation is small (less than 5%). PTE is considered as unnecessary for this case study.

3.2 *Application of AIP*

The production data are prepared in a two-week period (collected from historical records from 30 August to 13 September 2004). There were 46 bespoke jobs released in this period. After the system customization and data preparation, all data input are fed into PS to start the scheduling optimization. There are three sets of schedules to be compared as shown in Figure 5 and 6. The first schedule is arranged from the Earliest Due Date (EDD) rule which is the current standard scheduling technique. The second schedule is from the actual production record and the last one is the optimum from the AIP result.

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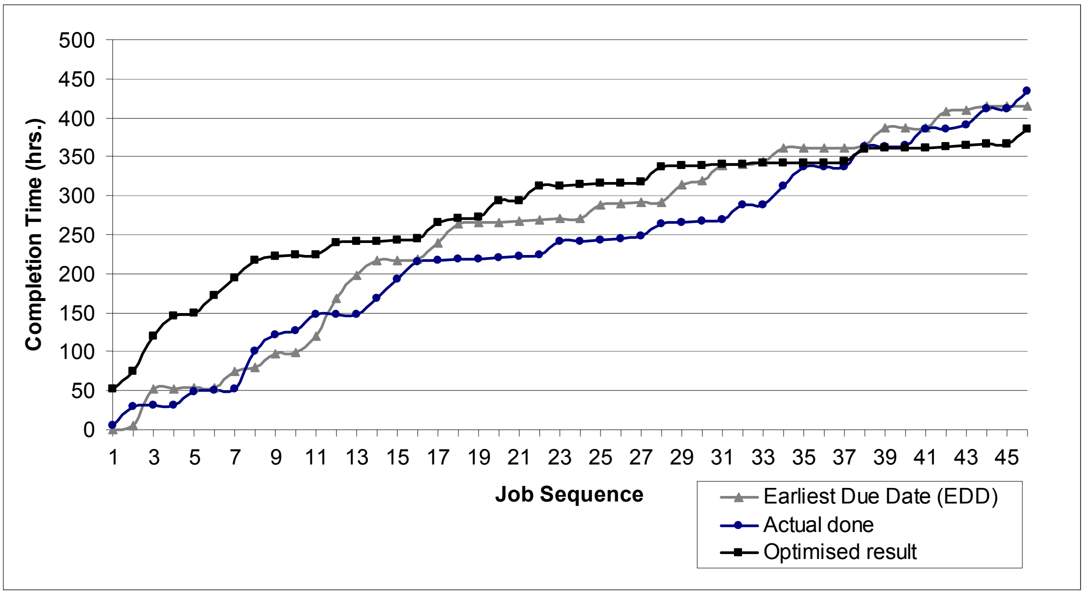

Figure 5: Completion Time Comparison of Scheduling Results

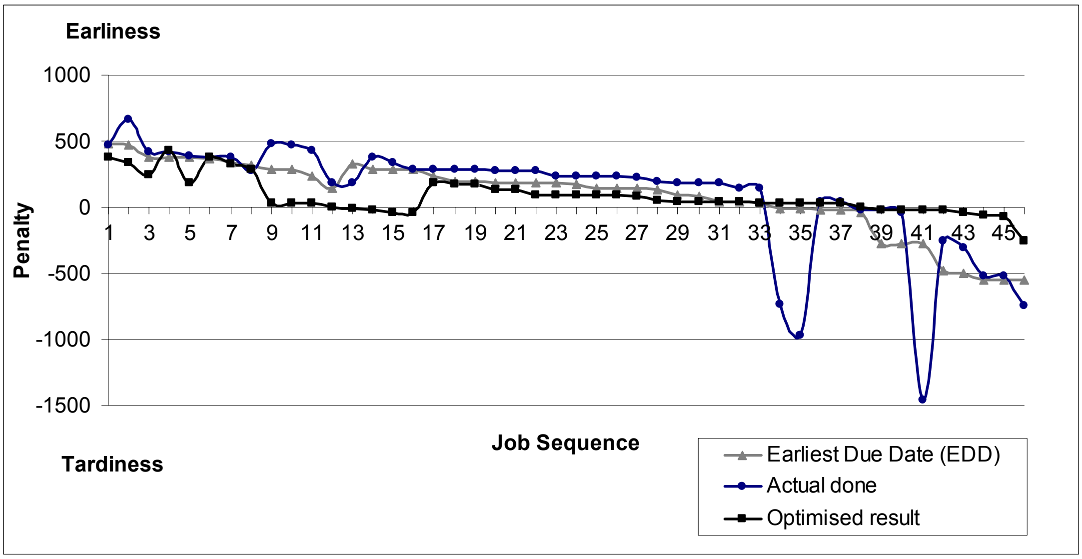

Figure 6: Earliness and Tardiness Penalty Comparison of Scheduling Results

Six objective functions are used to evaluate and compare the three schedules. Total-flowtime is a summary of all product completion time. It can show how well the factory resources have been utilized. Machine-idle-time is a total waiting time of all working stations. Total-penalty of earliness and tardiness is a total penalty of early or late completion of products from their due dates. Makespan is the length of production to complete all released jobs. The others are the number of products which are early and late finished, respectively. All the objective functions are subjected to the minimization which means the less values of the multi-objective function the better the schedule is. However, some of these objective functions are in reverse relationships. It is impossible that any schedule will achieve all function values at minimum. The result graphs (Figure 5 and 6) show that the optimized schedule has the least makespan and total-penalty but it has a slightly higher total-flowtime. These result values are opposite to the values of the actual-done schedule.

The summary of three scheduling results is shown in Table 1. The EDD schedule does not give the best results as the values of objective functions are in-between values of the other two schedules. It also does not guarantee the lowest number of late finish units because this value is still high as 13. It reveals that to execute the jobs in EDD sequence may result in a high total-penalty (even not the highest) with many early or late jobs. In addition, many jobs are executed too early and unnecessarily waiting in the stockyard.

In comparison, the actual-done gives relatively poor schedule result. The actual-done schedule tends to execute easy jobs (without waiting and required less processing time) first. This results in the smallest total-flowtime value but a very high (the highest) total-penalty value. In addition, its makespan is the highest. The actual-done schedule is considered a

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less effective one. The optimized schedule gives a considerably low and the least total-penalty. It tends to execute most jobs just slightly earlier than their due dates but some of them are still late finish. This results in a slightly higher total-flowtime. Although the optimized schedule gives the highest number of late finish units, it can still give very low and the least the total penalty. On average this optimized schedule is the best result out of the three because its all objective function values are relatively low to the lowest.

This successful AIP application on 'X' has shown the adaptability and flexibility of AIP and its possibility of real implementation. Benefits of AIP still can be seen on this case study. The important backbone part of the AIP is the data integration through the central database. That helps to automate the production planning process. Interoperability between the coordinated departments that involved in the production process can be achieved. Improved schedules result with more efficiency in term of time resource.

Table 1: A Summary of Scheduling Results

Objective functions	EDD	Actual done	Optimised
Total Flowtime	11673	10626	12990
Machine Idle Time	584	604	555
Total Penalty	11156	15683	5003
Makespan	415	435	386
No. of early finish	33	35	32
No. of late finish	13	11	14

4 CONCLUSIONS

The paper proposes an innovative production planning system for bespoke precast concrete products. The proposed AIP is a decision support system, which adopts artificial intelligence techniques: genetic algorithm (GA) and neural network (NN) to alleviate the complexity in bespoke precast concrete production. The system consists of three components for assisting different tasks namely: GDE for the product design, PTE for the productivity estimation, and PS for the production scheduling. They are integrated together through the central database.

After AIP has been developed, a bespoke precast concrete company (referred as 'X') was selected to be a case study of the trial implementation. This company has different details of production process from the configurations of AIP model but they are sharing the same bespoke production style. The differences of them were described and attended. General comparison concluded that this company is a simplified version of AIP. The collected actual production data were reformatted before being input of AIP. The result showed that GDE can extract the targeted product information well from the reorganized product drawings as it has been designed and developed for. While the schedule results from PS (or the optimized schedule) were compared with the EDD and the actual-done schedules. The result from PS showed relatively better than the other two. This case study shows the successful AIP application on another company settings and it helps evidence the generalization of the AIP for the real implementation.

The optimum production schedules that are resulted from AIP can increase the reliability of delivery services of precast manufacturers and shorten the lead-time of bespoke products. Consequently, construction operations which require offsite-components can reduce their wasting or buffer time and progress more efficiently.

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Virtual Buildings from theory to practice

P. Christiansson & M. Carlsen
Aalborg University, Aalborg, Denmark

ABSTRACT: We have now during 3 decades worked hard within R&D and practice to define, design and implement Virtual Building models to support the entire life cycle of a building and to support experience capture and input to new projects. The Cambridge UK Building Design System was an early version of a system to handle rather formalized building design in the mid 1970s. Around 1980 the IGES standard supported Cad primitive drawing exchange and the PDES/STEP work in the early 1980s laid the foundation for an object oriented handling of building process entities and model data exchange. The first object oriented Cad systems appeared in the second half of the 1980s. The more operational IFC standardization work was launched 1995 and is to some extent implemented and used in real building projects today.
The paper discusses the trade-off between using highly formalized building models and more loosely coupled building systems models and descriptions from the perspective of Virtual Buildings models, building process organization, building requirements models, and digital hand-over of buildings to clients. References are made to our participation and input to the national Danish Digital Construction R&D program, DDB. A proposed XML scheme to facilitate digital hand-over of building data and core metadata handling is commented on as well as a tool developed to facilitate the actual work to augment the virtual building model and building systems descriptions. The DDB program will result in public client regulations for requirements formulation in 2007.

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1 INTRODUCTION

We have now during 3 decades worked hard within R&D and practice to define, design and implement Virtual Building models to support the entire life cycle of a building and to support experience capture and input to new projects.

The paper discusses the trade-off between using highly formalized building models and more loosely coupled building systems models and descriptions from the perspective of Virtual Buildings models. References are made to our participation and input to the national Danish Digital Construction R&D program, DDB. A proposed XML scheme to facilitate digital hand-over of building data and core metadata handling is commented on as well as a tool developed to facilitate the actual work to augment the virtual building model and building systems descriptions.

2 MODELS AND MODEL ACCESS

According to Oxford American Dictionaries a model is 'a simplified description, esp. a mathematical one, of a system or process, to assist calculations and predications'. The building process comprises a number of actors involved in processes in different contexts as well as flow of information, materials and the building itself described as a virtual building, VB, from idea to physical completion and demolition (Christiansson 1999). Static product models build up the VB but it also contains embedded time dependent processes. The real world, as the building, can be described in form of systems containing partly common sub-systems and building elements. For example the esthetic building system, lighting system, indoors climate system, energy supply system, and human escape systems all contain window building elements and are part of the building usage system. See also figure 1.

During the design process client requirements are expressed as functional requirements on systems, evolving to detailed sub-functions and form, and systems given concrete content (instantiated) thus make paossible behavioral tests on the building systems to validate the building performance against input requirements.

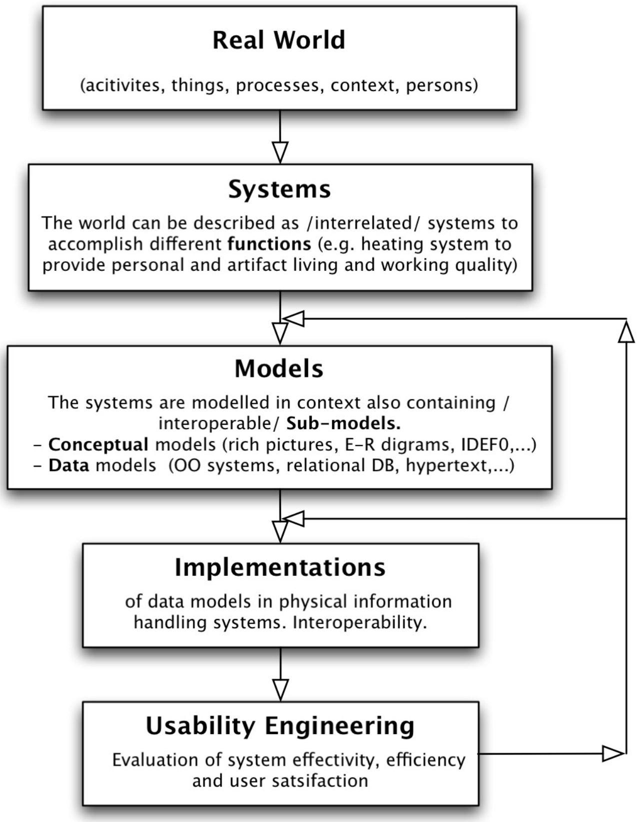

Figure 1. The real world is modeled and accessed from a User Environment, UE, to facilitate experience capture, design, construction, use and re-design of buildings.

The model of a building, in its different life cycle states, was traditionally made in paper and wood and 'accessed' through drawings and text documents on paper. During the latest decades the models are most often stored in digital format and accessed in diverse ways but most often through paper or digital documents (2D drawing and text documents). The distinction between storage and access media will get sharper in the future. We can see example on that now in the XML formatted information containers separated from XML based 'style sheets' description files (.XSL), to fit different user needs and available I/O resource (portable computer, PDA, mobile phone). See figure 2.

The complexity and flexibility in organization of the building process leads to large difficulties to build up highly formalized non-redundant models except for certain more standardized buildings and process organization, see also figure 3.

The favorable degree of optimum formalization of the building process will be different dependent on which actors view it applied. The client, future building owner, engineer, architect, contractor, and maintenance personnel will have different needs and requirements on the models for efficient and effective use in different contexts. 3D models and short-term interaction with analyses programs may for example today have higher importance for designers than building owners.

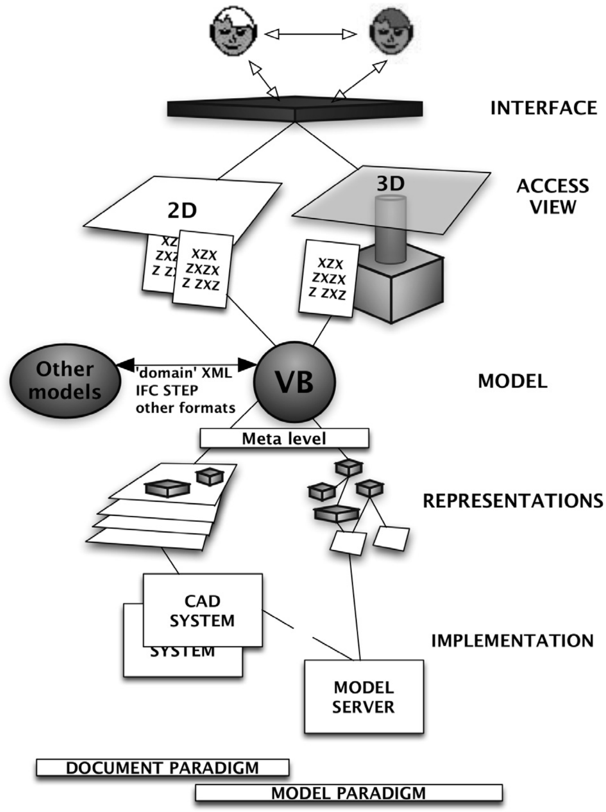

Figure 2. The Virtual Building, VB, model is accessed through more or less detailed representations. The VB sub-models may be partly overlapping and also contain redundant information.

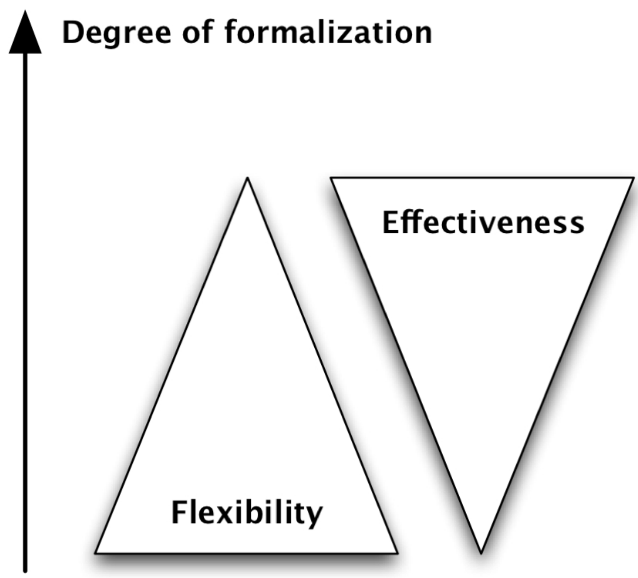

Figure 3 There might be a negative correlation between effectiveness and flexibility for different representations, from (Christiansson 1993).

The ideal situation is that the building process is organized in such a way that the total building life cycle cost and quality is optimal for given input resour-

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ces. A partnering organization may lead to more efficient handling of responsibilities for VB sub models and their interoperability and integration with analyses and simulation programs. It would also then be possible to more efficiently handle a Requirements model for the whole process, see also figure 5. Research undertakings have started to formulate models for digital requirements management though they are yet focused on requirement handling in the detailed design phase. See (Solibri 1999) and (Kiviniemi 2005).

3 BUILDING MODELING HISTORY

The building process models have during decades gone through de-formalization and subsequent formalization to more completely cover a wider building process domain. The building industry has now been engaged in building formalized digital descriptions (models) for more than 40 years of the building process and particularly of the building itself. An important driving force has been development of advanced Information and Communication Technology, ICT, tools from relational databases in the late 1970s to the Semantic Web in 2002.

Below are some highlights from the modeling/ICT history listed, see also figure 4.

– Ivan Sutherland creates SKETCHPAD (1960)
– Integration of building parts to a Product Model, (1970),
– Time-sharing computers (mid 1970s).
– User tools perspective. 3D modeling (1975),
– IGES. Initial Graphics Exchange Specification in USA (1979)
– Cad database integration (1980). Application spread physically in networks (1980).
– 1983. IGES/PDES. Product Data Exchange Specification/using step (USA) , ISO/STEP Standard for Exchange of Product Model Data
– First practical object orientation implementation (1985). CIB W78 conference in Lund 'Conceptual modeling of buildings' (1988)
– PDES/STEP General AEC Reference Model (1988)
– Integration of mixed representations. Knowledge bases (1990). Integrated networks on services level ISDN (1990), INTERNET accelerates. Process modeling focus (1990). WWW (1990).
– IFC Release 1 (1996).
– (1993). January, 40 known http servers. October, 200 known http servers.
– (1994). May, First International WWW Conference at CERN Geneva. (KBS-Media Lab, Lund University on the web in April). June, over 1500 registered http servers. 2.5 million computers on the Internet.
– XML (1998), Resource Description Framework, RDF (1998), Semantic Web (2001). See also (Christiansson, 1998 & 2003), (Lai et. al. 2003).

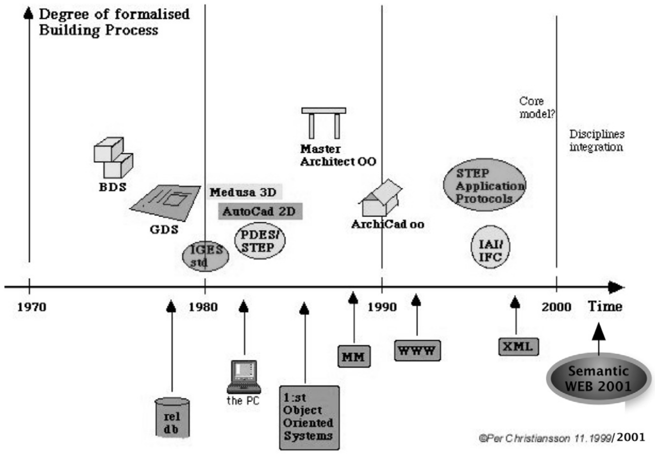

Figure 4. Building Process models development have during the latest decades had periodic focus on achieving a highly formalized non-redundant building product model, Virtual Building, VB.

4 THE DANISH DDB PROJECT

In 2002 the Danish national 'Digital Construction - a development program for the whole construction sector' in Danish 'Det Digitale Byggeri', DDB, was started. See also http://www.detdigitalebyggeri.dk. As a result the public clients will 2007 state a set of ICT requirements that the enterprises of the construction sector must meet if they wish to tender for public construction projects.

The program aims to develop pragmatic common denominators that can create consensus across subsectors and professional affiliations. And most important, the objective is to get agreed solutions implemented in the sector’s every day life. Before the Demands by Client scheme enters into effect, it will be modified based on experience gained from specific tests and from hearings and workshops held with the construction sector. Digital Construction has chosen to establish a learning network as a core activity in the program to secure a dialogue that crosses trade barriers, sub-sectors and fields of activities, and goes on between consortiums and staff in drawing offices, enterprises or on construction sites. An Advisory Board advises the National Agency for Enterprise and Construction. EBST, on the overall direction and progress of the development project. EBST also forms secretariat for the project, http://www.naec.dk/.

Four projects were launched in 2003 within client requirements formulation, (1) Digital tender, (2) 3D

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models, (3) Digital handover (Digital aflevering), DACaPo, and (4) Projectweb together with a project on Foundation for Digital Construction (classification and standardization issues). In 2005 the final project was launched namely, Best Practice - or in Danish 'Bedst i Byggeriet' - with a compilation of specific best-practice examples from real life, documenting how digital solutions in the different processes of the construction project can promote efficiency in the working process. See also http://www.detdigitalebyggeri.dk/english/0/10.

5 DIGITAL HANDOVER

The DACaPo project partners COWI (http://www.cowi.dk/ engineers, project leader), Pihl (http://www.pihl-as.dk/ building contractor), Denmark Radio (http://www.dr.dk/ facility manager) and Aalborg University (http://it.bt.aau.dk/) published in December 2004 the first version on a specification on requirements for digital handover. See also DACaPo workshop2 documentation at http://www.detdigitalebyggeri.dk/dacapo_ws2/0/10.

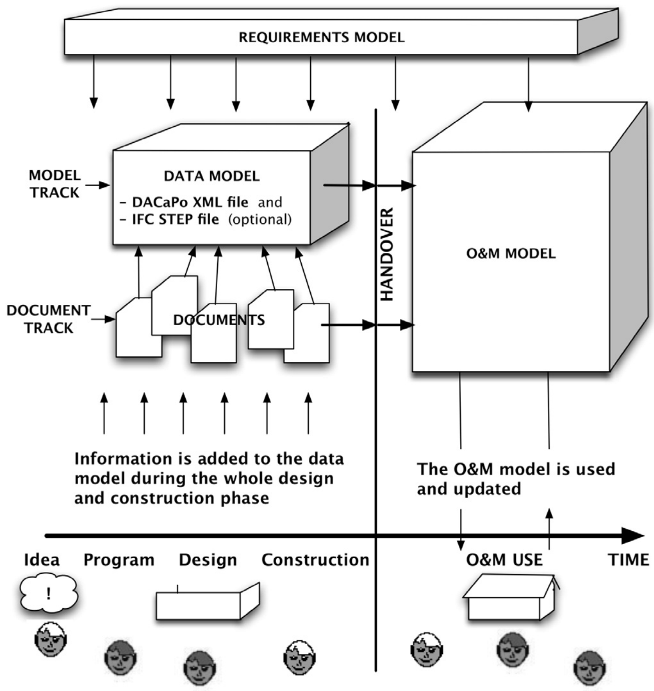

Figure 5. The first version of the Danish requirements for digital handover in 2005 is presently tried out at the Slots- og Ejendomsstyrelsen, Palaces and Property Agency, Ministry of Finance, http://www.ses.dk/.

The DACaPo consortium advocates a long term 2 track solution on data model development, ensuring a smooth transition towards a object oriented model, with possibilities to include traditional information containers (documents), see figure 5. A core meta data model must though be delivered in DACaPo XML format validated against DACaPo XML schemas (.XSD files).

6 DATA MODEL

The suggested Data Model is built around the building physical objects, see figure 6.

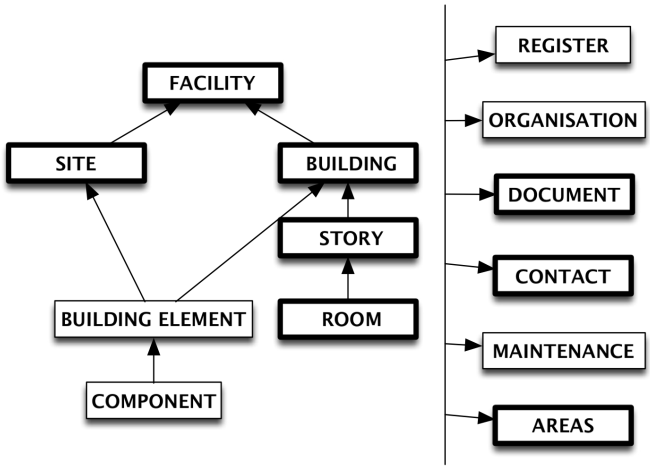

Figure 6. Required (bold) and optional objects of the DACaPo data model for digital handover.

The DACaPo meta data for marking documents is based on ISO 82045-5 (Application of metadata for construction and facility management), http://www.iso.org/. DACaPo XML is also harmonized with IFC XML and OIO XML (Offentlig Information Online http://www.oio.dk/). (http://rep.oio.dk/ebxml/xml/schemas/dkcc/2003/02/13/.
The DACaPo XML structure is developed in close contact with the International Alliance for Interoperability, IAI, http://www.iai-international.org/index.html , to ensure harmonization with IFC.
Three DACaPo XML schemas are defined (model, document, type). Document classes are Site, Building, O&M, and Economy. Within document classes documents are defined with label document type (kind) according to representation form (degree of structure such as locked/unlocked, editable, file/object) and file format (TIF, PDF, DOC, XLS, RTF, XML, DWG, DGN, and IFC).

7 SUPPORT TOOL

The support tool can be downloaded as a file from a local AAU DACaPo project site and opened in Altova Authentic 2005 SP1 Desktop edition (free download at http://www.altova.com/download.html). By using the support tool DACaPo XML files can easily be created and validated against web stored DACaPo scheme files (.XSD). The tool establishes references to external document such as text, photos, and drawings.
If there are client requirements on delivery of Building Element extension objects in large projects, the support tool will not be adequate to use due to ex-

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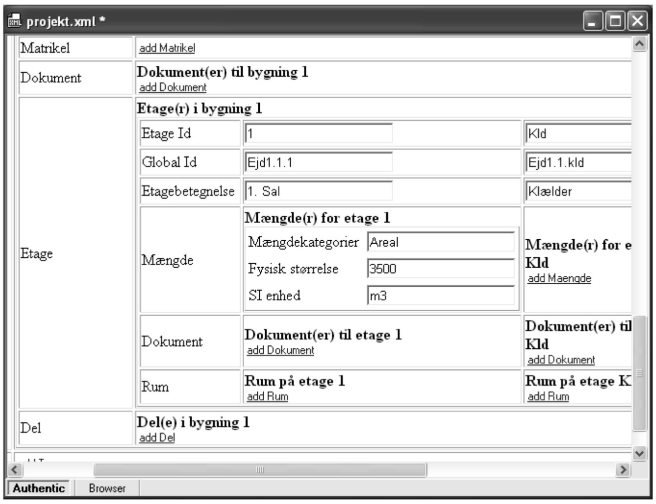
tensive manual data input. In that case it is better to expand existing modeling tools, such as CAD systems, so they themselves output DACaPo XML files.

The support tools graphic user interface has two main input areas, (a) Project information such as contact, date, and (b) O&M data based on the hierarchy Facility, Building/Site, Story, Room, Building Element, and Component as well as metadata and document references. Figure 7 shows an example on the support tool user interface.



DACaPo Support tool example.
(Etage=story, Mængde=quantity, Rum=room, Del=part)

Figure 7. DACaPo Support Tool user interface.

8 CONCLUSIONS

The suggested data model from the national Danish digital handover project, DACaPo, is now under test in real projects and will be updated based on captured experiences and further development of the Danish building classification and ongoing IFC advancement. The model is designed to handle mixed representations with focus on central meta data definitions and future more object oriented representations with possibilities to efficient handling of loosely coupled building systems models and descriptions using meta data information containers.

There is a great need for end user learning of new model based ICT tools and object oriented representations as a complement to traditional document handling approaches. The universities plays a central role in educating engineers in these domains, also in the perspective of life long learning and attracting students from industry. See also Christiansson 2004a) and (Christiansson 2004b).

A very positive bi-effect of more building process participants with high ICT competence is that we hopefully better can involve the building industry in specification of extensions of the existing modeling and analyses tools, to handle domain specific XML information also in a distributed semantic web environment with semantically coupled information containers.

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Rethinking Conceptual Structures and their Expression – Part 1: An Essay about Concept Formation and Symbology

W. Gielingh
Delft, The Netherlands

ABSTRACT: Meaningful communication between people, organizations and information processing systems - using any form of symbolic expression - requires the unambiguous and precise definition of terms. And although symbolic arguments can be expressed with formal rigour, it is still unclear what symbols or terms mean for individual people, organisations or information processing systems. Even formal and official standards use subjective and imprecise definitions of terms. This paper detaches conceptual structures from symbols, analyses their cognitive origin, and proposes an approach that may support a more precise and view independent expression of knowledge.

1 THE CHALLENGE OF COMMUNICATION

1.1 *Communication through symbolic representation*

Large construction projects require the involvement of many people and organisations, often using various information systems. The success of a project depends partially on the quality of information and on the effectiveness of communication. There is an increasing interest to share information in electronic form, so that up-to-date information can be accessed without delay by all interested parties. Moreover, there is a trend to migrate from document oriented information sources to data orientation.

Information can be defined as knowledge that is expressed in symbolic form. Author and reader (or user) must agree about the symbols used and about the concepts that they represent. This requirement applies to information of any kind in any form.

People that are part of a community associate similar – but not necessarily the same - concepts with a particular symbol. Such conceptual differences may cause miscommunication.

1.2 *Discipline views*

A factor that contributes to the problem of communication is that different disciplines have different ‘views’ on a given subject. Information that is relevant for one discipline, may be irrelevant to another. Moreover, a term may have different meanings for different disciplines. The term ‘floor’, for example, has a different meaning for a building user, an architect, a structural engineer or a supplier of elevators.

1.3 *Standards and Formal Specifications*

The need for a precise definition of terms used in construction exists already many decades. It has led to several national and international standards such as Sfb and BSAB in Sweden, CPI and Plowden in the UK and ISO 6707. Such classifications standardise terms, but not meaning.

With the emerging need for the sharing of electronic data in construction projects, standards have been developed – or are still in development – that define the structure and semantics of data. Examples are ISO 10303 parts 225, 228 and 230, and the IAI/IFC’s for construction.

Also for legal purposes such as laws and regulations it is common practice to define terms. All member states of the European Union have developed their own definitions of terms for construction.

Although standards are developed with the intention to support a consistent usage of terms, the standards themselves are usually inconsistent and use different and imprecise definitions. As an example, the term ‘wall’ is defined as follows:

- ISO 6707 - *Wall*: a vertical construction usually in masonry or in concrete which bounds or subdivides a construction works and fulfils a load bearing or retaining function.
- IAI – *Wall*: a vertical construction that bounds or subdivides spaces. Walls are usually vertical, or nearly vertical, planar elements, often designed to bear structural loads.
- The Netherlands national regulation for construction (Bouwbesluit) does not recognize the term ‘wall’ but uses in stead the term ‘*space-divider*’:

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a construction that subdivides spaces. Elsewhere, this regulation defines that a construction is a load-bearing part of a building.

– Encyclopedia Brittanica – *Wall*: Structural element used to divide or enclose, and, in building construction, to form the periphery of a room or a building.

These examples raise questions such as:

1 What is vertical, or 'near-vertical' (ISO, IAI)? What are space-dividing structures that are not vertical or horizontal? See also figure 1.
2 Is a non-planar vertical structure, such as a cylindrical space divider, not a wall (IAI)?
3 What is a construction (ISO, IAI)?
4 Is a Roof also a Wall (Encycl.Britt.)?
5 What is meant with 'subdivision or enclosure of spaces'? Does a curtain subdivide or enclose spaces? Or a fence? And can a window be a wall?

In other words: what are we talking about?

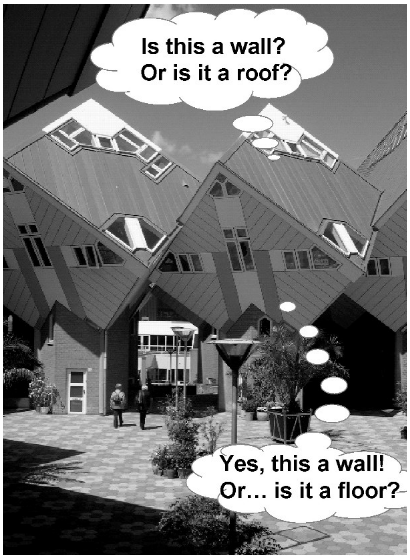

Figure 1. The 'Cube-houses' in Rotterdam, the Netherlands, challenge conventional Building terminology.

Even standards for direct interpretation by computer applications, based on formally specified schemas or ontologies, have weak foundations. ISO 10303 (STEP), the IAI Industry Foundation Classes, as well as the new generation of OWL based ontologies, use terms of which the meaning is described in plain English. Certain ontologies restrict definition to a single word. But dictionaries give often multiple definitions for each word, and different dictionaries give different definitions.

1.4 *The philosophy of meaning*

'Meaning' and 'semantics' have been subject of many studies, theories and debates in linguistics, psychology, philosophy, computer sciences and mathematics. Most theories find their origin in the work of the Greek philosophers, more in particular that of Aristotle. Aristotle writes in *De Interpretatione*:

'Spoken words are symbols of experiences in the psyche, written words are symbols of the spoken. As writing, so is speech not the same for all people. But the experiences themselves, of which these words are primarily signs, are the same for everyone, and so are the objects of which those experiences are likenesses'.

The above is a 'free translation' that meets the purpose of the current discussion reasonably well.

The term 'semantics' is derived from the Greek word 'sema', which means 'sign'. Words in a language are signs or symbols that refer to 'experiences in the psyche'. This idea of Aristotle is often depicted in the form of a meaning triangle, with has at its corners: a symbol (occasionally referred to as a term or sign), a concept (i.e. an idea or thought) and a referent. For most symbols, the referent is not a single 'thing' but a set of things. This set is then referred to as the *extension* of the symbol. The extension of the word 'horse', for example, is the set of (all) horses. The inverse of extension is *intension*: that what a word means or signifies.

Most existing theories concerning 'meaning' are based on either extension or intension. ISO 10303 (STEP) defines the term 'concept' as: 'an abstraction derived from the observation of particular instances' [Danner et al 91]. This is an extensional definition. But what about things that cannot be seen, but are abstract or imagined? And what if the things that are observed are not the same? Only if two parties point to the same physical things and decide to give these things the same name, they may be able to communicate effectively. For an international standard, the above definition is inadequate. Also, it does not solve the aforementioned problem with the concept 'floor'.

In logic and mathematics, the term 'semantics' is restricted to expressions. It does not address what a symbol represents. For example, an argument in logic is said to be semantically correct if valid conclusions can be drawn from a valid set of premises. Logic and mathematics are abstract sciences that are detached from reality. The latter is accurately described by Bertrand Russell [Russell 1901]:

'Pure mathematics consists entirely of such asseverations as that, if such and such a proposition is true of anything, then such and such another proposition is true of that thing. It is essential not to discuss whether the first proposition is really true, and not to mention what the anything is of which it is supposed to be true... If our hypothesis is about anything and not about some one or more particular things, then our deductions constitute mathematics. Thus mathematics may be defined as the subject in which we never know what we are talking about, nor whether what we are saying is true'.

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The same holds for formal logic or any science that is build on top of formal logic, including computer science. For many applications this may not be a concern, but models of reality or of things that are supposed to be part of reality must have a firmer foundation. The issue discussed in this paper is about the formation and scope of concepts, detached from existing theories for symbolic representation.

2 UNDERSTANDING THE PROCESS OF CONCEPT FORMATION

2.1 *From subjective cognition...*

How do people learn and develop knowledge? In recent decades, significant new knowledge has become available through neurological and psychological research [f.e. Maturana 1998 and Neisser 1976].

Humans learn by experience. But the huge amount of information that the human senses provide is 'analysed' and interpreted in an unconscious process before it results in awareness. This process is called *Perception*. An awareness that results from a sensory experience will be called a *Notion*.

Many sensory experiences do not lead to awareness. The few experiences that do, leave an impression that is far from objective.

Successive experiences may be remembered at a certain level of detail. Repeated experiences with the same or similar phenomena result in the development of cognitive structures in the human brain, called *Schemata* [Neisser 1976]. A schema is an understanding of a larger whole: it is a complex of interrelated and remembered experiences. Properties or features that successive experiences have in common, are reinforced, others may be forgotten. A perceptive schema for a particular animal, for example, is therefore never a precise description of that animal; it is at most a caricature.

Schemata may result from any array of impressions with particular Notions in common; hence they may apply to things of the same kind, or to the same individual creature in successive encounters. Properties or features that are not noted do not add to the formation of schemata. Hence, schemata are subjective and depend heavily on the ability of a perceiver to note commonalities or differences.

Schemata play on their turn an important role in perception. New impressions are compared with existing schemata. They enable the perceiver to recognize things and to anticipate. A person who was attacked by an aggressive dog once may be cautious during new encounters.

Schemata may be detached from their original experiences and become independent sources of information for the human mind. In that form they become *concepts*. Certain concepts may be associated with symbols such as words, so that they can be communicated to other people. But as the number of concepts in the human mind is larger and also more complex than a language can represent, any expression is at most an approximation of actual knowledge in the human mind.

2.2 *... to objective cognition*

Perception is subjective. No two human individuals have the same experiences, and even if they are confronted with the same phenomenon they may interpret it in different ways. Assuming that the human senses do not differ significantly, these differences are primarily caused by the schemata that guide the extraction of knowledge from an observation.

Perception can be made less dependent of human interpretation by a more rigorous process of observation and interpretation: the (empirical) scientific method. Modern empirical science is also based on experience, but it uses calibrated instruments in stead of human senses. It uses also a more or less standardized process of interpretation, in which disturbance by systematic errors is minimized. A scientific experiment can be repeated and verified by others, and a publication is reviewed by independent experts before the results are exposed to a wider audience.

A scientific experiment and the interpretation of its results is never free from perceptive distortion; a scientific theory is at most an approximation of reality. But as this process is less dependent on individual factors and can be repeated by others, it is considered as an *objective* cognitive process.

3 A SIMPLIFIED MODEL OF COGNITIVE CONCEPTUAL STRUCTURES

In a simplified model of the cognitive process, conceptual knowledge is formed by Notions and Schemata. From hereon, the term 'Schema' will be replaced by 'Perceptive Frame' - or shortly 'Frame' - in order to avoid confusion with the term 'schema' that has a different meaning in the field of Information Technology.

3.1 *Notions*

A Notion will be defined as: a sensory experience that results in awareness. Notions are usually perceived as properties or features of a phenomenon. But they do not only depend on the phenomenon itself: also the sensory and perceptive system plays a role. The sensor can be a human sense, but is preferably a calibrated instrument, used in the context of a scientifically accepted measuring process.

An example of a Notion is 'Colour'. If the observer is not able to distinguish Colour, it will not be

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noted. Such limitations can be caused by the sensory equipment or by other factors, such as the observation of an object in monochromatic light.

Colour is not a real property of an object. If the object is non-transparent and does not emit light by itself, colour tells something about the reflection of light by the surface of the object in different parts of the electromagnetic spectrum. How Colour is perceived depends on the sensory system. The cones in the retina of the human eye are sensitive in three distinct regions of the electromagnetic spectrum. This characteristic can be used to approximate the impression of colour by a vector with light intensity values for three regions in the spectrum, such as Red, Green and Blue for the additive colour system, or Yellow, Magenta and Cyan for the subtractive colour system. The human eye is only sensitive for radiation with a wavelength between 400 and 750 nm.

The reflection of light by the skin of an object may also be expressed as a spectral curve or as a reference Colour (such as the Pantone® colour system). Hence, there may be several different Notions that provide information about a single property.

A Notion is not the same as a property. It provides information about a property, and it is also *the only way* to obtain information about a property. A Notion may or may not be consistent with other Notions of the same property. This distinction is essential for the approach described in this paper.

Scientific communities develop standard procedures for the sensing and perception of certain Notions, so that more objective conclusions can be drawn about the intrinsic properties of an object. An example is the Notion ‘Weight’ and the Property ‘Mass’. Mass is intrinsic to a physical object, but it can only be determined through a force that acts upon it, such as the Earth’s gravitational force. What is measured in the latter case is Weight. An object weighs slightly less near the Earth’s equator than near the poles, so that a standardized measuring method is needed to derive Mass from Weight. In this case, measuring devices are calibrated with the help of a reference object with a mass of 1 kilogram.

3.2 *Perceptive Frames*

A Perceptive Frame (or, simply, a Frame) will be defined here as the set of notions that is relevant for a particular task. A Frame guides the extraction of information from sensory experiences.

No distinction will be made here between the sensor and the system that interprets sensed data. In reality both play a role, but for practical reasons it is convenient and sufficient to consider sensing and interpretation as a single mechanism.

Domain experts in construction projects extract information that is relevant for their job; the rest is omitted. A structural engineer translates the weight of building components, the planned activities inside the building, and external agents (such as wind force or earth quakes) into static or dynamic forces that act upon the main structure.

This process of extraction and simplification is not different from perception: domain experts use perceptive frames that contain only relevant notions.

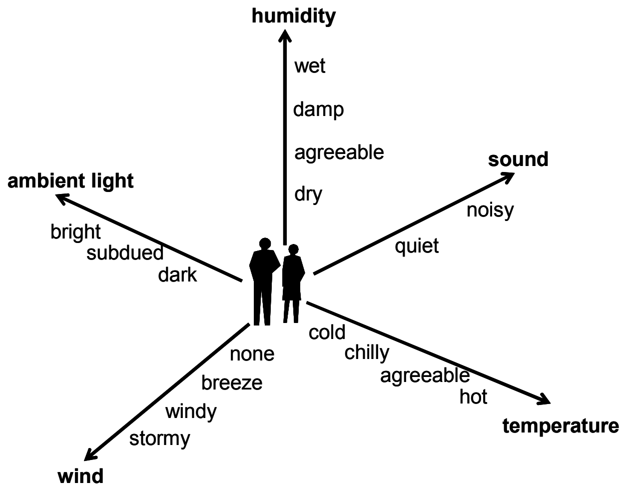

Figure 2. Example of a subjective Perceptive Frame for the description of ‘Shelter’, having five relevant Notions.

The forgotten role of Differentiators

The use of Notions as a means for concept definition is not new. The Greek philosopher Plato developed a method for definition, based on division of classes. It was applied in almost unchanged form by Aristotle.

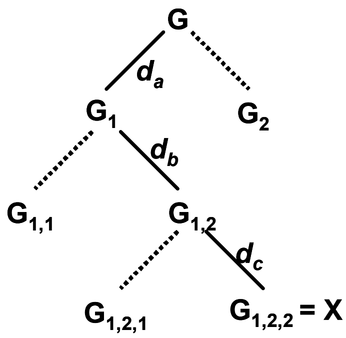

Figure 3 Definition of Meaning by Division of Classes

To determine what X is, first determine the largest class G to which X belongs. Then, divide G into parts (say G_1 and G_2) and determine to which (sub)class X belongs. Suppose this is G_1. Divide G_1 on its turn into parts (say $G_{1,1}$ and $G_{1,2}$) and locate X in one of these.

This procedure is continued until a subdivision is reached that is identical to X. The nature of X is then given by the entire division, which can be represented as an inverted tree; see figure 3. The class to which a thing belongs is called its Genus, and the characteristic that differentiates it within this class is called Differentia. Combining a Genus with a Differentia defines a (sub)class, and the entire set of differentiae needed to arrive at X

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– indicated as d_a, d_b and d_c in figure 3 - defines X [Barnes 1995].

This idea is widely used for the classification of things, such as biological species. It is also adopted for the specification of information systems in the form of conceptual schemas or object hierarchies. In these cases, the principle is known as specialization.

Strangely enough, differentiae are absent in most modern specification and implementation languages. Only two languages, known to the author, support differentiae: IDEF1x (or: ICAM Definition Method 1 extended) and UML (Unified Modelling Language). In both cases, differentiae are called discriminators. *Their usage is free of obligation and does not play a role in the definition of meaning. Most modellers ignore them.*

Plato's differentiae differ on one important point from the Notions proposed in this paper. In Greek philosophy - and applied in same form in today's information technology - differentiae are part of a class hierarchy. They refer to characterizations or properties of the things that are being classified. The Notions proposed in the present theory are independent of the things being classified: they are part of Perceptive Systems.

3.3 *The role of Notions in Concept Formation*

Notions in the present theory are *independent of the things being classified*: they are part of Perceptive Systems, represented here by Perceptive Frames. This important difference with classic theory (see boxed text above) is illustrated by an example.

Suppose that the Notion of Colour would play a role in concept formation. The ability to sense and perceive Colour must be attributed to a Perceptive System. Without this ability, the Perceptive System is not capable to make a distinction based on Colour. Furthermore, conceptual differentiation based on Colour may not be restricted to a single class-hierarchy.

Although the value of a Notion tells something about the subject that is being examined, it depends on the Perceptive System whether it is interested in noting it, and, if so, how the Notion is valued.

This understanding is essential for resolving the problem of different 'views' on a given subject: only by the distinction between Notions and Properties, it is potentially possible to resolve conflicts that are caused by different Perceptive Systems.

3.4 *An example*

The following example makes this idea more concrete. Figure 4 shows a Perceptive Frame for 'Persons'. This Frame differentiates the Genus 'Person' by means of two notions: (a) Age and (b) Gender.

The Notion of Age supports the distinction between (1) adult persons and (2) children. The Notion of Gender distinguishes (3) male persons from (4) female persons. The two Notions can be applied together, and that results in four additional concepts: (5) boy (= a minor male person), (6) girl (= a minor female person), (7) man (= an adult male person), and (8) woman (= an adult female person).

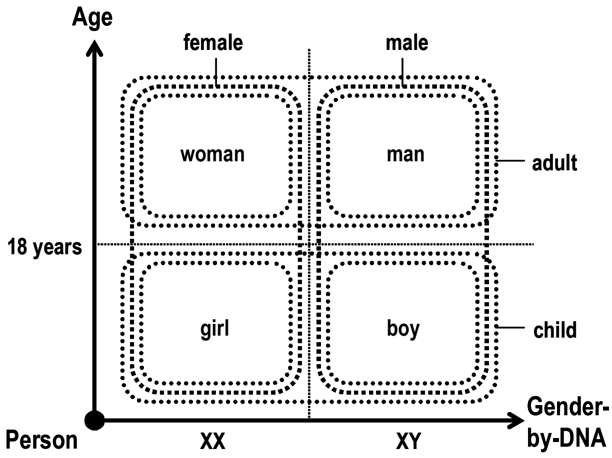

Figure 4. A Frame for concepts relating to Persons based on two Notions: Age and Gender.

It is recommended to use concrete (i.e. measurable and verifiable) notions, such as the legal age and biological gender (i.e. gender according to a DNA test). This makes the description of these concepts precise and objective.

Alternative notions for the same property may be 'Legal Gender' (i.e. Gender according to passport or civil registry) or 'Informal Gender' (i.e. Appearance). In most cases, these alternative notions will produce the same results. But in the case of transsexual persons or travestites, the outcome may be different.

Different Notions are part of different Frames, and it is recommended to keep Notions within a Frame consistent. In this example, it is possible to define a Legal Frame (using Legal Age and Legal gender as Notions), a Biological Frame and an Informal Frame.

The above example demonstrates also that two different Notions with just two subclasses each result in *eight* different concepts related to 'Person'. If more notions are used, the number of resulting concepts increases exponentially.

4 A CONCEPTUAL ARCHITECTURE FOR CONSTRUCTION

4.1 *An Architectural Frame for Space Dividers*

Figure 5 shows an Architectural Perceptive Frame for Vertical Space Dividers. The Genus of this example is 'Vertical Space Divider'. The Frame consists of two Notions that act as differentiators: (a) Human Passage, and (b) Visual Transparency.

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‘Human Passage’ and ‘Visual Transparency’ can both be differentiated into: (1) Closed, (2) Controllable, and (3) Open.

For ‘Human Passage’, ‘Open’ means that nothing blocks a person to pass the Vertical Space Divider. ‘Closed’ means that it is impossible to pass the Vertical Space Divider. ‘Controllable’ means that the passage can be open or closed. A Space Divider with Controllable Human Passage is better known as ‘Door’. Further details about the type of control may result in further detailed concepts of ‘Door’. For example, the Notion may be further differentiated into manual control versus automatic control, lockable or non-lockable, and so on.

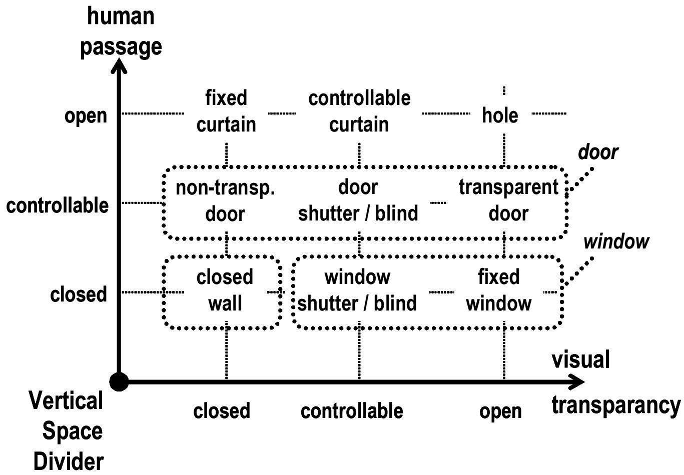

Figure 5. A Frame for Vertical Space Dividers, using two Notions: Human Passage and Visual Transparency

Other Notions that may be relevant for Space Dividers are ‘Heat Transmission’, ‘Noise Transmission’, ‘Light Transmission’, ‘Fire Resistance’ and ‘Strength’.

4.2 *The need for a clean conceptual structure for Construction*

The examples given sofar are all based on a generic ‘Root Concept’ (or Genus) that forms the starting point for the definition of specific concepts. The disadvantage of having these together with Concepts specified by Notions is that two kinds of Definition are applied concurrently. Is it possible to develop a clean conceptual system, entirely based on Notions?

The next (more complex) example will be expressed in a lexical notation. The following conventions apply:

– Names of Perceptive Frames begin with an F.
– Names of Notions begin with an N.
– Names of Concepts begin with a C.
– A Perceptive Frame is defined by one or more Notions.
– A Perceptive Frame may import Notions from other Frames. Through such an import, conceptual integration across Frames will become easier.
– A Notion is defined by a set of possible values.
– A Concept is defined by reference to another Concept and zero, one or more differentiating Notions. In case there is no differentiating Notion, the two Concepts are equivalent.

In the following examples, there is only one Genus or Root Concept, called ‘C_Anything’. This concept is by definition meaningless. Meanings of other concepts follow from the Notions used.

First, three Frames are given: (a) the Root Frame, (b) a generic Frame for Networks, and (c) a Frame for Topological concepts. These three frames form a definition hierarchy.

Frame F_Root (Genus)
Canything

Frame F_Network
Import: F_Root
Notions
NRef: {Ref, NoRef}
Derived Concepts
CNode:= **C**Anything[**N**Ref (NoRef)]
CLink:= **C**Anything[**N**Ref (Ref)]

Frame F_Topology
Import: F_Network
Notions
NDim: {0; 1; 2; 3}
NSideInside: {Side; Inside}
Derived Concepts
CVertex := **C**Node[**N**Dim(0),**N**SideInside(Inside)]
CEdge := **C**Node[**N**Dim(1),**N**SideInside(Inside)]
CFace := **C**Node[**N**Dim(2),**N**SideInside(Inside)]
CVolume := **C**Node[**N**Dim(3),**N**SideInside(Inside)]
CEdgeEnd := **C**Node[**N**Dim(0),**N**SideInside(Side)]
CEdgeSide := **C**Node[**N**Dim(1),**N**SideInside(Side)]
CFaceSide := **C**Node[**N**Dim(2),**N**SideInside(Side)]

The F_Network Frame has a single Notion that distinguishes between referential and non-referential concepts. It results in two concepts: C_Link and C_Node.

The F_Topology Frame imports the Network Frame and adds two Notions: Dimensional Order (N_Dim) and the Notion of Side versus Inside (N_Side_Inside). The latter Notion refers to the idea that a bounded geometric shape has rims (the sides) and an area between these rims (the inside). Notion N_Side_Inside is independent of dimensional order, i.e. it applies to topological entities of dimension 1 (edge), dimension 2 (face) and dimension 3 (volume). All topological entities are considered as Nodes, relations between them are considered as Links, but these details are omitted to keep the example simple.

The following example is a Frame for Building Architecture. It imports the Notions of the F_Topology Frame but not its derived concepts.

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Frame F_Building_Architecture
Import: F_Topology
Notions
NDim: {0; 1; 2; 3}
NSideInside: {Side; Inside}
NShelter: {Interior;Exterior}
NFaceOrient: {Horiz; NonHoriz}
NHorFaceSideOrient: {Up; Down}
NHumanPassage: {Closed;Controllable; Open}
NVisualTransparency: {Closed; Controllable; Open}
Derived Concepts
CSpace:= **C**Anything[**N**Dim(3),**N**SideInside(Inside)]
CSpaceBound:= **C**Anything[**N**Dim(2),**N**SideInside(Side)]
CSpaceDivider:= **C**Anything[**N**Dim(2),**N**SideInside(Inside)]
CInterior_Space:= **C**BuildSpace[**N**Shelter(Interior)]
CExterior_Space:= **C**BuildSpace[**N**Shelter(Exterior)]
CWall:= **C**SpaceDivider[**N**FaceOrient(NonHoriz)]
CFloor:= **C**SpaceDivider[**N**FaceOrient(Horiz)]
CWallSide:= **C**SpaceBound[**N**FaceOrient(NonHoriz)]
CFloorSide:= **C**SpaceBound [**N**FaceOrient(Horiz)]
CInteriorWallSide:= **C**WallSide[**N**Shelter(Interior)]
CExteriorWallSide:= **C**WallSide[**N**Shelter(Exterior)]
CFloorTop:= **C**FloorSide[**N**HorFaceSideOrient (Up)]
CCeiling:= **C**FloorSide[**N**HorFaceSideOrient (Down)]
CClosedWall:= **C**Wall[**N**HumanPassage(Closed)]
CDoor:= **C**Wall[**N**HumanPassage (Controllable)]
CHole:= **C**Wall[**N**HumanPassage (Open)]
CWindow:= **C**Wall[**N**VisualTransparency(Open)]

The 'N_Shelter' Notion makes a distinction between the interior and the exterior of a building. 'N_Face_Orientation' notes whether a Face is horizontal or not. 'N_Hor_Face_Side_Orient' notes whether the normal vector of a Face Side of a horizontal face points upward or downward. The two latter Notions are only applicable if the relevant topological entities are associated with geometric information. This detail is omitted for simplicity.

The Notions 'N_Visual_Transparency' and 'N_Human_Passage' were discussed earlier.

It is not the intention to present a complete Building model here. The example intends to show how the path between a meaningless concept (C_Anything) to concepts such as 'Wall', 'Floor', 'Ceiling', 'Door' and 'Window' can be traversed. Conforming this approach, a *Door* is defined as: *Anything (of 2-dimensional order) which divides spaces, is not horizontal, and which provides controlled passage of human beings*.

This example demonstrates how a complete definition can be given through a tree of Notions – and not more than that.

4.3 *Do we still need Symbolic Expressions of Concepts?*

In the above examples, Notions are used to specialize concepts. It is however possible to define any concept as a specialization of 'C_Anything'. For example, the 'Door' concept can also be expressed as:

CAnything[**N**Dim(2),**N**SideInside(Inside), **N**FaceOrient(NonHoriz), **N**HumanPassage (Controllable)]

And as the concept 'C_Anything' is meaningless by definition, it can also be removed from the description. Thus, any concept is formed by a set of relevant Notions, for example:

NDim(2),**N**SideInside(Inside), **N**FaceOrient(NonHoriz), **N**HumanPassage (Controllable)

... which is the equivalent of 'Door'.

The resulting structure is a co-ordinate system for multi-dimensional conceptual spaces. The ordinates within such a system make symbolic representations of concepts redundant and thus unnecessary.

4.4 *Do we still need Integration?*

To understand the answer to this question, it is convenient to return first to the example of 'Person'. Suppose that this case is modelled by means of a symbolic expression, for example the Express language (ISO 10303-11).

Knowledge about an individual person, say a 7 year old boy, can be represented in nine different ways, of which only two will be given here:

```
TYPE Gender =
  ENUMERATION OF (female, male)
END_TYPE

SCHEMA 1
  ENTITY male_person
    Age: REAL
  END_ENTITY
END_SCHEMA

SCHEMA 2
  ENTITY child
    Gender: Gender
    Age: REAL
  END_ENTITY
END_SCHEMA
```

At the level of a conceptual schema or an ontology it is unclear that the two entity types describe the same boy, and that the information at the data level is equivalent. The two entity types are semantically not equivalent. In fact, they represent two different views of the same reality.

The only way to transfer data from one schema to the other is to develop a mapping from one to the other, with the inclusion of rules that guarantee a semantically correct transfer.

This problem can be reduced but not solved by the introduction of a common supertype, for example the entity 'Person'. It has one attribute that is in-

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herited by its subtypes: 'Age'. However, it is still not possible to see that an instance of 'male_person' may actually refer to the same boy as an instance of 'child'. This problem is caused by the fact that important knowledge is hidden in the specialization tree. The difference between 'Person' and 'Male_Person' is 'Gender', but this knowledge is not made explicit. Using the notation presented in this paper, this same case may be expressed as:

NGender: {Female; Male}
NAge: {Z+}
CBoy:= **C**Person[**N**Gender(male),**N**Age(<18)]
and
X:= **C**Person[**N**Gender(male),**N**Age(7)]

where X represents all available information about the individual person.

The Notions that differentiate concepts are treated here in the same way as normal attributes, so that the description itself is independent of a chosen view.

As it is possible to replace 'C_Person' by its defining set of Notions (see 4.3), this conclusion is valid for *any* information.

Hence, in the approach presented in this paper, integration problems are limited to situations where a single property results in two or more different Notions. The property 'Gender', for example, may be obtained via three different Frames, each using different methods to obtain the required information. This results in three incompatible Notions: 'Biological Gender', 'Legal Gender' and 'Informal Gender'.

Such conflicts can be resolved if the involved parties agree about one and the same method for noting Gender, or if they recognize the three Notions as separate, independent Properties.

5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 *Summary*

Most theories on meaning (or definitions, semantics) address the meaning of symbols (or terms, words, expressions). It happens frequently that two people (or disciplines, applications) associate different concepts with a common symbol. The most widely adopted way to solve this problem is to define 'neutral' concepts on which all parties should agree.

This approach fails because modern knowledge is much richer and varied than what symbols can represent. An artificial increase of the number of symbols is not adequate either, because using different symbols for 'almost, but not precisely the same' concepts creates a new hurdle for communication.

The essential question is: what are the similarities of concepts, and where do they differ?

This paper proposes a model that complies with human cognition: the process through which people learn. Essential components in this approach are *Notion* (i.e., the sensory experience that leads to awareness) and *Perceptive Frame* (i.e. a set of Notions that guides the understanding of a larger whole).

Notions provide information about properties of real world phenomena. They are not the same as properties (where properties are defined as characteristics that are inherent to phenomena). All knowledge about real world phenomena, including properties of these phenomena, is obtained through Notions. There exists no 'neutral', view-independent knowledge about reality.

Perceptive Frames are integrated by combining their Notions. If different Notions refer to the same property, one Notion must be chosen as the primary (preferred) Notion. It should then be possible that any knowledge, expressed within the context of an integrated Frame, can be shared or communicated without any loss of content or intent. This potential needs to be explored further.

5.2 *Conclusions and recommendations*

The approach presented in this paper focuses on the cognitive principles that result in concepts. A method based on these principles may support a precise and unambiguous definition of concepts, not disturbed by different 'views' on a given subject.

It is not (yet) the purpose of this paper to suggest a method as an alternative for existing modelling methods. Such a development, and the examination of practical applications and their implications require further research.

The ideas presented in this paper are part of a larger theory that will be published later this year [Gielingh 2005].

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Provenance Metadata for Shared Product Model Databases

E. Petrinja & V. Stankovski & Ž. Turk
Chair of Construction Informatics, Faculty of Civil and Geodetic Engineering, University of Ljubljana, 1000 Ljubljana, Slovenia

ABSTRACT: The process of saving metadata committed to track all changes to some data, is known as "provenance". In the AEC/FM sector provenance data can be exploited for tracking all interactions of different users between each other and with parts of data. For a particular application, we need to consider which metadata are essential for future queries and who is going to use these. The IFC standard already contains some provenance concepts in its entity structure. We have considered these provenance concepts to build a provenance tracking software. The provenance ontology server was developed by using the OWL ontology language, already available IFC concepts and some complementary concepts that we had to include for the sake of generality of our implementation. The developed prototype allows us to upload an IFC file to a web enabled service that parses it and saves instances of retrieved concepts for later queries, according to the ontology we have defined.

1 INTRODUCTION

Managing AEC/FM projects is a challenging task, especially when it comes to the evolving tendencies to outsource different parts of a project to partners World-wide. Information technology gradually makes it possible to control these complex underlying processes. Computer aided engineering modeling standardization is an issue that has been largely taken in consideration in the past. Many standards have been adopted, the most important being the ISO 10303 family of standards (known with the acronym STEP). The Industry Foundation Classes (IFC - http://www.iai-international.org) standard has been developed specifically for the AEC/FM sector and is conforming to the STEP standard.

For the purpose of managing the product design process a considerable amount of metadata has to be saved along the project data. These data are important for future changes of the project, optimization of particular modeling methods, re-use of already adopted work methodologies and other important managerial issues. In this paper we refer to these metadata as "provenance" data. Few research projects have already considered provenance data from different prospective like myGrid and PASOA projects. We focus our research efforts to understand how it is possible to effectively extract provenance data from already existing IFC files and add some additional provenance information to these IFC data files.

In this paper we present the design and a prototype of a system for managing provenance data about IFC data files. A particular attention in the design phase was given to ensure interoperability of the system with other IFC enabled software products, such as ArchiCAD, Autodesk and others. The working prototype is available through a web browser and it is platform independent. It allows uploading of IFC files, it extracts provenance data from these files and it saves the provenance data in a persistent storage system, which was designed by using the MySQL (www.mysql.com) data management system. The provenance data is formatted and stored according to the conceptual model, which was built by converting specific IFC schema entities and functions like the ifcOwnerHystory entity into the OWL (www.w3.org/TR/owl-features) language, which was found to be well suited for this purpose. The OWL language is standardized by the WWW Consortium and it is used to define complex conceptual models, such as IFC. In the terminology of the OWL standardization work-group these conceptual models are also called "web ontologies". By using the OWL language it is actually possible to define axioms, concepts as well as instances of the concepts. The use of OWL has contributed a flexible and modularized system that offers a high level of interoperability with other already developed IFC compliant programs, which are used by engineers, architects and construction managers.

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2 THE PROVENANCE METADATA CONCEPT

A better classification of data present on the web was the main reason for the distinction between data and its presentation (Barners-Lee, 1997). Along the data we have to consider also metadata that describes it. Provenance data are just part of these metadata, which is concerned with the time of creation, change or deletion of a described data. These kind of metadata is usually referred to as provenance data. We can define provenance data from the end product view as metadata relating data to other data (Myers et al., 2003) or from the process view point as the documentation of the process that leads to some results (Groth et al., 2004).

The web gives us the opportunity to search millions of documents and it has given to researchers another opportunity of gathering data and knowledge in an effective way. However accuracy and trust in knowledge found is not assured as it was with paper based knowledge representation. Data from the web can be changed frequently and by different individuals, but rarely the changes are registered with appropriate metadata that is saved along the data or in other databases. Provenance data provides a traceable path to the origins of other peaces of data. Using an appropriate mechanism to save provenance data, we could solve partly the problem of trustworthy of documents found on the web. At the moment many partial software solutions already exist. Scientists can annotate in-silico experiments on their file system, into some databases or into an electronic notebook, but a standardized prescription of which provenance data is important to be saved and how to share it with others, is still missing.

Knowing what actions lead to a particular value of an element in the product model by saving provenance data of that transactions is important from at least the following viewpoints:

– Legal - Who is responsible?
– Professional - Why does it have such value?
– Managerial - Who is doing the work here?
– Re-use - Can we re-use the process next time we do something similar?

There are two different granularities of provenance metadata (http://www.nesc.ac.uk/esi/events/304) the course-grain and the fine-grain provenance. First refers to movement of data between different databases (Bunemanet al., 2000) in the process of creation of different curated databases. The second traces provenance data generated by workflow management engines and services enacted by a particular workflow. It is argued that the automation of provenance metadata saving mechanism is essential for an efficient tracking of all necessary information to make it possible to rerun workflows and to obtain already computed results by changing only a part of input data (Bose, 2002). Manually entering the information could lead to incomplete provenance documentation, moreover, people are not willing to spend a lot of time tracking and annotating such data.

Automating the process of tracking provenance data and saving it in different databases would allow us to save as much data as we wish or we think we could use in the future. However, there is a cost benefit in using provenance data for certain application. Saving huge amounts of data that could be used one day is not feasible. We have to decide which provenance metadata is really worth saving for future queries. Different provenance data consumers may need completely different parts of data. Besides, everybody has a personal view on the process tracked and registered by a particular part of provenance metadata. We are tempted to save all possible information that a process or a workflow produces. However there are limitations. It is possible to conclude that the amount of provenance metadata is different for every single application whether it is scientific or not. A standardized list of the important topics and parts of the process to be traced is necessary for all possible utilization of provenance metadata saving mechanisms.

3 RE-VISITING THE IFC STANDARD

The STEP standard for product model data is an effort to solve the long lasting and extremely expensive lack of standardization in the segment of product models and product models data exchange between various stakeholders of the manufacturing industry. STEP is now a mature standard implemented in almost all software applications covering single aspects of the manufacturing industry. It is well known in the USA where it is implemented in the AP-203 protocol and in Europe where it is implemented in a similar protocol named AP-214.

A representative group of software developers, information providers, engineers and other stakeholders founded the International Alliance for Interoperability (IAI) organization in 1994. Its main purpose is formulation of AEC standards that would be acceptable World-wide. The first release of the IFC standard was published one year after the foundation of the IAI organization. The main goal of the IFC standard is to achieve interoperability of various software products that cover different stakeholders in the AEC sector. The IFC standard was derived from the already existing ISO 10303 standard (STEP standard) and specified in the Express language (ISO 10303:11). The Express language was developed for conceptual modeling of domains within the field of product data. It was structured with a conscious attempt to avoid including constructs directed towards the ease of implementation or development of physical schemas. Its main constructs are entities that

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have associated attributes and constraints. The second are written using an expressive mix of a declarative and a procedural language.

The IFC standard has changed considerably since the first version. The actual up to date standard is the release IFC 2x2. Since the 2x release the standard core of the standard is fixed and only additional parts change over time.

Founding its initial formation on this already well consolidated and accepted standards, IFC had grew fast and it became a solid and trustworthy standard. It also uses many concepts from research and development projects in the area of information technology.

Its developers describe the four main axes along which the IFC standard extends. The axes are:

- lifecycle that explains how the standard tries to cope with the entire engineering process and every single stage connected with the modeling of a construction product,
- discipline where the objectives of the standard are, to make interact every discipline (or role) that is involved in the process of product modeling,
- the level of detail is also an important topic in the creation of the IFC standard because the vast array of concepts that are present in the AEC/FM information world is virtually impossible to include in a single standard and
- the software axes that is also a very important topic when there is an attempt to create a standard that allows complex interoperability between various applications.

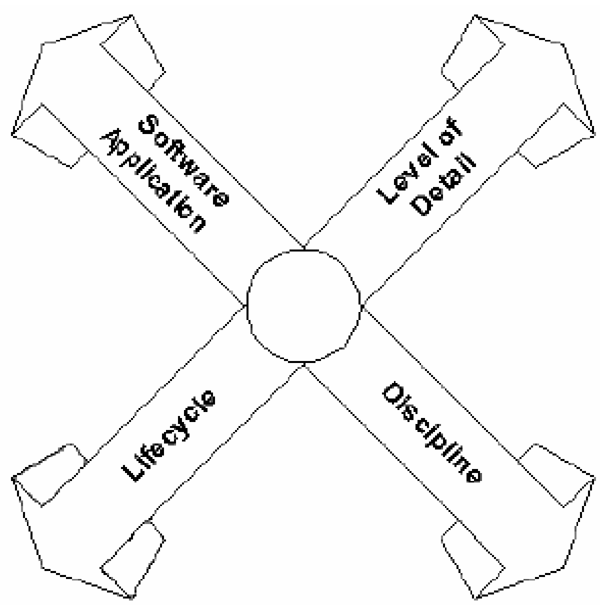

Figure 1. IFC Axes (source: http://www.iai-international.org)

The IFC model architecture is structured into four layers that are connected one with the other by the gravity principle (see Figure 1). Conceptually lower layers cannot reference objects from higher layers but the contrary is possible. The main four layers are (from the lower to the higher layers): Resources layer, Core layer that is subdivided into the Kernel part and the Extension schema part, the Interoperability layer and the higher Domain layer. The IFC kernel consists of the conceptually highest part of the model, all other concepts are specified by a particular concept from the kernel part. The central concept for all others that are specified, is the IFCRoot concept. Attached to this principal concept is also the IFCOwnerHistory. The first level of specialization of the root concept in the IFC standard represents three specific concepts that are:

- ifcObject which describes all physically tangible items,
- ifcPropertyDefinition representing the generalization of all characteristics of objects and
- ifcRelationship that objectifies all relationships that might occur in the model.

A similarity with the OWL ontology definition can be found in higher concepts of the IFC model. A more in depth view is presented in the ontology part of this paper. The ifcObject concept is devided into seven (second level of specification) sub concepts: ifcProduct, ifcProcess, ifcControl, ifcResource, ifcActor, ifcGroup and ifcProject. The ifcRelationship concept specifies into five sub concepts: ifcRelAssigns, ifcRelDefines, ifcRelAssociates, ifcRelConnects and ifcRelDecomposes. IfcPropertyDefinition is specified with two sub concepts that are: ifcTypeObject and ifcPropertySetDefinition.

All simple data types presented in the IFC model shall be specified as defined data types in our ontology.

From the release IFC 1.5.1 all software implementing the standard can undergo a testing process and if certain prescribed quality standards are meet, the software is appropriately certified. The software may be approved for a particular IFC release, different certifications for different applications and similar.

4 PROVENANCE ONTOLOGY CODED WITH THE OWL SYNTAX

Our provenance application relays on ontology technology that became an important research topic in the late nineties. The central role of ontologies is to keep semantics about every concept present in a particular domain. Frequently used definition of ontology is that it is an explicit formal specification of how to represent the objects, concepts, and other entities that are assumed to exist in some area of interest and the relationships that hold among them (http://www.doi.org/handbook_2000/glossary.html).

They were introduced in the so-called "Semantic Web Stack" as the central tool for saving the semantics in the envisioned future web (Berners-Lee, 1997).

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Two persons can communicate because they have a common understanding of the concepts they are talking about. We are thought first the basic and later more and more complex concepts about everything that is around us. We learn rules that govern the world around us every day. However these basic concepts do not change a lot from the principles we already know. There is a huge effort invested by every single person to learn and understand the common concepts. This makes him able to communicate with others that have learnt same or very similar concepts. Computers did not take advantage of this learning process in their past, so they can not understand what is written in simple text files for example.

There is also another problem concerning human to computer interaction. Namely, the natural language used by humans is extremely difficult to be used to define commands for computers (research is done in this sector as well), so a more formalized language has to be used. The amount of formalized computer programming languages that were defined in the last century is huge. XML is one of them. It defines the syntax to be used for expressing almost anything we would like. It is nowadays accepted as a general standard on which the envisioned Semantic Web is based.

In XML we can write a line in this way: <user>SomeName</user>. Using tags we delimit a part of the text that holds a word. We understand that the word SomeName must be a name of somebody is using something, because we have the common concepts understanding in our minds, but to the machine it does not mean anything, unless we have a definition of the tag <user> written in a document that is accessible to the machine. Many different languages for expressing ontology concepts have been used in the past, some of them are: FLogic, OCML, LOOM, OKBC, Ontolingua, KIF, RDF(S), OIL, DAML+OIL and the most recent OWL. We can define the meaning of a concept in an XML file also by using the DTD notation or the XML Schema, but ontologies are much richer in these semantic expressing power. The OWL Web Ontology Language was designed for use by applications that need to process the content of information instead of just presenting information to humans. It has evolved from the former ontology language DAML-OIL and facilitates greater machine interpretability of Web content than that supported by XML, RDF, and RDF Schema (RDF-S) by providing additional vocabulary along with a formal semantics. OWL has three increasingly-expressive sublanguages: OWL Lite, OWL DL, and OWL Full. Using it there are almost no concepts we can not describe. However, the OWL Full expressive power is so great that it does not guarantee computability when DL logic rules are applied.. OWL DL on contrary is a bit more restricted and less expressive but it complies with DL logics rules and can be processed in different forms. We had used the OWL DL notation for expressing the provenance ontology used in our application.

Many different tools and toolkits for building and managing ontologies have been developed so far.

We used the Protégé application (http://protege.stanford.edu) that was developed at the Stanford university and it is now available as version 3.0. At the moment it is probably the most elaborate and complete toolkit for managing ontologies. For the purpose of our application simple text OWL form of the ontology was used and Protégé allows exporting the entire ontology project into the desired owl format. Additional editing is possible with a simple text editor application. With one of the many graphical plug-ins that are available for Protégé, the ontology can be represented in a more understandable graphical format.

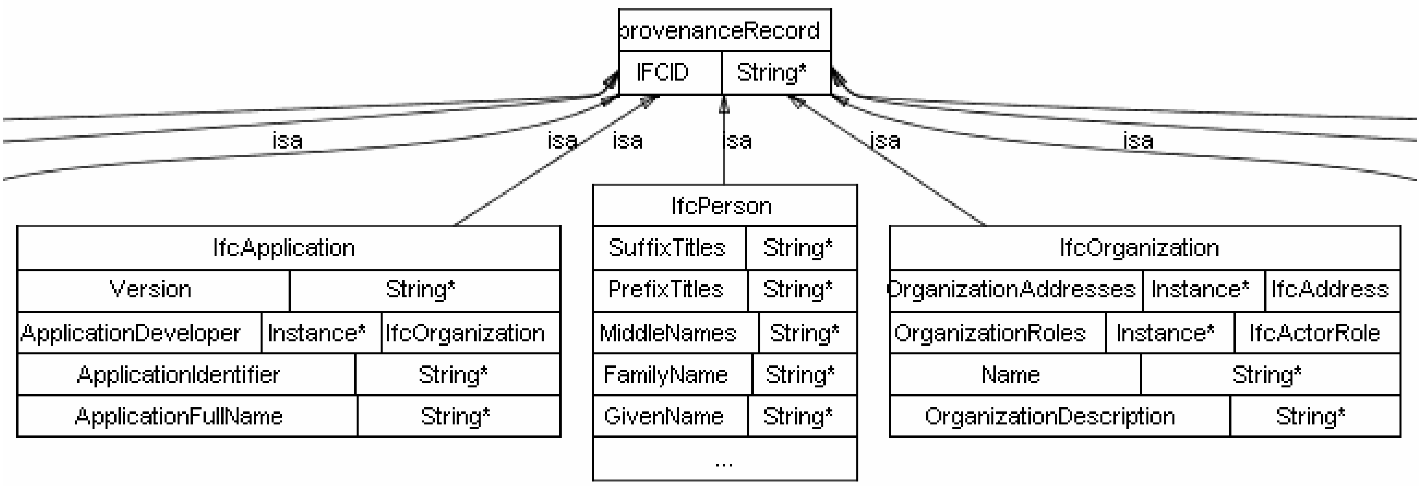

Figure 2. Provenance ontology

In our application we defined a relatively simple ontology that was focused on only some IFC entities concerning provenance concepts. The main goal in the development of this prototype application was to reuse the already available concepts defined in the IFC standard and implemented in various IFC com-

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pliant applications already available to the community. First we decided to limit the scope of this application to the IFC schema version 2.0 mainly because the last ArchiCAD application version is based on this schema as well. It is largely used also by many other IFC compliant applications (as Autodesk ADT, Visio…). A more general development taking in consideration all IFC schemas available (at least the last three versions), will be an issue for future work. For the purpose of our research we restrained ourselves to entities in the IFC schema that are considered useful for some provenance data tracking. The main entity of the IFC standard describing concepts close to provenance data is the ifcOwnerHistory entity (as already mentioned before) and few sub entities. The fact that this entity is attached to the root entity makes it a very largely utilized concept of the schema, because every single instance of an entity defined in the IFC schema can have some data that is connected to the ifcOwnerHistory entity. Root properties are inherited by all sub entities and by their instances. Interesting ifcOwnerHistory sub entities are ifcAuditTrail (7), ifcTransaction (3), ifcApplication (4), ifcOrganization (4), ifcAddress (13), ifcActorRole (2), ifcPersonAndOrganization (4) and ifcPerson (6). The number near each entity name is the number of attributes of every single entity that is defined in the IFC standard and one by one included into our ontology.

In the IFC standard these nine entities form a subtype super-type tree but for a better management of instances we gathered them at the same level under the provenanceRecord concept in our ontology. Our ontology root concept provenanceRecord has only one property that is the IFCID number present at the beginning of every line of an IFC part 21 file. OWL ontology parent properties are inherited by all sub concepts, and the IFCID property is thus present in all provenanceRecord sub concepts. It could be also possible to add to the provenance ontology some comments or annotation concepts that are usually present in the provenance data, however, this was not essential for our research. Our aim was to combine IFC entities with an ontology centered provenance server. However for a more complete provenance server, such concepts would be a useful help to server users. Properties defined in the IFC schema are of different types. They can be simple data types as Strings, Integers and others or relational types that connect to other entities present in the IFC schema. Similarly we can define two different types of properties in OWL ontology: DataType properties and Object properties. The properties used by our prototype have been appropriately mapped between the schema and the ontology.

Part of the ontology is visible in the simple text form and part in a graphical representation visualized by the Protégé plug-in.

```
<?xml version="1.0"?>
<rdf:RDF
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
   xmlns:owl="http://www.w3.org/2002/07/owl#"
   xmlns="http://www.prov.org/prov_IFC20.owl#"
  xml:base="http://www.prov.org/prov_IFC20.owl">
  <owl:Ontology rdf:about=""/>
<!-- Classes -->
  <owl:Class rdf:ID="provenanceRecord">
  </owl:Class>
  <owl:Class rdf:ID="IfcPersonAndOrganization">
    <rdfs:subClassOf rdf:resource="#provenanceRecord"/>
  </owl:Class>
…
<!-- ObjectProperties -->
  <owl:ObjectProperty rdf:ID="OwningUser">
    <rdfs:domain rdf:resource="#IfcOwnerHistory"/>
    <rdfs:range rdf:resource="#IfcPersonAndOrganization"/>
  </owl:ObjectProperty>
…
  <!-- DatatypeProperties -->
  <owl:DatatypeProperty rdf:ID="IFCID">
    <rdfs:range
rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
    <rdfs:domain rdf:resource="#provenanceRecord"/>
  </owl:DatatypeProperty>
…
<!-- DatatypeProperties -->
  <owl:DatatypeProperty rdf:ID="TransactionDate">
    <rdfs:range
rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
    <rdfs:domain rdf:resource="#IfcTransaction"/>
  </owl:DatatypeProperty>
</rdf:RDF>
```

Figure 3.Part of the ontology coded in OWL language

5 THE PROVENANCE DATA SAVING SERVER

Our aim was to develop a prototype provenance server application that would be available through a simple web browser, that it is an essential part of almost any personal computer today, so that our application is accessible to virtually anyone having an internet connection, a browser and can go online. This envisioned goal has led us in the process of deciding which technology to use in the implementation of the prototype. A web application can be utilized by users that use different operating systems and/or computers architectures.

Examination of these requirements led us to the decision to use the Java programming language for the development process. However Java alone is not enough for writing a web enabled application so we wrote the web part of the prototype with JavaServer pages language combined with simple html. We used Jakarta Tomcat for simulating a local server.

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This servlet container can be used as an effective online web server. JSP applications are usually structured with some html/JSP pages and some javaBeans that are pure java classes. JSP is like a bridge between the vastly utilized html representation of data on the web and a powerful programming language as Java is.

The central part of our prototype is relaying on the Jena API (http://jena.sourceforge.net). It is a java framework for building semantic web applications. It provides classes and methods for creating and managing RDF, RDFS and OWL documents. The entire framework includes different semantic web concepts and tools:

– RDF API
– Reading and writing RDF in RDF/XML, N3 and N-Triples
– OWL API
– In-memory and persistent storage
– RDQL – a query language for RDF.

We did not use the RDF specifications connected APIs for our prototype, nevertheless because of the integration of different classes inside the Jena framework, the OWL API relies strongly on the RDF API and the main model structures in OWL model schema are inherited or specialized from RDF classes. To achieve our goal we used the persistent storage mechanism supported by Jena (see Figure 4). The rationale is as follows. The envisioned prototype must be able to store enormous quantities of data that must be accessible as quickly as possible. A persistent database storage mechanism is almost obligatory for storing big quantities of data. IFC part 21 files are usually very large. A common single family residential house project like the one we used as a test example had nearly one hundred thousand lines of Express language syntax code. A file based storing mechanism can be good for testing the prototype, but it could have some serious efficiency problems with real life project data. Jena supports three different database systems (MySQL, PostgreSQL and Oracle). We implemented the prototype using the MySQL database management system.

In Jena it is possible to create an ontology model (OntModel) that is an extension of the Jena RDF model. The default model uses OWL Full as the ontology language, so we had to consider the limitations we wanted to take into account for the OWL DL language. By simply using the modelFactory method we create new models. Later we can import already available models from some files or from the persistent storage in a database system (MySQL in our case). If parts of the ontology are not jet created, we can model them according to our needs and append them to the model. The most important objects we can insert into an ontology model are ontology concepts, properties, restrictions and instances. All four objects are derived from the OntResource super class and thus have a common insertion and modification procedure. The OntResource is by itself a Java interface that extends the Jena's RDF Resource interface. Ontology models can be interfaced by the Jena graph to a reasoner that is not predefined. It can be an external application run separately from the central application and can answer user queries. Our application's queries were predefined by ourselves and integrated into the main application class. A separate reasoner was not necessary. However, for future development of the prototype we will have to consider which reasoner would better fit our needs.

In Figure 4 we can see the entire architecture of the prototype. The central part is represented by the main Java class that is physically a compiled .java class saved in the class folder of the Tomcat deployment folder. All necessary java libraries must be placed in the lib directory where we have copied also the Jena API classes. We decided to keep the entire provenance server application coded in a single java file. For a more complex prototype, an appropriate code split mechanism should be adopted.

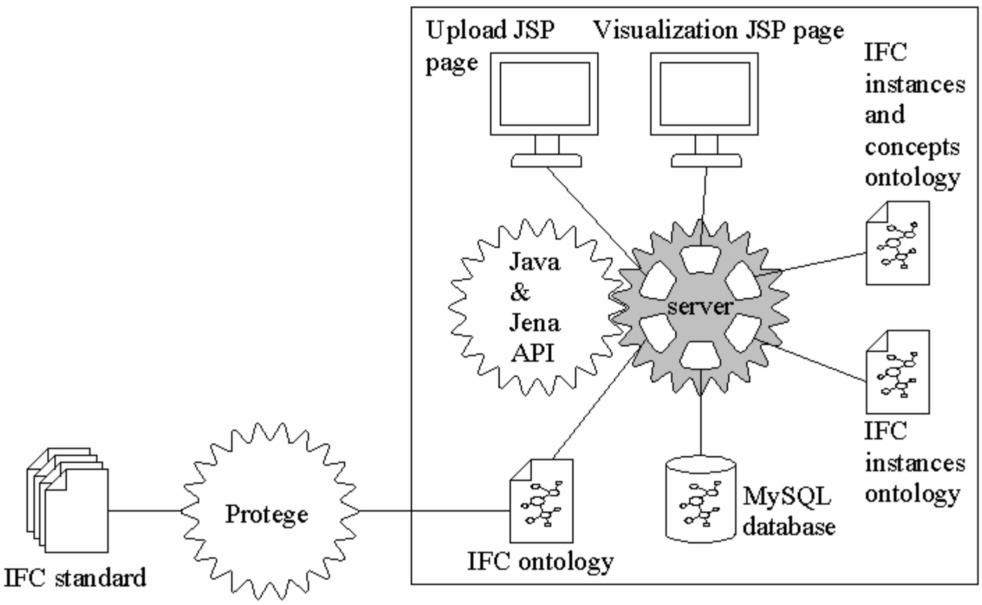

Figure 4. Prototype architecture

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In Figure 4 we can see that there are three ontology files and one file, which is database enabled. The main OWL ontology of the IFC version 2.0 LONGFORM schema is saved separately from the instances. Keeping separately ontology concepts, properties and rules from the instances, we have a clearer picture of the ontology structure and we can reuse the ontology without the instances. Nevertheless the amount of data instances could be considerably greater than the classes and properties part of the ontology. Keeping them separate is thus a smart decision and the Jena toolkit supports this practice. The IFC version 2.0 concepts ontology were prepared as already described and the file saved along the main java class file. Instances files are created during the process of data uploading by the prototype. For the control reasons of the prototype, we allowed the application to create an OWL file with both the concepts and the instances together in the same file. We can import this file easily into the earlier mentioned ontology application Protégé, where we can check the correct instances saving process. This file is created only for the purpose of checking the prototype coding and it will be of minor importance to an end user.

The main repository of instances is saved into the MySQL database. Jena creates automatically tables necessary for its proper functioning and saves instances in a RDF triplet form. It saves separately subjects, objects and predicates. By uploading different IFC files, the server creates separate tables and names them according to the name of the just uploaded file. Instances are all created from a single instance class, so we had to invent a mechanism to keep their identity unique. Thus a mechanism for keeping their identity unique was necessary. We included a unique number in the name of every single instance that is present in each line of a document written in the Express language.

Two JSP pages were created. One for uploading IFC files and the other for queering it and visualizing the provenance data stored in the uploaded files. A more efficient and rich tools are planed for the future development of our provenance prototype. Figures 5 and 6 represent the upload and the visualization screenshots.

The core of the server application is a parser that extracts data from the uploaded IFC files and saves them according to the defined ontology in appropriate instance elements in a database. We have conducted an extended research to find an already implemented parser for IFC files coded in java language, but we have found only some limited versions available on the web. For this reason, a new provenance data extraction mechanism was implemented. We wanted the server to collect only data concerning provenance data saved in the processed files. The application finds first just the lines containing provenance data then it finds out what kind of data is written in each line by matching it with the information retrieved from the uploaded ontology and than it saves each part of the data in separate variables according to the same ontology. The IFC schema defines exactly which part of data can be saved in a particular position of each line. It is thus straightforward to match the extracted data with the correct ontology properties.

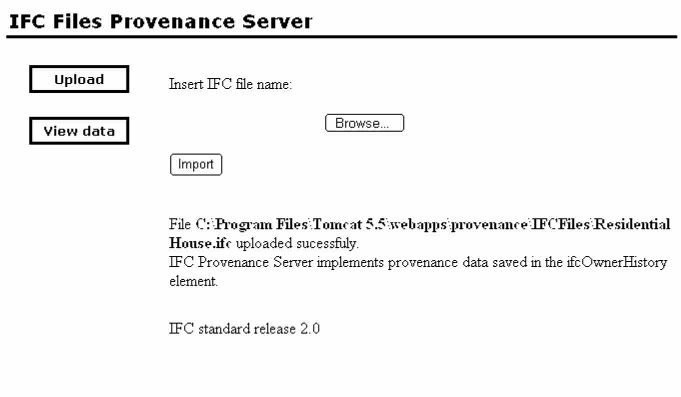

Figure 5. IFC Files Provenance Server Upload screenshot

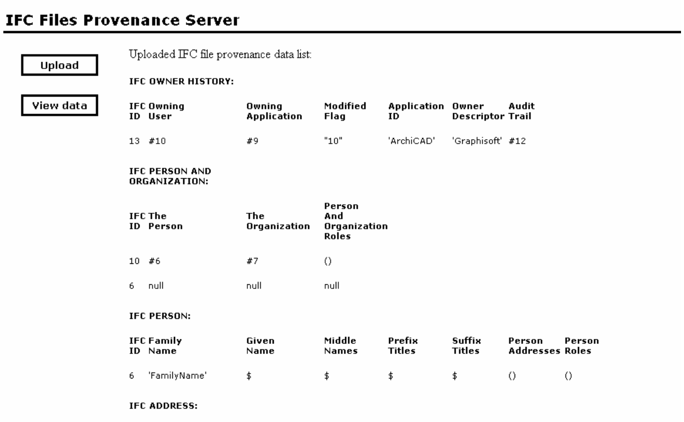

Figure 6. IFC Files Provenance Server Visualize screenshot

6 CONCLUSIONS AND FUTURE WORK

The paper is concerned with the relatively new research area of provenance data management. Collecting metadata about events occurring in the process of modeling, an AEC/FM product can be of great importance to the future reuse of some already used or developed methods and methodologies. It can make possible a more reliable truth conformance checking mechanisms and can help avoid unnecessary mistakes in future similar projects. An important research part of the work presented in this paper is the utilization of ontologies to save and manage provenance metadata. By dividing the conceptual and the instances part we can manage the repository better and can use different ontology concepts or entire ontologies within the same database and the same provenance management server prototype. The central part of the prototype presented, was the web enabled IFC files management system. Provenance

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data is extracted from the uploaded files according to the conceptual layer stored in the ontology and saved into the MySQL database. The saved data can be queried and visualized in a web page as well.

Future work will regard the full implementation of the provenance server with other functions and the support to at least three last versions of the IFC standard schema. We will try to make it possible to query the provenance repository in more sophisticated ways. We would like to produce web centered system for saving additional data as well, along the already implemented functions extracting and saving IFC provenance data.

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An Ontology Web Language Notation of the Industry Foundation Classes

J. Beetz, J. P. van Leeuwen & B. de Vries
Eindhoven University of Technology, The Netherlands

ABSTRACT: In this paper we describe and discuss an OWL notation of IFCs, its advantages over generic XML schema representation, its various fields of possible application, and our implementation of it in a multi-agent framework.

1 INTRODUCTION

1.1 Problem domain

Formats for integrated building models for the description of buildings covering their complete lifecycle have been a major topic in the ICT/AEC research community (Amor et al. 1995, Eastman 1995). The actively ongoing effort of the International Alliance for Interoperability (IAI) to bring together various software vendors and research institutions has led to a standard that is increasingly accepted by the AEC/FM industry: The Industry Foundation Classes (IFC). While the main means of data modeling for this format have been the ISO certified STEP and EXPRESS (ISO 10303) languages, recent developments introduced eXtensible Markup Language (XML) technologies into the process. Data modeling and processing with XML has been embraced by other industries and a number of initiatives have led to the adoption of XML as core technology for the exchange of business relevant data. Although the AEC/FM industry is traditionally fragmented and slow in embracing new technologies, a number of initiatives (ifcXML, aecXML, BLIS-XML, bcXML and others) have aimed to extend, integrate or complement IFC with XML. However useful and promising these developments are, the use of XML does not constitute a virtue in itself.

Although the biggest advantage of XML is its standardized, well-formed and plain-text nature which enables developers to read and understand it and to work with it in a vast collection of (freely available) tools, it requires a significant amount of engineering, manual work and coordination to enable interoperability. The reason for this is that XML does not solve the problem of semantic interrelationships of data models.

To further automate development processes and enable high-level processing of data, the Semantic Web (SW) initiative has opened the door to a new era of 'intelligent' data exchange "in which information is given well-defined meaning, better enabling computers and people to work in cooperation" (Berners-Lee et al. 2001).

In order to create this machine-readable meaning, the underlying expert knowledge has to be encoded in high-level classifications (ontologies) in standardized ways. The W3C has recommended to use the Ontology Web Language (OWL) (Bechhofer et al. 2004) that is based on the Resource Description Framework (RDF). OWL allows suitable tools to reason on data and to draw conclusions from the statements made about a specific subject, such as a building.

One of the most promising applications of this technology is the creation of web services (McIlraith et al. 2000) and agent based systems (Weiss 2000) to introduce new means of distributed collaboration for the AEC/FM industry. In such a scenario, expert domain knowledge such as building standards, product databases or even structural calculations could be encoded in the form of expert agents or web services that are automatically discovered and consulted. The paper describes how the OWL representation of IFCs forms the basis for the creation of such agent systems that represent building elements and services as well as building expertise. The introduction of formalized rule sets (i.e. using the Semantic Web Rule Language (SWRL)) and agent based services is within the scope of our future research.

In this paper we present and discuss the work that was done on the derivation of an OWL ontology

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from the EXPRESS Schema of the Industry Foundation Classes version 2x2.

2 MOTIVATION

Several researchers within the AEC/FM community have identified multi agent based systems as a promising technology to assist (distributed) collaboration, decision making and design. Several promising prototypes have been implemented and demonstrated the potential of this technology in various fields (Meißner et al. 2004).

The classic architectures of software agents rely on the ability of any single agent to reason about the outside world based on an internal representation that it keeps of the outside world. Furthermore, in multi agent systems agents must be able to communicate with each other about some aspects of their environment, beliefs or plans. This makes it necessary to rely on common concepts about the outside world and the ability to communicate about them in shared language.

An ontology is "a formal specification of a shared conceptualization" (Gruber 1993, Borst et al. 1997). Data models – even if they are as feature-rich as the ones described in EXPRESS and UML - should not be confused to be the same as axiomatic theories about "the things that are" (ontologies). However, creating a hierarchical, relational model to store data as has been done in the IFCs constructs such an ontology as a side-effect.

Rather than crafting special purpose ontologies and language codecs for multi agent system, the large body of knowledge that has been built up by the IFC community over the years could be used.

Outside of agent systems, the notation of AEC/FM content in an XML-based ontology description format like OWL can be used for various applications within the Semantic Web context:

– Information discovery and retrieval. Distributed information such as building related product catalogues, maintenance information for FM purposes etc. can be indexed and searched including their semantic relations.
– Semantic Web services. Complex services, such as building physics simulations could be wrapped into web services describe how to interface and interpret themselves.
– Distributed data storage: Unlike EXPRESS based models, information in XML can be stored in different physical locations and later be linked together.
– Mapping into other description formats: with several existing standards and data models in existence, mapping in an n-n manner is much more demanding than mapping to a pivot ontology. An IFC based ontology of AEC/FM content with its large set of nodes could be a candidate for such an pivot ontology.

Furthermore, an OWL-based description of the IFCs has some advantages over EXPRESS-based and XML Schema based methods:.

– User base: Compared to STEP EXPRESS based technologies with their small user base and its niche market character, XML is a widespread technology with a vast set of existing tools that could significantly ease the development of new tools by smaller companies and research institutions.
– Predefined relations, restricted constructs and expressiveness: Although there is often more than one solution to model a certain concept in OWL in different ways, the set of possibilities is more limited than on the lower levels of the language stack (XML, XMLS, RDF/RDFS). This helps to establish a commonly used "best practice" model and hence helps avoiding fragmentation of standards.

3 RELATED WORK AND RESEARCH

Creating an XML notation of EXPRESS part 28/21 has been on the roadmap of the ISO TC184/SC4 for quite some time now, and several implementations are available. However, one of the weaknesses of an XML schema approach, is that some of the expressiveness of the EXPRESS Schema definition language is lost. Another approach lies in the translation of STEP part 21 into an XML notation of the Unified Modeling Language. Although much more straightforward and strict, some language constructs just cannot be translated.

An open source implementation of an EXPRESS-OWL transformer has been created for the Oil and Gas production facilities ISO 15926 in the context of the OMPEK project by (Batres et al. 2005) Based on the open source "osexpress" parser, a basic transformation into OWL using the Jena API has been created. Although some language constructs are still missing, a basic ENTITY/class hierarchy along with some properties of the IFC schema can be created with it. To date this is the only Open Source tool available.

Lima et al. (2004) have created an EXPRESS-to-OWL-transformer as part of the FUNSIEC project. Again, the output of the transformer is limited to the purposes of the project (mapping between different ontologies).

The free set of tools that have been created by the exff.org team around David Price and others approach the translation effort by cascading XSLT transformations via UML/XMI (Price & Bodington 2004).

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In the context of the e-COGNOS (Lima et al. 2003) project, an ontology based on DAML+OIL (the predecessor of OWL) was created describing building and construction related concepts in a multilingual way.

4 UNDERLYING TECHNOLOGY

4.1 STEP EXPRESS

The Standard for the Exchange of Product Model Data (STEP) that is described in the different parts of the ISO 10303 has been the key technology in the exchange of data within many large industries for a very long time. The definition of objects, their relations to other objects and their constraints are defined in the EXPRESS (ISO 10303 part 11) language. This very powerful means of data modeling was developed in the early 1980s predating UML and XML. It was aimed at being a flexible, extendible and scaleable modeling language easy to be read by human experts. However successful in many industries, only a very limited amount of developers is familiar with it. Simple examples of EXPRESS schemas include classes with primitive types like

```
ENTITY door;
SUBTYPE OF (buildingPart)
  height: REAL;
WHERE
  WR : height > 0;
END_ENTITY;
```

Describing a concept door that in addition to everything inherited from an existing concept “buildingPart” has a property height of the primitive type ‘REAL’ that is constraint to values greater than zero.

4.2 RDF/RDFS

The Resource Description Framework (RDF) and its schema definition extension (RDFS) are XML-based description and modeling formats that have gained increasing popularity in recent times. It is based on simple predicate-subject-object triplets connecting any two resources (subject and object). By making statements about statements, very complex descriptions can be built up. The resources themselves are denoted by uniform resource identifiers (URI). Since URLs are a special form URIs, data models and instance data based on them can be distributed over different physical storage locations. This is a clear advantage over STEP where no distribution is supported. Since RDF is not designed to be understood by human readers, a schema language (RDFS) was added that introduces predefined constructs, such as classes, properties and constraints, making modeling of complex concepts easier.

4.3 Description Logics

Description Logics (DLs) are a set of formal languages to represent knowledge in a certain domain based on atomic concepts and roles. The roots of DLs lie in first order predicate logic. They are the basis of ontology description languages such as OWL.

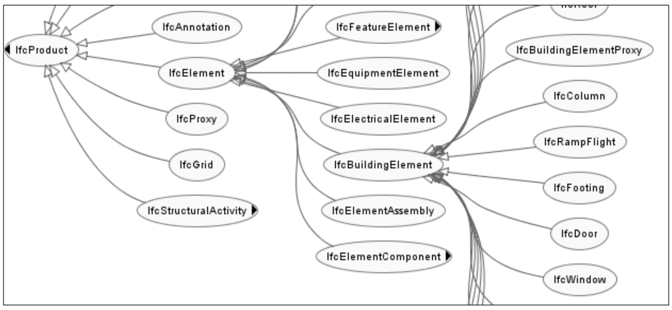

Figure 1. Extract from a simple class hierarchy of the IFCs in OWL.

4.4 OWL

Based on and extending RDFS the W3C recommendation for the description of ontologies, the Ontology Web Language (OWL) has received a lot of attention over the recent years. Historically it has evolved from the description logic language SHIQ (Horrocks et al 2003). The current grammar and syntax has evolved from the DAML + OIL (McGuinness et al 2003), the result of the joint efforts of American (DARPA Agent Markup Language – DAML) and European (Ontology Integration Language – OIL) projects. It comes in three different flavors of complexity and expressiveness:

– OWL lite, with some basic extensions to RDFS introducing property restrictions, universal and existential quantifiers
– OWL DL, adding enumerated classes, boolean combinations of classes and restrictions, the concept of disjointness and full cardinality.
– OWL full, sharing the same vocabulary as DL but removing some limitations from DL.

With the amount of freedom and expressiveness that each layer adds, the decidability for reasoning engines and the compatibility to other Semantic Web applications is limited down. For a discussion on decidability see (Heflin 2004).

OWL as well as RDF(S) models can be written in two different syntaxes, with the XML-based version intended for actual web use and the N3 notation for easier consumption of human readers.

The small example given in an EXPRESS model above could be expressed in OWL as follows:

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```
<owl:Class rdf:ID="buildingPart"/>
  <owl:Class rdf:ID="door">
    <rdfs:subClassOf
rdf:resource="#buildingPart"/>
    <rdfs:subClassOf>
      <owl:Restriction>
        <owl:cardinality
rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
        >1</owl:cardinality>
        <owl:onProperty>
          <owl:DatatypeProperty rdf:ID="height"/>
        </owl:onProperty>
      </owl:Restriction>
    </rdfs:subClassOf>
  </owl:Class>
  <owl:DatatypeProperty rdf:about="#height">
    <rdfs:range
rdf:resource="http://www.w3.org/2001/XMLSchema#flo
at"/>
    <rdfs:domain rdf:resource="#door"/>
  </owl:DatatypeProperty>
```

In the above example, each door is said to have exactly one property height. But what about the constraint that is given in the original EXPRESS schema, that every door height must be greater than zero? For some datatypes, these kinds of restrictions can be expressed by setting the datatype to the according XML schema type, such as xs::nonNegativeInteger. In this case, no such restricting type exists for floating point values in the standard. While this easy problem might even be solved on the XML schema level, there are a number of more complex rules used as constraints in the IFCs that require an additional level of definition. For this purpose, the Semantic Web architecture introduces an additional layer: rule languages.

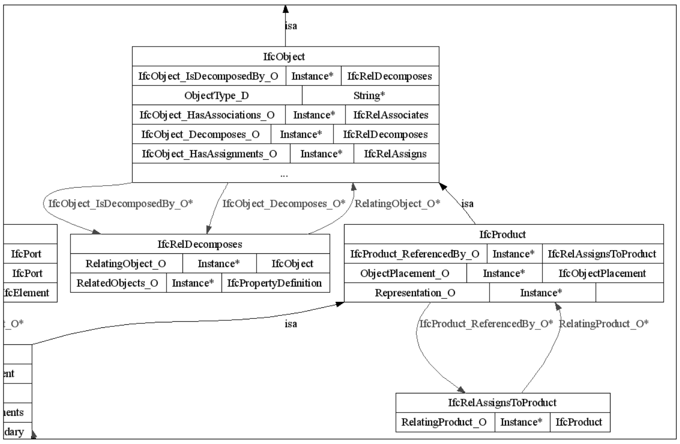

Figure2 Excerpt from a graph visualizing slots of the OWL model of the IFCs

4.5 *RuleML/SWRL*

The Semantic Web Rule Language (SWRL) combines OWL with a subset of the Rule Markup Language developed by the RuleML initiative. It has been submitted for comments to the W3C and will eventually become a full recommendation. With SWRL, complex rules can be defined in a standardardized way, enabling reasoners to check constraints or infer 'new' knowledge from a given ontology[1].

The flexibility and expressiveness of SWRL will allow most of the EXPRESS constraint to be modeled. The fact that even some basic numerical computation can be described for a reasoner to solve is promising for this purpose. For the above case a formal notation might look like this:

```
door(?x) ^ hasHeight(?x,?height) ^
swrlb:greaterThan(?height, 0)
-> WR1(?x,true)
```

EXPRESS construct	OWL construct
ENTITY	Class
SUB/SUPERTYPE	subClassOf
SELECT	Class and subClassOf
INVERSE	inverseOf / InverseFunctionalProperty
ENUM	DatatypeProperty […] owl:DataRange […] owl:one of […] rfd:List or enumerated classes.
Cardinality constraints	owl:cardinality, owl:minCardinality, owl:maxCardinality
Simple Types	Simple XML Schema types
WHERE domain rules	Possibly through SWRL rules in future
collections: LIST, SET, BAG, ARRAY	Only unordered (?)

5 TRANSFORMATION

Two different approaches to derive an OWL notation of the Industry Foundation Classes have been taken in our research:

5.1 *OWL from XML schema via XSLT*

In this approach we created an XSLT file that can be used to transform the Part 28 XML schema (XSD) of the IFCs 2x2 into an OWL file. In the XSD solution, some basic elements and attributes that are common for all concepts are defined externally on a lower level.

One of the obstacles to overcome to achieve a transformation is the difference in element order and nesting between XML Schema and OWL: XML files that are compliant to a certain schema must strictly adhere to the element order and nesting modeled in the schema. In RDF files and consequently in OWL, the order of elements and their position within a single file or even their storage location can be chosen freely (i.e. a property of a class

[1] The classic example of such an inference is the uncleOf property: If an individual x has a father y who has a brother z then the individual z is the uncle of x.

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can be defined in another file on another server. On the one hand this has some advantages when creating derived knowledge representations; on the other hand, this introduces many consistency problems. A clear advantage over proprietary parser/transformers (as in the second approach) is the ability to use standard tools for the transformation, as the set of XSLT features that was used was kept compatible to most of the popular engines. Furthermore, the same strategy can be used when handling instance data.

Although the complete ENTITY/class hierarchy found in the XML schema notation of the IFC can be transformed into OWL along with all of the constraints, the information being lost while deriving the XML notation was reason enough to attempt a second approach, trying to capture as much of the underlying knowledge encoded in the original EXPRESS schema as possible.

5.2 *OWL from EXPRESS schema*

In this second approach the OWL notation is derived directly from the original EXPRESS schema format of the IFCs. This made the creation of a proprietary parser necessary, which was build on top of the java/ANTLR-based lexer provided by the open source osexpress (Luebell 2001 and Parr & Quong 1995) project. With this approach, we are able to make use of the full range of EXPRESS constructs. To date, we have implemented most of the basic types, relations (including the reverse relations that are not captured in the XML schema), enums and cardinality constraints. This results in an ontology with over 850 classes and more than 4000 overall frames[2].

The most important advantage of this approach over the intermediate XML schema translation is, that with it, it is possible to maintain all the additional knowledge that is captured in, e.g., the over 300 WHERE domain rules in the core model and that is not transferable into XML schema.

6 CONCLUSIONS AND FUTURE WORK

In this paper we have presented and discussed two approaches to derive an ontology in the OWL notation from the Industry Foundation Classes modeled in EXPRESS schema. We have outlined the potential of such ontology in the context of multi agent systems and the broader context of various future Semantic Web applications. We have shown, that much of the knowledge that has been created by the effort of the IFC community can be captured and used with the large set of (free and open) tools that are under active development by the large community around the Semantic Web. Furthermore, we have shown how upcoming standards such as SWRL are potentially well suited to capture even complex constraints, which is not possible with lower level modeling standards such as XML schema alone.

Ongoing and future research is aimed at using this ontology both as internal representation of domain expert agents in collaborative design scenarios and as a language codec for the inter-agent communication in multi-agent systems. In this context we will also have a look at how this ontology might be used as a pivot ontology for the mapping between various other models such as the ISO 12006-3.

[2] The ontology has been validated by the WonderWeb and the Pellet validators

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Question-Answer system for object-oriented analysis and design

P.I. Sosnin & E.P. Sosnina
Ulianovsk State Technical University, Ulianovsk, Russia

ABSTRACT: This paper describes the results of studies and implementations which can add basic Rational Unified Process (RUP) flows by a special workflow to support "Interaction with experience". Such workflow is developed with orientation on RUP on the basis of a special NetWIQA system that supports question-answer reasoning of a design team. NetWIQA allows designers to create the drafts of the basic RUP samples for their subsequent coding and use in RUP environment or without reference to RUP; set of samples based on the protocol of QA reasoning, its analysis and necessary transformations. NetWIQA is the client-server QA processor with the special command system.

1 INTRODUCTION

The Rational Unified Process (Kroll & Kruchten, 2003) and relative systems of object-oriented analysis and design (OOAD) characterize the modern approach to Computer-Aided Design. Such means give designers an interactive access to useful patterns and sample actions, and it is used to manage the design activities and to borrow the necessary samples with the purpose of their rational implementation in the process of designing and its results.

The RUP gives us the access to normative models of design experience and knowledge prepared to be used in a corporate network. The models of experience in RUP are the richest source of questions, e.g. questions checking conformity of the project to the appropriate standards; questions, which provide personal and collaborative understanding, rational decision-making, and etc. Such questions are invariant to the contents of the project, but are very important in designing.

Unfortunately, RUP has no effective means for current work with questions and answers presented as human reasoning, i.e. reasoning of designers. At the same time reasoning is the basic way of interaction of people with the design experience and its models.

Those OOAD systems, in which interaction with the experience is realized obviously, e.g. in BORE system (Henninger, 2003), use methods and means of access only to typical decisions and are based on Case-Based Reasoning (CBR) approach.

Below we submit the results of our studies and implementations which can add basic RUP flows by a special flow to support "interaction with experience". Such workflow is developed with orientation on RUP (but irrespectively of RUP) on the basis of a special NetWIQA system that supports question-answer reasoning (QAR) of a design team in a corporate network.

2 RELATED WORK

The domain of our study includes the similar works with experience, knowledge and its models, e.g. Rational Unified Process and similar techniques of automated design; Question-Answer techniques and systems; presentation and processing of experience in Case-Based Reasoning approach to computer-aided design.

RUP and other OOAD toolkits effectively solve the task of processing of patterns and templates (Galic at al., 2000), i.e. every pattern being the certain model of experience presents one of the typical project decisions to be applied in other projects. At the same time RUP structure has no means to support the work with personal knowledge and experience of the every member of a team and collaborative knowledge. The concept and term "Experience" is not practically used in RUP documents and papers.

Last years we have observed a growing interest to Question-Answer (QA) techniques and systems. Many important scientific and practical results were obtained in several domains, e.g. in retrieval of relevant information in distributed, multimedia, multilingual and multi-agency data sets; in automated

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learning in traditional and distance education; in automated design and decision-making in the different areas. But despite more than 40 year studies “we are just beginning to explore question-answering as a research area” (Hirschman & Gaizauskas, 2001). The main directions of QA research are named in the Roadmap Paper (Burger et al., 2001) and focused on: question taxonomies, its understanding, ambiguities, and reformulations; context and data sources of QA; real time and interactive QA; advanced reasoning and user profiling for QA.

At the same time the directory of IBM papers (www.redbooks.ibm.com) mentions the concept QA, or Question-Answering, only 4 times and doesn’t mention the QA work with human experience at all.

Question-Answering systems are also implemented in the work with knowledge and experience in Case-Based Reasoning techniques (Yang at al., 2003; Han at al., 2003; Branting at al., 2004). We consider these approach to be one of the main solutions, which provide the effective modeling and processing of knowledge and experience in Artificial Intelligence domain.

At last, we would like to mention the system BORE (Building an Organizational Repository of Experience) as one of the most related toolkits (Henninger, 2003) to our study, but BORE application of QA is limited to the set of pre-conditions for working with the necessary rules of technique.

3 INITIAL STATEMENTS

Our purpose to develop automated means of interaction with experience is caused by a number of reasons, e.g.:

1. We are sure that modeling of experience is much more important than modeling of knowledge for future development of Artificial Intelligence.

To prove it we should realize that human intelligence appeared while evolution, and was an answer to a question "What can add the genetic forms of experience?" While its evolution, Intelligence got the functions of self-organization, self-development, transfer and use of out-genetic components of experience.

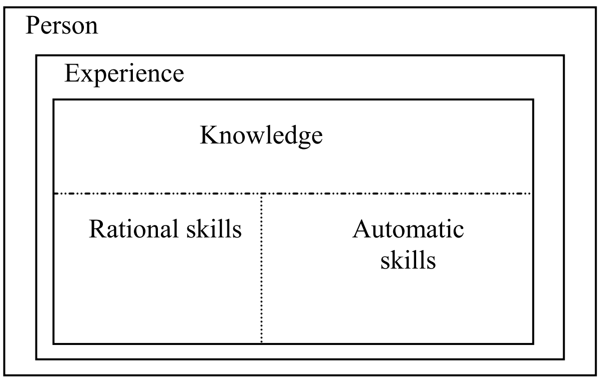

Figure 1 Experience and knowledge

The basic function of Knowledge, being the main part in the structure of Experience (Fig. 1), is its ordering, which increases efficiency in accessing to the components of experience, e.g. rational skills and automatic skills. We consider that the studies in AI domain should be based on Intelligence and Experience as the key concepts.

2. We claim that question-answering, being a natural function in intelligence, is an effective way to access experience for its application and development, e.g. for automated design.

The question is understood by the author as a specific natural/artificial phenomenon active when it is necessary to apply experience. The concept of “question” is understood and defined as a mismatch between the potential experience, necessary to implement a project, and the real experience of a design team.

The question controls the access to experience and its development through the answer and the process of answering, and such management is the essence of a question. We consider that if Case-Based Reasoning is used in forms of Question-Answer Reasoning while designing, it will provide naturalness in interaction of designers with experience and its models. Positive functional potential of QAR is much higher, than functional potential of CBR.

3. We believe that studies in Computer-Aided Design and the solutions are the great source of tasks and ideas to develop Artificial Intelligence. During design, experience and intelligence are used naturally.

Here presented studies and techniques are based on the following hypothesis:

QA interaction with experience consists of natural and artificial components being a complex unit. Such interaction may be much more effective if:

1 Question-Answer Reasoning of the designers is step-by-step registered in a special database of the project.
2 The results of QAR registering (QA protocol) are investigated, transformed to useful models, and used to support the next steps of interaction with experience in designing.

It has a number of useful interpretations such as:

1 QA protocol registers any design process as a research experiment, so representing “the primary measuring information” about design process and about the used control facilities.
2 Contents of the protocol reflect a real reasoning, which can be investigated to increase the knowledge about a “phenomenon of reasoning and questions”.
3 Each of the registered questions and answers admits its interpretation as an event essential for reasoning and design process, that allows to con-

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sider the protocol as “a network of events” ordered in time.

4 Protocol is a data structure (QA structure) with its practically useful set of operations. Such interpretation of QA structure corresponds to the experience of Computer Science in the area of data structuring for adequate presentation of a QA protocol.

4 COMPARISON WITH RUP

To indicate the place and role of our NetWIQA system in OOAD framework, we present its possible association with RUP.

Scheme on Figure 2 generally shows that NetWIQA allows designers to create:

– drafts of the basic RUP samples (for example, all kinds of UML diagrams: Use-Case, Classes, Collaboration, Activity and so on) for their subsequent coding and use in RUP environment or other related OOAD means;
– drafts of the basic RUP samples for their application in the current project without reference to RUP (using only the possibilities of NetWIQA);
– a set of samples based on the protocol of QA reasoning, its analysis and necessary transformations (such samples are presented below).

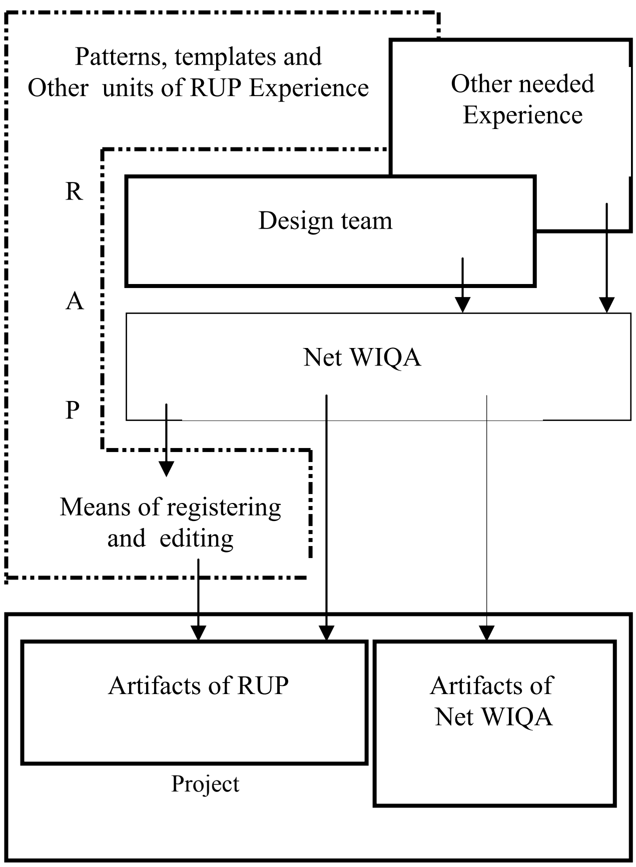

Figure 2 RUP and NetWIQA

The system is based both on RUP models of experience and personal experience of the members of design team. NetWIQA has a rich set of operations to interact with all models of experience.

5 QA PROCESSOR

First of all processor NetWIQA is a system for supporting of the collaborative design process. This system gives the members of design team an opportunity of QA recording of the step-by-step designing to the uniform QA protocol.

NetWIQA is the client-server processor with the special command system with the following functions:

– to make QA protocols of QAR;
– to represent the protocols or their parts as the applied models (dynamically visualized and controlled graphs; models of prototypes for sample actions; the arguments, motivation and purposes);
– to transform the protocols to network structures (QA event nets, QA Pert nets and QA Petri nets);
– to analyze texts of questions and answers (the analysis is aimed at decoding and representing of semantics of reasoning with first-order predicate logic).

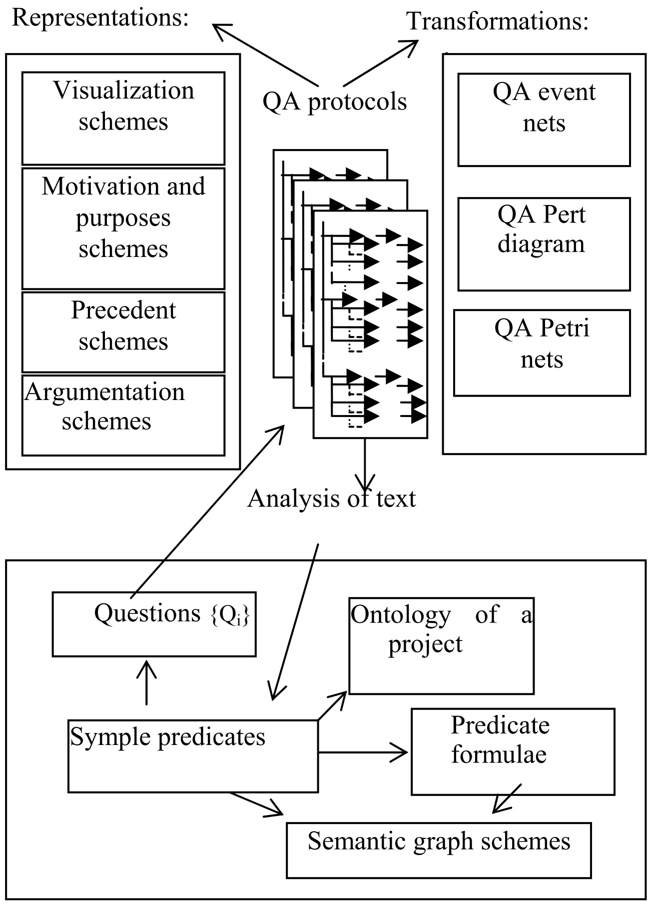

Figure 3 A set of QAR artifacts

QA processor has two set of the commands, e.g. instruction dialogue through the visual list of alternative commands; and plug-in mechanism that pro-

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vides an access to default commands and new accessible functions.

These operations of QA processor are enough for development both the basic UML and RUP samples, and QAR samples (Fig. 3). In more detail, our processor is developed according to the component approach as the 3-layer architecture on the basis of Borland MIDAS technology.

It consists of layers:

1 QA database and Experience database (Libraries of QA templates and other samples of experience),
2 business-logic kernel (server),
3 presentation layer ("thin client”).

The business-logic layer provides direct data access for the clients, and performs all data processing. Server component of QA processor consists of an application server, system magazine, synchronizer and etc. connected through TCP/IP sockets with Borland Socket Manager utility.

The third presentation layer of the system architecture involves a client library, a library of synchronizing flows, a library of configuration, a client workstation, and the configuration utility to adjust users, working groups and projects. The client workstation uses plug-ins to connect necessary functional modules to expand the set of QA applications, and in such a way additional applications to work with design experience and knowledge are built-in QA environment.

QA processor has the distributed and shared structure. The separate components can function on different computers in the local business network.

QA processor should ensure automated performance of the following main tasks:

– effective information and control support in Computer-Aided Conceptual Design of the automated systems;
– current unified documenting of processes and products, open for intellectual interaction;
– development of data and knowledge bases of complex projects and their interactive use while the conceptual design;
– controlled forming and accumulation of employees experience as QA databases of a design organization;
– control of automated designing, e.g. due to the rational choice of the direction of processes while design decision-making;
– controlled interaction between designers in collaborative work in the structure of a corporate design network;
– communicative document circulation in the corporate network;
– controlled training and learning during designing and operation of complex systems.

6 QA TECHNOLOGY

QA command system supports the workflow "Interactions with Experience" as the special set of applications, each of which perform the certain task of QA technique. At present we have developed about 40 utilities that are accessible to designers through WEB-environment of a client workstation. The structure and the access to the service utilities are realized according to the interactive RUP-model.

Each service task is submitted as:

– its QA pattern that are copied to QA database of the project and applied at the next case of the service task;
– interactive form to support its convenient application.

To demonstrate the functions of these applications let us name a few of them, e.g. "To solve a task", " To answer a question", "To construct the answer", "To prove the answer", "To discuss the answer", " To fill-in the pattern", "To set the requirement", " To generate the specification", " To determine the front of work", "To plan", "To control visualization of QAR fragment", "To generate the educational unit", "To control knowledge". The given utilities show that some applications of QA processor support also operative training for the members of a design team, e.g. to learn the certain design process.

QA technology is applied in any project as coordinated performance of the set of utilities and tasks appointed to the members of a design team. At any time each designer usually works with the dynamic set of the service and project tasks.

The common work begins with the utility "Conceptual design", which calls the following task "To open the project" as the initial condition of QA database of the project. The initial condition of a task-tree is submitted in Figure 4.

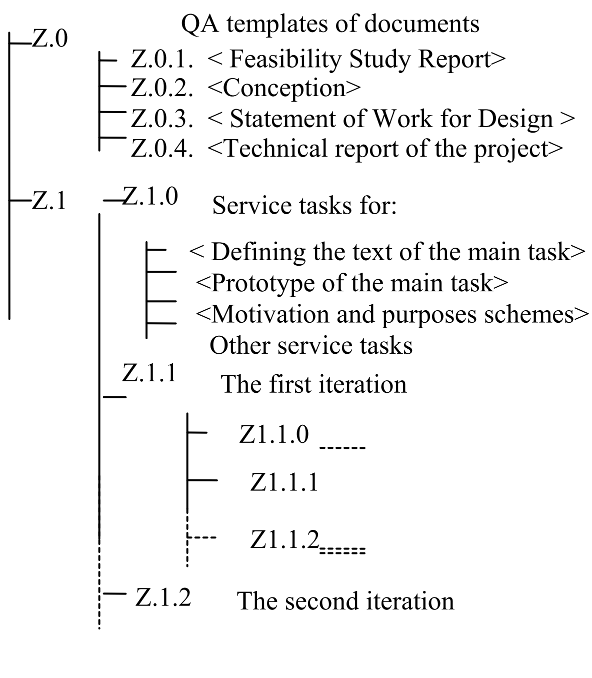

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Figure 4 Task structure of the project

The standard QA patterns of further documenting are loaded at the initial state of QA database. So, e.g. the State Russian Standards require that any CAD/CAM/CAE system includes the standard documents, i.e. "Conception" (analogue of "Vision" in RUP), "Statement of Work for Design" and "Feasibility Study Report". Each pattern of documenting represents the system of normative questions which should be copied to QA database and answered during design process.

The system service utilities provide "interaction with experience" for the definite project tasks, which are formulated and solved during design.

At any moment, design and service tasks make a uniform graph, where each task is interpreted as a “question -task".

Each task is coded by a symbol "Z" and index appropriate to a place of this task in the project (index "0" specifies that a task has utility functions). Indexes allow designers to determine not only inner project tasks from utilities, but also the tasks of different iterations of the project.

Each task in a tree can be in one of the following conditions - "decided/solved", "unsolvable", "postponed" and "executed". Any task has the set of attributes with references to its templates in QA database.

Each project work is supported by QAR while decision of the task. NetWIQA step-by-step protocols all questions and answers and their relations (Fig. 5) in QA database of the project. Here we see only QA relations, while the database also includes other relations (for example such as temporary, personification and cause relations).

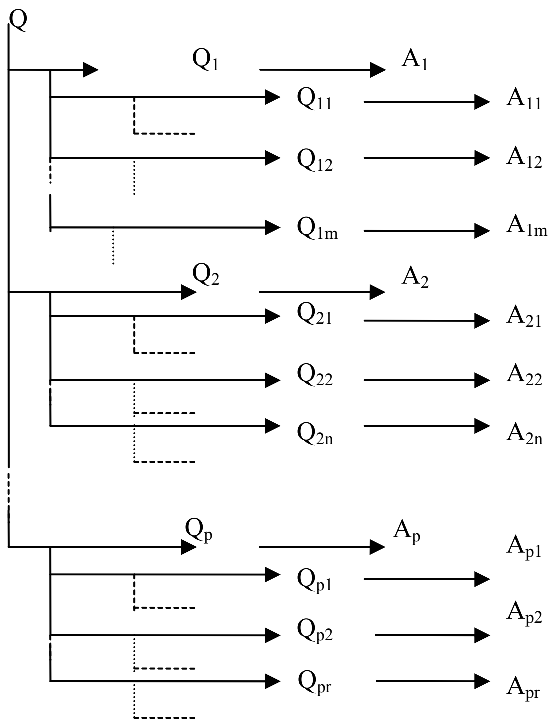

Figure 5 Question-answer structure of the task

Questions and answers get symbolic codes and indexes appropriate to their types and place in the project. Questions have two subtypes, i.e. Z-task and Q-quiry. Q-quiries require the answers to be got from experience database. If any Q has not got the answer, it is changed to Z-subtype.

The answer class is wider and includes subtypes "A-answer", "I-idea", "H-hypothesis", "S-specification", "R-requirement", "M-motive", "O-purpose", "E-decision", "P-procedure" and "F-formula".

The QA structure of any task is a dynamic data structure composed during the decision-making and reasoning. There are 3 types of questioning activity:

– automatic reference to experience "automatic skill"
– rational reference to experience, e.g. with a question of Q-subtype;
– rational reference to experience, e.g. with a question of Z-subtype;

The model of QA process is extended to the event QA networks and other network models of coherent sets of questions and answers. It requires to solve the tasks of detection of questions, their identification, adequate coding and modeling, and effective application. For these purposes QA processor has the means of text analysis with automated translation to PROLOG-like and semantic net languages.

7 QA PROCESS

At definite time t_i the reasoning QAR(t) goes to QAR(t_i)-state, which has its causal potential that gives the possibility to move the reasoning forward to the next state QAR(t_{i+1}). In this aspect the “history” of previously made work, represented in QAR(t)-codes, influences the next rational step of reasoning. Next steps both for reasoning and for design can be defined by means of question-answer analysis of QAR(t)-codes.

General statement of each project task should be defined before Question-Answer working with this task. Special definition of the task (as its general statement) uses a special pattern to present a task as 3 structured text blocks.

The first reflects the main purpose of a system under design, which is specified by its potential users. Here we begin the work with the basic Use-Case diagram for the task in UML language.

The second defines the main techniques to perform Use-Case diagram for the task. It provides construction of the basic diagram of business -objects of UML.

The third defines technology of implementation of a system under design. Information of this block is applied in conceptual design as context information.

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Analysis of a text T_0 of the general statement of a task and its translation to PROLOG-like language are used for extraction of questions to begin and continue QAR.

More detail it is based on step by step registering of questions and answers in accordance with following technique:

1 The set of questions $\{Q_i\}$ is taken from the text $\grave{O}_0$ and coded by adequate texts T (Q_i.

2 Actions of item 1 are executed for each text T (Qi, therefore the set of questions $\{Q_{ij}\}$ and their codes $\{T(Q_{ij}\}$ is formed. Actions of item 2 are used to control the correctness of question codes and for the choice of those questions $\{Q_k\}$ which will be used for the next step of detailization from the set $Q = \{Q_i\} \cup \{Q_{ij}\}$. Other questions are recorded for their application in the subsequent steps.

3 Set of answers $\{A_k\}$ and their codes $\{T(A_k\}$ is formed and registered in QA database.

4 Each text $T(A_k$ is processed as the text $\grave{O}_0$. The cycle 1-4 is repeated until the project comes to the end.

The work with questions, answers, QAR and RUP artifacts are controlled with the help of the appropriate system utilities.

The number of especially important actions (operations, command, plug-in mechanism, application of QA processor includes:

1 For questions: detection of obvious questions (on their indicators, predication (through translation on Prolog-like language, identification (on patterns, concrete definition (for types, assignment of meanings to attributes (as to the phenomenon of event type, argumentation.

2 For answers: creation, assignment of a type, change of a type, registration of a condition, editing of the contents, assignment of meanings to attributes (as to the phenomenon of event type, argumentation.

3 For QA groups: transformation to the node, expansion into QA structure, transformation to the event net, visualization of a network, analysis of a condition, choice of a direction of development, scrolling of dynamics (on inquiries.

4 For text: creation, transformation, grammar analysis, semantic analysis, transformation to the semantic graph, visual analysis, supporting of a phenomenon of attention.

8 CONCLUSION

In this paper we present the additional step in development of the application toolkit and technique for OOAD. This step includes the special workflow "Interaction with Experience" applicable to the RUP scheme of OOAD. Such workflow is based on specially organized QAR, its protocol as primary design information and processing for effective conceptual design in collaborative environments.

Methods and means offered, investigated and realized by the authors open some new possibilities to control CAD processes such as: effective monitoring of a QA process; analysis of opportunities of parallel coordination of work in a design team (with the purpose of distribution of work between the executives in typical design decisions); demonstration (at a suitable speed) of the development of events at the certain time interval of automated design; demonstration of the current condition of automated design at the certain moment; training to the typical decisions (CAD samples) and development of design skills; personification of events for subsequent definition of authorship and contribution of the members of a design team.

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Classification and Coding of Entities of Construction Data Domain

A.S. Pavlov
Moscow State University of Civil Engineering, Russia

D.S. Kulitchkov
Russian President Academy for the civil servants,
Institute of advanced training for the civil servants, Moscow, Russia

ABSTRACT: The classification of objects and their properties is necessary for the semantic description of construction data domain. The authors have offered the facet-hierarchical classification of entities in construction. The authors propose also the project of classification of main concepts in data domain of construction: settlements, territories, buildings, resources, properties etc.

1 INTRODUCTION

The various software are widely applied at present in practice of building design. The software have formed by the different development engineers and uses various databases and formats for a data storage and data transfer. Thereby the problem of interoperability appears, in another word that is compatibility of various software products among themselves.

The interoperability of information systems is divided on syntactical and semantic parts of object-oriented description. The syntax abstracts both from concrete objects, and from their sense. It is applicable for the formal description of the object's properties. Semantic component is the description of a sense of concepts in generalized classes of data domain objects. The semantic analysis of data domain is therefore the development of a hierarchical classification of main concepts used in construction. Such classification, though is not the comprehensive semantic description, ensures improving interaction of information systems in the construction.

2 SEMANTICS AND CLASSIFICATION

Gottlob Frege (1848-1925) and Ferdinand de Saussure (1857-1913) have laid the main principles of a linguistic semiotics. The founders of philosophical semantics were Alfred Korzybski (1879-1950) and Rudolph Carnap (1891-1970). The "constructions theory" of Carnap consist that some concepts express analytically through other concepts, and forms the hierarchy. Empirical and axiomatic concepts are the basis of a hierarchy. The artificial concepts can form the high levels of hierarchy.

The dual notion of any classification system is necessary for the complete description: that are taxonomic (i.e. typology of objects) and meronomic (i.e. formalized description of properties).

A point in the **n**-dimensional space of its attributes can represent any object. To classify met object it means to refer it to one of being available groups of objects. Coordinates of objects were in this area, are the attributes of object (merons).

Many classification systems are used, namely enumerated, hierarchical, facet, many-dimensional, etc. The hierarchical and facet classification methods are used most frequently.

The subsets are strictly enclosed each other by hierarchical method. The hierarchical method allows us to construct a concept tree of any depth that enables to classify large manifold of information. This method requires however the beforehand ordering of the attribute set and does not allow the including of new attribute in a middle of the tree structure.

The facet classification is based on parallel separation of generally set of objects on the independent classification attributes. The facet method is more flexible, and it allows the look-up on the arbitrary combination of attributes. The length of a code is relatively big, but this defect cannot be considered essential in conditions of the up-to-date information processing. The absence of a hierarchical system of interactive access to the complete concept list is more serious defect.

Most convenient is the combined hierarchical-facet classification. This principle is used for example in Statistical classification of economic activities in the European Community.

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3 CLASSIFICATION IN BUILDING ACIVITY

The qualifiers in data domain of construction are based mainly on the functional attributes, i.e. on the purpose of objects. The basis of the classification of production and services in Russia are the International Standard Industrial Classification of all Economic Activities - ISIC and Central Product Classification - CPC. The code of branch is taken four digits and the code of product – three digits. The classification comprises more than 4200 concepts relating construction, including more than 1000 kinds of works and services, more than 1200 names of building constructions, details and other resources, more than 1700 kinds of the enterprises, buildings and structures, about other 300 abstract concepts (sections of the projects, performances of buildings etc.).

The Russian qualifier of production comprises around 52500 groups and names of production, including more than 5 thousand names of material resources used in construction (not counting the productive facilities). The amount of kinds of resources used in construction is significant more. The Russian state estimate code is contained about 28 thousand names and marks of materials and construction item.

The classification of objects will actualize the paradigm of object formation "ancestor – descendant". But it is necessary to describe such relations, as "consists from…" and "has properties…" and other. Really, the object of construction is characterized by the internal structure, properties etc.

The authors consider, that the system of concept and objects classification for construction data domain should have the following properties:

– The amount of concepts must comprehend the really and abstract concepts of business processes not only for building, but also for adjacent data domain

– The structure of classification must have the internal logic; that will permit fast search both in interactive or automatic mode

– The classification must comprises not only concepts, but also properties of objects

– The classification must describe the enclosure of objects

– The depth and breadth of a branching should be adhering to optimum, to be sufficient for accommodation of a fair quantity (up to hundreds thousands) of concepts

– The addition and modifications of a classification structure at various levels should be flexible without a modification before the created documents

– The additions in the distributed databases must be possible

– The actual information technology must be applicable.

4 THE PRINCIPLES OF CLASSIFICATION

The authors are developed the following principles of classification in construction data domain for sufficing the indicated requests.

1. The construction business is the large open dynamic system. The typology of concepts of such data domain should be rather extensive and multiform. The following main kinds of concepts should be enveloped: types of building objects and their parts, resources, processes both conditions of creation and existence of objects, property and relationship of objects, abstract concepts used in the descriptions. By object-oriented modeling it is necessary to create classes simulating objects and concepts. The attachment of objects to concept is carried out by creation of the reference on the taxon (an element simulating concept), or by the global identifier.

2. Is proved, that any structure of data domain can be shown as hierarchical classification. That allows the unambiguous identification of concept. Thus, it is useful to apply a facet-hierarchical classification of concepts. The concept hierarchy in computer models can be supplied by the reference on a higher level of a classification. In artificial systems (the classification of an information, production etc.) it is usually enough 5-10 levels of a hierarchy, in natural systems (for example, biological) - up to 20 and more levels.

3. The existing systems of classification are represented as the tree graph or forest graph not have cycles and intersections. The real objects (both natural, and artificial) are not always interpretable as strict classifications. For example, the waterproof can be classifier as roof systems or fundament systems; the steel pipes can be used as constructive bearing elements, for HVAC system or for installation of the productive facilities etc. The object can therefore belong simultaneously to several concepts, enclosed each other or intersected - such method is named as a poly-classification. The multiple references on concept suppose more high levels in other branches for realization of this method.

4. The construction data domain comprehends the objects both artificial, and natural origin. Artificial objects play the more significant role. By classifier of artificial objects the inductive method cannot be guaranteed logical convergence of a hierarchy in the upper point. It is expedient to apply a deductive top-down classification of concepts. At the uppermost level can be chosen the concepts, which are divided in turn into natural objects and artificial objects.

5. The history of development of a science shows, that each science creates the typology of investigated objects in own way. The classification of objects however is made on their most essential indications, which can be composed in four groups of a generality: an origin, structure, properties and purpose of objects. So, the typology of biological or geological

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objects is based on the indications of a common origin, typology of chemical substances – on their structure, typology of physical bodies – on their properties and so one. For artificial objects a basis of a classification frequently becomes area of their purpose. The application of one of four groups at each step of the branching of the hierarchical tree is defined by the concrete situation: they can alternate, combine, or repeat.

Many classifications can exist because every material object has several various attributes. For correct perception of information it is expedient to select the main classification, which should be demonstrative, argumentative and should allow addition and modification. As shown is higher, the revealing of concepts is not univalent. It is possible to choice only one of variants of typology solution, par example on cause of usability. One of the most important attributes groups is a generality of application of construction objects.

6. Hierarchical classification is necessary for practical organization of interactive man-machine searching and entering of information, because it is enough for computer systems to ensure uniqueness of a code. That is simply reached by serial encoding of concepts. The significant time is necessary for looking up the concept by the interactive dialogue with the computer. The classification should be designed therefore so that the search of the necessary element would take short time. The structure of the search tree must be optimized for this purpose with allowance of properties of man-machine dialogue. Then the optimum branching of a tree should be defined by the criterion of a velocity of interactive search.

7. Both taxons and objects must have the global identifiers for univalent recognition of objects. The construction of the taxon identifier should not limit possibilities of extension the intermediate hierarchy levels. The combined code with reflecting of a level of a hierarchy, and taxon position at the given level is possible.

8. Nobody has been yet create a uniform classification of all concepts. Not only concept, but also objects have a hierarchical nature: they are enclosed each other and by that they will make a hierarchy system. To see analogies of wildlife, the biosphere of a planet is constructed on a principle: biosphere - population - organism - functional system - organ - tissue - cell. Each object is nested in another object of a highest level, for example, the organism is not a part of other organism, but is a part of a population. Every level of the classification is not conterminous with another level. That can be seen in microcosm (molecule - atom - nucleus - particle) and macrocosm (metagalaxy - galaxy – star conglomeration - heavenly body).

5 CLASSIFICATION OF CONCEPTS

It is necessary to develop a hierarchy of concepts in accordance with hierarchy of nested objects. In construction data domain it means about nested building systems. The classification of concepts should be created for each nested objects level of data domain. The association of such classifications in certain "super-classification" has not real sense, however it can be used for computer processing of encoding. The principal scheme of classifications of data domain is shown in a Figure 1.

Fig. 1. The scheme of classifications on the data domain at the various levels of nested objects

It is expedient to use a signifying encoding for identification of concept, on which it would be possible, the reconstruction of hierarchical relations between concepts. The combined encoding is offered. It consists of pairs of the hierarchy level description and concept number at the given hierarchy level. We shall designate a hierarchy level by the lower case Latin letter. The second letter designates second sublevel etc. Decimal digits following the level letters designate the number of concept. The amount of sublevels and numbers is not limited. Points as facet encoding of qualifiers divide the pairs. At each level there can be some classifications (for example, classification on various attributes of objects). They are numbered within the limits of a level. Let's note a concept code in the EBNF (Extended Backus-Naur Format, ISO/IEC 14977):

```
lower ::= 'a'|'b'|'c'|'d'|'e'|'f'|'g'|'h'|'i'|
          'j'|'k'|'l'|'m'|'n'|'o'|'p'|'q'|'r'|
          's'|'t'|'u'|'v'|'w'|'x'|'y'|'z';
   level  ::= {lower}+ ;
   pair   ::= level number ;
   concept_code  ::= pair {"." pair }* ;
```

Example: «`c2.ca1.d8.da34.f3.fb14.h8`».

Such encoding ensures arbitrary escalating and modification of a classification structure during realization. The restriction concerns only adding of highest levels: there are no letters up to the letter "a", therefore it is necessary to enter reserve highest

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levels, par example, levels "a" and "b". Only declaration order of registration is necessary for addition the new concepts in a global web with minimum centralization. The scheme of a hierarchical classification with application of a combined encoding is shown in a Figure 2. The dotted lines are shown the additional references to other branch. It is enough for creation the hierarchy to have the references to higher hierarchy levels.

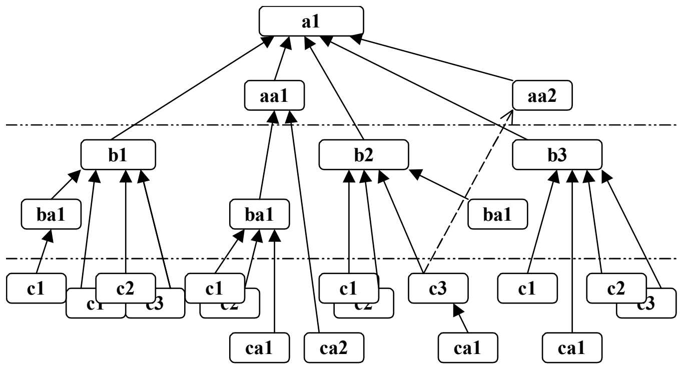

Fig. 2. The scheme of the hierarchical classification

Let's establish as a first approximation hierarchy of data domains to reserve the area of encoding for data domain of construction. The fragment of classification of buildings on destination is shown in Table 1.

Table 1.Top level of data domains

Code	Data domains
b1	Abstract entities
b2	Nature
b3	Life
b4	Noetic entities
b5	Industry
b5.c1	Traditional production
b5.c2	Mining
b5.c3	Energetic
b5.c4	Food processing industry
b5.c5	Textile industry
b5.c6	Manufacturing industry
b5.c7	Chemical technology
b5.c8	Metallurgy
b5.c9	Mechanical engineering
b5.c10	Electronics engineering
b5.c11	Building
b5.c11.d1	Building objects
b5.c11.d2	Design
b5.c11.d3	Resources
b5.c11.d4	Technology
b5.c11.d5	Facility management
b5.c11.d6	Hydraulic engineering
b5.c12	Transportation
b5.c13	Trade
…	etc.

The authors develop the classifications of some main concepts in construction data domain: settlements, territories, resources, properties etc. The fragment of classification of buildings on destination is shown in Table 2.

Table 2.Classification of buildings

Code	Type
b5.c11.d1.eh1…	Building objects:
...f1	Residential building
...f1.fa1	Capital residential building
...f1.fa1.g1	One-apartment residential building
...f1.fa1.g2	Multi-apartment residential building
...f1.fa1.g2.ga1	Multi-apartment building up to 2 floors
...f1.fa1.g2.ga2	Multi-apartment building up to 5 floors
...f1.fa1.g2.ga3	Multi-apartment building up to 9 floors
...f1.fa1.g3	Hostel
...f1.fa1.g4	School sleeping house
...f1.fa1.g5	Sleeping house for disabled persons
...f1.fa1.g6	Sleeping house of sanatorium
...f1.fa2	Non-capital resident building
...f1.fa2.g1	Mobile camping-van
...f1.fa2.g2	Container-house
...f1.fa2.g3	Garden house
...f2	Public office building
...f2.fa1	Sales and catering building
...f2.fa1.g1	Shop
...f2.fa1.g2	Trade pavilion
...f2.fa1.g3	Emporium
...f2.fa1.g4	Apothecary’s
...f2.fa1.g5	Restaurant
...f2.fa1.g6	Coffeehouse, Teashop
...f2.fa1.g7	Canteen
...f2.fa2	Public utilities
...f2.fa2.g1	Hotel
...f2.fa2.g2	Motel
...f2.fa2.g3	Public service, laundry
...f2.fa2.g4	Automobile service
...f2.fa2.g5	Garage
...f2.fa3	Health services building
...f2.fa3.g1	Clinic
...f2.fa3.g2	Out-patient hospital
...f2.fa3.g3	Day hospital
...f2.fa3.g4	Health center
...f2.fa3.g5	Maternity hospital
...f2.fa4	Education building
...f2.fa4.g1	Nursery school, child center
...f2.fa4.g2	Comprehensive school
...f2.fa4.g3	Art school
...f2.fa4.g4	High school
...f2.fa4.g5	Retraining school
...f2.fa5	Culture building
...f2.fa5.g1	Museum
...f2.fa5.g2	Library
...f2.fa5.g3	Archive
...f2.fa5.g4	Studio
...f2.fa5.g5	Exhibition hall
...f2.fa5.g6	Philharmonic
...f2.fa5.g7	Theatre
...f2.fa5.g8	Cinema
...f2.fa5.g9	Concert hall
...f2.fa5.g10	Studio
...f2.fa5.g11	Sport hall
...f2.fa5.g12	Planetarium
...f2.fa5.g13	Dancing
...f2.fa5.g14	Culture center
...f2.fa5.g15	Club
...f2.fa5.g16	Circus
	etc.

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The separate part classification is made for design documentation and technical rules. Example of the concept code for documentation: "b5.c11.d2.e2.f3.ff1.g2.gf8.gk1.hg8.hk3.hp2.hu5".

It means "The territorial quotations for building rehabilitation".

6 CLASSIFICATION OF OBJECTS

The 128-bit numerical significance of the universal unique identifier UUID (or GUID) is applied for identification an object in memory of the computer. In this significance first 60 bits are used for an entry of discrete time of object formation (amount of 100-nanosecond intervals from introduction of Gregorian calendar style). The 14 bits are used for the computer clock synchronization sequence and 48 bits – for address of computer knot in the global web. Remaining bits are used for version number and attributes field. The standard function `CoCreateGuid (GUID*)` can be used for obtaining UUID in Microsoft environment space. The casual digits are generated, if any of necessary data are inaccessible. UUID in 16-digit format with separators takes 36 bytes, for example: “`AC5C6360-248C-447F-8976-92A3F102 9507`”.

The uniqueness of a model of object in memory of the computer however does not guarantee against a collision by creation of several models of the same real object. It can result in dissociation of data about object and to distortion in the design documentation. It is expedient to appropriate a unique identifier not to model but to object itself. The offered scheme of encoding of nested objects can be used for this purpose. The unique encoding of construction should include codes of administrative or territorial division, town-planning and architectural documentation. Par example, the encoding of construction located in Moscow, can look as follows: «`CP643.DF46.DP280.DU597.EP1.FK12.FP0099`». The similar method can be used for the constructions, elements of buildings and so one.

The level of nested objects is a basis of hierarchy division of data domain. The preliminary study of the structure of nested construction objects has shown, that for the description of such structures there are enough 12-16 basic levels. For a label of such levels we offer to use capitals of the Latin alphabet. The sublevels etc can be added if necessary. Then in the EBNF the entry of encode of a □lassifycation can look as follows:

```
digit::='0'|'1'|'2'|'3'|'4'|'5'|'6'|'7'|'8'|'9';
upper::='A'|'B'|'C'|'D'|'E'|'F'|'G'|'H'|'I'|
        'J'|'K'|'L'|'M'|'N'|'O'|'P'|'Q'|'R'|
        'S'|'T'|'U'|'V'|'W'|'X'|'Y'|'Z';
nest_level   ::= {upper}+ ;
number       ::= {digit}+ ;
classif_code ::= nest_level number ;
```

Par example: «`DA2`».

Let’s enter the generalized uniform conditional names of nested hierarchy levels for all data domains (Tab. 3). Any additional sublevels can be added of course. The common abstract concepts are not included into this system, as are not objects.

Table 3. Generic and building nesting object levels

Level code	Generic level	Building object level
A	Generic	
B	Concept	
C	Global	Geography
D	Common	Regional
E	Major	Urbanistic
F	Grand	Architectural
G	Prevalent	Building
H	Extended	Room
I	Individual	Construction
J	Special	Industrial
K	Specific	Technical
L	Distinct	Production
M	Partial	
N	Single	
O	Chemical	
P	Physical	

The levels A and B are reserved for the description of microcosm, and lowest levels – for microcosm. They will coincide for any data domains. Level "I" at center of a level structure is supposed for the man, as "measures of all things".

The levels C and D are expedient for fixing behind geographical concepts, common for many data domains with real "terrestrial" objects. The encoding of sublevels has reservation of codes (between named sublevels four reserve unnamed sublevels).

The fragment of nested building object sublevels is shown in Table 4.

Table 4. Hierarchy of construction object sublevels

Sublevel	Definitions and examples
FF. Ensemble	Element of zone, limited to arterial roads and other boundaries (ensemble, group of quarters or enterprises)
FK. Quarter	Element of buildings limited to streets (micro-region, quarter, block of enterprises)
FP. Site	The group of objects, which building construction is carried out on a one project
FU. Locality	Part of building site, were in one place
GF. Stage	The project determined part of the building construction, created without interruption
GK. Start-Up	The part of stage, ensuring output of production or services (power plant unit etc)
GP. Group	The technologically completed part of a complex (facilities, some homogeneous constructions)
GU. Subgroup	The homogeneous part of a group, technologically unit
HF. Building	Isolated object of the immovable (building, structure, road, planting)
HK. Section	The part of building (Entrance, block, workshop, technologic train)
HP. Space	Isolated part of section (floor, cellar, aisle)

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Table 4. Continued

HU. Room	Isolated part of space (room, staircase, bay)
IF. Structure	The functionally homogeneous part of a building (foundation basis, foundation system, bridging, walls, roof, HVAC system)
IK. Block	The spaced or constructional homogeneous part of a structure (foundation, wall, ceiling, roof batter, part of HVAC system)
IP. Facility	Mono-functional part of the block (unit of equipment)
IU. Construction	Separate or repeating construction (opening, plate, panel, column, beam, farm, down-comer)
JF. Aggregate	Assembled part of a construction (reinforcement, door, window, pipeline, aggregate)
JK. Device	The composite device (3D bar-type reinforcement skeleton)
JP. Part	The part of device (console of column, bar reinforcement mat, flat skeleton)
JU. Component	The component of construction (fabric reinforcement mesh, parallel-lay-wire tendon)
KF. Unit	Assembled component of a construction (unit, shutter, support, pipeline, cable, reinforcement position: rebar, array, mesh)
KK. Subunit	The constituent of a unit (furniture, valve)
KP. Pack	Gang of homogeneous elements (mark of reinforcement)
KU. Element	Element of construction
LF. Item	Accessory item (longitudinal reinforcement bundle, embedded item, stretching wire)
LK. Subitem	Part of item (gusset, corner plate, hitch plate, bolt)
LP. Detail	One-piece element of a construction (single rebar, binder, blanket, layer)
LU. Subdetail	The least homogeneous part of a details (edge, seam, hole)

7 CLASSIFICATION OF PROCESSES

The life cycle of production is the complex of processes from initial revealing of market needs before final sufficing of the raised requests. According to standard [ISO 9004-1-94], the main stages of life cycle are: marketing, development of production, process planning, purchase, production, check, packing and storage, realization and distribution, mounting and commissioning, service, after-sale activity, recycling.

The aforesaid list of stages is typical just for large-scale industrial production. For construction business-processes, which differs by uniqueness and by large duration of objects creation, not process, but project approach is incident. The concept of life cycle for project management is formulated in [Pavlov 2003]. Life cycle of building object is practically identical with the investment cycle. The following list of stages of building object life cycle is offered:

– Creation of an intention of the project;
– Substantiation and planning of the investments;
– Research and experimental effort;
– Exploration and design;
– Realization of contract tenders;
– Contract conclusion;
– Preparation of building production;
– Erection of buildings and structures;
– Mounting of the equipment;
– Laying of the communications;
– Starting-up and adjustment works;
– Going into operation;
– Assimilation of a potency;
– Realization of trial production consignments;
– Operation;
– Repairs;
– Renovation;
– Termination of operation;
– Liquidation.

8 CONCLUSION

The classification of objects and their properties is necessary for the semantic description of construction data domain. The authors have offered the facet-hierarchical classification of entities in construction. Many classifications exist simultaneously at different levels, for example, classification of buildings, constructions, and projects. It is necessary to divide first of all such levels from each other. At parallel levels are located the independent entities: objects, resources, properties, processes etc.

The codification of entities is necessary for an entry in an electronic and paper kind. The Latin letters designates each level. The concept of one level is differed by number. The letters and the numbers will derivate a unique code of concept. The intermediate levels can be added arbitrary.

The individual object has the unique identifier and code of their entity. The object has also properties, which have the value and code of entity. All objects thus differ and can be circumscribed with a desirable degree of a detail. The authors propose the project of classification of main concepts in data domain of construction: settlements, territories, buildings, resources, etc. The top levels of a classification of building objects properties, classifications of the relations, conditions, processes and resources are developed also.

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eProCon: electronic Product Information in Construction

G. Gudnason
Icelandic Building Research Institute, Reykjavik, Iceland

J. Hyvärinen
VTT Technical Research Centre of Finland, Building and Transport, Espoo, Finland

C. Finne
Building Information Foundation (RTS), Helsinki, Finland

S. Larsson
GDL Technology Nordic Europe, Bjärred, Sweden

ABSTRACT: The lack of industry standards and agreements for electronic presentation of information on building products is hampering seamless eWork, eProcurement and integration of value chain activities in the construction industry. Technical and trade information about building products is not available in electronic form to designers, contractors and facility managers that would make it possible for them to easily re-use it in design systems and to find, compare and procure products on-line. The eProCon project brings together nine partner organizations: the Building Information Centers in all five Nordic countries, two technology partners and two research institutes. The purpose of this consortium is to demonstrate a dynamic value adding information services network in the Nordic countries for brokering building product information by electronic means. The Building Information Centers have been brokering building product information on behalf of manufactures for more then 20 years to the construction sector, using proprietary information systems that are incompatible in content, functionality and technical solution. The primary impact the eProCon project will have on the current state of the art is enabling interoperability between these systems and allowing them to share content (and enrich the content), thus becoming one virtual service available for all Nordic end-users. The demonstrated integration platform, applying Service Oriented Architecture, includes: 1) the core integration layer enabling the existing Nordic information services and a new product portal to act as a single Nordic virtual service to its end-user, 2) the update layer enabling manufacturers and suppliers to interact with the information contained in the services and 3) the catalog layer, which enables 3rd party buy applications to access the information. The paper will report on the approach selected in the eProCon project and first prototype implementations.

1 INTRODUCTION

As the use of ICT systems is becoming more advanced, requirements for data exchange and enterprise wide interoperability is seen as a key issue for improving productivity and information management in the construction value chain. While software vendors focus on intra-enterprise and inter-enterprise interoperability requirements, the majority of organizations in the Construction Industry (97% with fewer then 20 employees) are Small and Medium Enterprises (SME) and Very Small Enterprises (VSE). Typically these organizations operate low-end software solutions from multi-vendors that where not designed to interoperate across platforms and find it a challenge to collaborate in the virtual enterprise and exchange information between activates in the construction value chain. Kazi and Hannus (2001), Hannus and Kazi (2000) described linking between enterprise systems hooked through flexible interfaces to a central VE repository as the means for inter-enterprise information exchange, while the International Alliance of Interoperability (IAI) develops Industry Foundation Classes (IFC), neutral conceptual model for describing the building product that can be exchanged between applications. Despite these efforts and several major research initiatives to create an interoperable platform for the construction industry, the Product Data Technology (PDT) has not yet made high enough impact in the industry. Standard objects described by product data model, in shareable libraries, are still not readily available for use in design, construction and maintenance/operation processes that may move the industry towards model based construction and integrated solutions. To move the building product and material industry which represent a significant part of construction value chain (estimated at 40% of total construction works) towards new ways of working there need to be an underlying economic motivation. Meanwhile no common agreement exists for electronic description of building products and multitude of representations will emerge as readily available technology makes new start-ups easier and less

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costly – multitude of web-sites, information brokers and eMarketplaces.

Later in this section several initiatives are discussed that have addressed the different needs of building product information delivery so that it can be transparently shared, exchanged and re-used in different construction applications across platforms.

1.1 *Background and Motivation*

Building Information Centers in the Nordic countries have for more then 20 years provided services to the building product and material industry by operating show rooms for display of building products providing industry practitioners with access to information and a place to learn about available product ranges. Additionally they have published paper-bound product information sheets covering a wide range of building product types. In resent years information about manufacturers and their products have been made available on the Web.

Currently the Nordic building information centers have a dominant market position and collectively represent over 7000 product manufactures and suppliers in the Nordic countries and provide information on hundreds of thousands of products. The Building Information centers have developed proprietary information systems based on their own data models and national classification systems resulting in incompatible systems, at the Nordic level, both in content, functionality and technical solution (e.g NOBB in Norway, RT-files in Finland and VaruDB in Sweden).

Industry requirements for open systems capable of data integration on the application level and support for on-line trade are being recognized as necessary steps to maintain market leadership as similar systems from elsewhere are trying to penetrate the market.

1.2 *Objectives*

The eProCon project is funded by the Nordic Innovation Centre and brings together nine partner organizations: the Building Information Canters in all five Nordic countries, two technology partners and two research institutes. The purpose of this consortium is to demonstrate a dynamic value adding information services network in the Nordic countries for brokering building product information by electronic means. The primary impact the eProCon project aims at over the current situation is enabling interoperability between dissimilar information systems and allowing them to share and exchange product information, thus becoming one virtual service available for all Nordic end-users. This will:

- Enable construction professionals and facility owners to search for building products across the Nordic countries
- Provide synergy across the Nordic building product and materials market and strengthen its competitiveness and international standing.
- Provide infrastructure for small and medium sized enterprises to participate in the rising electronic market, to extend their market reach and lower their cost to market.
- Improve the Nordic position to influence development initiatives in this area
- Create a fair market environment for SMEs in which they can compete on equal terms
- Increase information value and re-use.

Additionally the eProCon project aims to provide a domain model for enriched catalogue and product information (demonstrated in a “Product Portal”) and services that enable access of information providers (manufacturers and suppliers) for producing and maintaining product catalogues and 3rd party eProcurement and buy-side applications and eMarketplaces.

1.3 *Past Initiatives*

Projects in the past have addressed the requirements of the construction participants for electronic product information, more efficient search mechanisms and procurement of products. RINET (cic.vtt.fi/rinet), CONNET-MPS (www.connet.org), PROCAT-GEN and ARROW (Newnham and Amor, 1998) aimed at demonstrating product model approach to product information and use of parametric search methods.

Others initiatives of particular interest that focused on need when working and trading across borders, aspects of a single market e.g multi-lingual content and construction semantics.

Lexicon - ISO 12006-3

The Lexicon is a product of STABU in the Netherlands (Woestenenk, 2000a,b). The Lexicon is a tool for developing and maintaining vocabularies (taxonomies). The Lexicon was one of the source documents for the ISO 12006-3 standard, (ISO, 2000), pre-pared by working group WG6 of ISO TC59/SC13 and defines the information model on which the standard is based. The scope of the standard is to specify a language-independent information model, which can be used for the development of vocabularies used in information about construction works.

Two efforts are concurring to partially populate the Lexicon, in Holland the BAS project for Civil-Engineering works in the Dutch and English languages and the Norwegian BARBi (BARBI) project, which is now testing the use of reference data for

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product catalogues based on sawn timber, windows and doors.

E-Construct project

The eConstruct project developed a communication technology for the Building Construction (BC) industry and a BC vocabulary called the bcXML. The developed solutions are focused on eCommerce and eBusiness in the supply chain of construction. Like Lexicon, the eConstruct project presents Meta-Models for a common neutral BC vocabulary (Taxanomy) in multiple languages that will enable exchange and language translation of information without loosing meaning (semantics). The model collects BC objects (terms) and property definitions in dictionaries. Some constructs of the Meta-Model have been harmonized with the IAI IFC to enable integration with PDT. The object of interest is the shared ifcXML_COS model (Common Object Schema), which provides among other things, the definition of object properties and collection of properties into property sets. In the bcXML model the property definition is called a "Specification". The specification describes the characteristics of construction objects contained in the "bcDictionary".

E-Construction CEN/ISSS workshop

The CEN/ISSS E-construction workshop (van Nederveen et al., 2002) took off in end of 2002. The objectives of the workshop is to consolidate and draw from previous efforts and results of EU research and cluster projects and international initiatives and to set forth a holistic standardized approach to implement ICT in relation to eCommerce and eBusiness in construction. The workshop will develop five interrelated standards to meet its objectives.

– European eConstruction Framework, a high abstraction level which describes the of the world of construction
– European eConstruction Architecture identifying common meta-schemas, schemas, taxonomies, APIs and software tools
– European meta-schema consolidating on-going and previous efforts from eConstruct, ICIS, IAI etc.
– European eConstruction Ontology that will be an open, agreed taxonomy for the European construction industry
– European eConstruction Software toolset, which will comprise of tools for realization of the standard architecture and that can be shared among actors

2 PRODUCT INFORMATION - MATCHING THE REQUIREMENTS

In the introduction we mentioned that manufacturer's need to be economically motivated to meet the requirements of the industry for re-usable product information Table 1.

Table 1. Example of re-usable Product Information

Product specification	Can we use a descriptive or performance based description of the product directly in our specification?
Construction classification schema	Does the product information contain the ordering and identification we use in our project?
CAD object	Can we drag and drop or import the graphical representation and technical properties of a product into our design system?
Product certificate	Does the product carry quality certificate and code compliance?
Guidance	Can installation and maintenance guides be imported into design and product documentation?
Environmental declaration	Is there a statement by manufacturer that gives declaration of environmental performance?
Product catalogue	Can we use manufacturer article number, product description and price directly in our ERP?
CE-Marking	Can the product in question be freely exported/imported in the EU market?
Global identification	Does global identification of the product match ours e.g. DUNS, EAN, UN/SPSC?
Business documents	Is the information following standard procurement documents?

The question most frequently asked is how can we solve the technical and functional requirements for re-usable product information from the industry practitioner point of view, but to much less extent how do we also, provide the mechanisms that match the manufacturer requirements for re-usable information, ideally from the same information source, which must be the key to motivate manufacturers to produce re-usable product information the industry requires, especially when taking into consideration the large number of SME participating in the construction value chain.

The eProCon project looked at three information processes as the bases for re-usable product information:

– eWorking during design and construction of a facility. eWorking deals with the data integration in the building lifecycle where product information is shared, exchanged and re-used transparently between application and lifecycle stages over networks through standard interfaces and data models.
– eProcurement where material and product suppliers are identified that can supply the needed

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goods, matching the design specification and agreement on prices, order and delivery is reached. eProcurement provides the technology so that buyer and seller business applications can handle electronic transactions and exchange business documents transparently.

– eProduct and eCatalogue content management broadly described as the process where product information is created, filtered, organized, archived, published and disseminated. eProduct content management focuses on product data (the corporate asset) and the integration of that data into business and eCommerce applications, whereas eCatalogue management focuses more specifically on data within product catalogues. eProduct and eCatalogue content management systems generally provide the technology that integrates structured and unstructured information sources so that they can be maintained and accessed as if they were a single source to produce enriched product information e.g. literature, catalogues, promotion and sales material in the proper format and codification and for integration with supply chain collaborators.

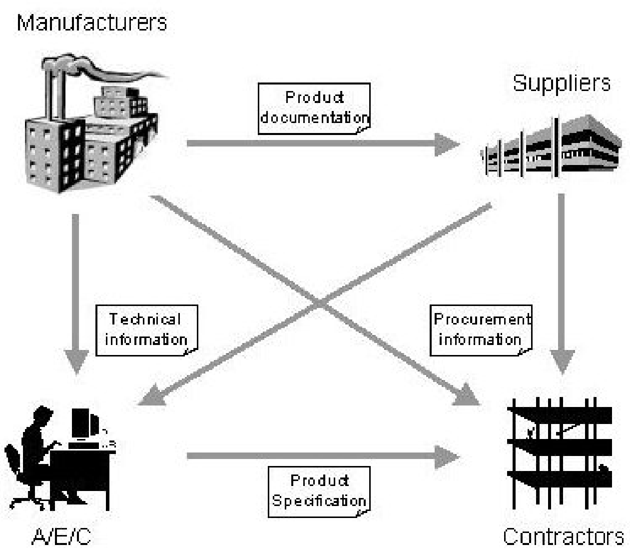

Figure 1: Product Information in Construction

Put into context Figure 1 illustrates the basic roles and relationships between actors in the construction value chain.

Traditionally, product information is discovered in a peer-to-peer topology. Designer and contractors use established contacts to obtain information, company archive, browse the web or follow-up on advertisements to find the products they need on each occasion. Similarly manufacturers discover suppliers of components for assembly into their products (not shown in figure) and as re-sellers for their products and vice versa. In this arrangement valuable effort is spent in searching for the right organization, product or component often by trial and error approach.

As the Internet majored a large collection of information services have entered the marketplace (Figure 2) that provides single access to company and product information from an array of manufacturers and suppliers. This topology has proven efficient in dynamic markets where fragmentation is high such as in the construction industry.

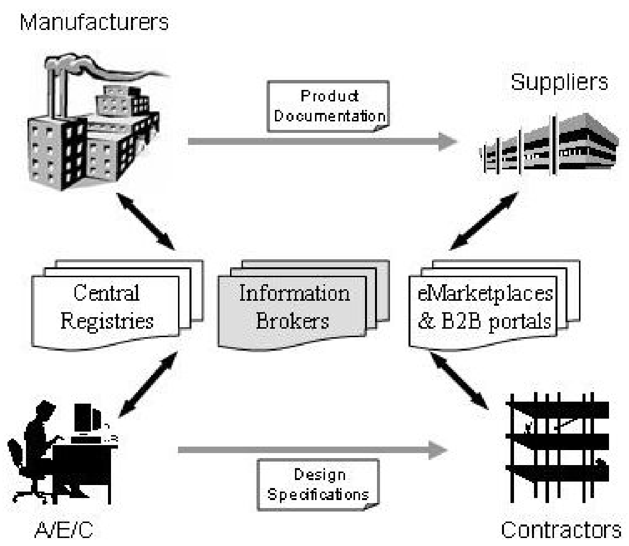

Figure 2: Service Providers as Infomedieries

Figure 2 identifies three types of information services, each of which perform a special role in the product information delivery, but provide different type of services to its customers and use different methods, detail and classifications to present its content. Providers may offer one or more of these services consolidated to their customers or separately as standalone information products.

Registries provide repositories for information about businesses including information about the services and the products they provide to be discovered by potential business partners or autonomously by applications. The more widely recognized registry standards are Universal Description, Discovery and Integration (UDDI) (www.uddi.org) and OASIS ebXML Registry/Repository (www.oasis-open.org).

The UDDI provides a platform-independent, open framework for describing services, discovering businesses, and integrating business services using the Internet. A UDDI implementation is primarily a mechanism to advertise and discover Web services. However a UDDI registry is a general-purpose registry and therefore not limited to registration of Web-services. It contains categorized information about businesses and the services that they offer that can be discovered by business partners over standard interfaces. Cope and Amor (2002) conducted an investigation into using UDDI registries as alternative to traditional catalogues offered by vendors and the ability of UDDI to handle information about product manufacturers and suppliers, their business offerings and further information in a brokering framework.

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The work further studied searching for products matching a particular classification and extensions that could include product parameters.

The OASIS ebXML Registry/Repository standard is emerging as a key component of developing Web Services for e-commerce and many other uses. It is also a general registry, which can be used not only for business but also for any other organization and for any purpose. The OASIS standard uses a generic and extensible information model that can be adapted to many uses. This information model includes the ability to have arbitrary associations between entries in the registry. Furthermore, the standard includes a repository. Any type of data can be stored in the repository including Web Service descriptions, XML data and documents, binary data (such as images, sound files, video data, executable application files, CAD files etc.). Consequently, the OASIS ebXML Registry can be deployed as a public registry, a private registry used within an organization, or a registry shared by an organization and its partners.

The Information Broker's core activity is to collect and aggregate varied information from a range of information sources and make it available as a collection to their clients. Its business model aims for the broker organization to add value by further processing, organizing, profiling, cross indexing and making reference to external information as part of the service. Information brokers may in fact author much of the content themselves and provide expertise and service to their clients in content provision - as is the case with the eProCon information services partners. The McGraw-Hill Construction (Sweets) (www.construction.com/ProductCenter), Corenet – Construction and Real Estate Network, E-Catalogue (www.corenet.gov.sg), and the Barbour Index (www.barbour-index.co.uk) are well known examples of product information service that fall into this category.

eMarketplaces and B2B portals main focus is to bring buyers and sellers together and facilitate transactions in business-to-business (B2B), business-to-consumer (B2C) relationships. eMarketplaces are mainly sell-side i.e. represent the selling agent and specialize in particular vertical markets e.g. Steel24-7 [www.steel24-7.com]. The content in general is characterized by the business transactions and business services available in the eMarketplace, although its is evident that the detail of information is becoming of higher standard including detailed product information, design details and technical specifications that can be used for making design decisions as well as for procurement.

Registries are likely to play a major role in facilitating integration in eBusiness and provide the infrastructure for single electronic markets. One example of a worldwide registry is the Internet Domain Name Server registry that enables identification and location of computers in the global network. The important concept of registries is that it allows companies to maintain their services and product information in-house vs. outsourcing it to information service providers like described above and yet still be equally visible in the marketplace. Registries also support the generation of dynamic supply chains in the virtual enterprise.

Clearly, for manufacturers to be visible in the electronic marketplace they may need to register with several service providers and re-enter company, product, catalog, and service information into dissimilar systems and formats.One point of service aimed at by the eProCon project was to facilitate a single source of information that could autonomously be syndicated to various types of services or be referenced, downloaded when greater detail and other documentation is needed such as in the case of eMarketplaces.

3 METHOLGY AND DEVELOPMENTS

3.1 *eProCon Integration Model*

When developing the solution for interoperability of existing product information systems hosted by the building centers and for them to provide re-usable product information several alternatives for neutral data representations where reviewed as considerations: A) The Industry Alliance for Interoperability (IAI) Industry Foundation Classes (IFC) information model - the key technology for interoperability and information sharing between heterogeneous software applications in the building industry (the IFC 2x introduced the ifcXML specification that defines the complete IFC Model in the XML Schema Definition Language (XSD) as opposed to EXPRESS and provides an alternative approach to information sharing), B) existing XML/B2B standards and C) proprietary solution designed for optimized response and minimized complexity.

In order to support the varying data already available in the existing systems a normalization of the product information data models was carried out. The normalized data model was then analyzed with respect to the standards. The review lead to the shared view and conclusion of the consortium, despite the fact that great interest was to follow the IAI-IFC standard, that a custom-tailored solution adhering to the standard when possible should be adopted as the integration solution. The risk and potential cost involved following or adopting one standard over another, especially in the XML/B2B field, was a deciding factor. Also taking into consideration, complexity and ease-of-use of the core integration specification to enable the building centers to exchange product information transparently and for end-users to find information across the Nordic ser-

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vices the requirement for 3rd party application integration support was not considered feasible using the proposed specification. The alternative solution was to implement programmatically a three-layer approach, Figure 3 that could be incrementally realized by the building centers and fitted more readily to their business plan. The solution further aimed at greater flexibility and support for current and emerging XML/B2B standards.

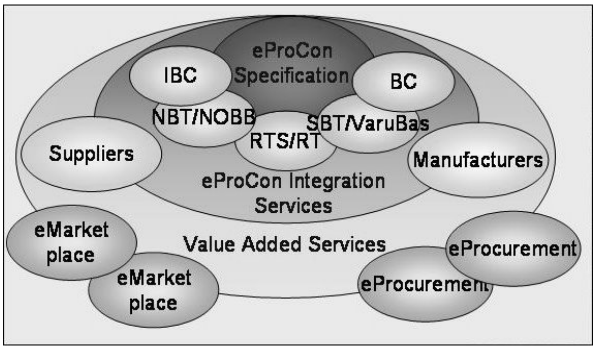

Figure 3: eProCon Value Network

Figure 3 identifies the three main integration points aimed at in the eProCon project:

1 Data integration of building centers information systems
2 Controlled data access by information providers
3 Data sharing with 3rd party eProcurement and buy-side applications and eMarketplaces

3.2 *Technology description*

eProCon underlying integration strategy is based on Service Oriented Architecture (SOA) where web services are leveraged as integrators between distributed applications.

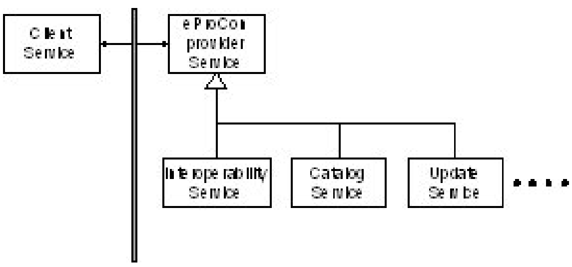

Figure 4: The eProCon Integration Services

The web service architecture provides a standard, technology independent platform to expose the functionality of an application regardless of language, operating system or vendor component architecture used for its implementation. Web services are self-describing and use open Internet standards for message transport and discovery, description and invocation respectively (XML, HTTP, SMTP, UDDI, WSDL and SOAP). The SOA further provides a component model that inter-relates the different functional units, in this case web services, through well-defined interfaces and contracts.

Figure 4 illustrates the selected approach satisfying the generic requirements of the business services. The pilot implementation of the eProCon Integration layer includes three service types: 1) The eProCon Integration Service, which provides data integration of existing information services, 2) Update Service, which enables information providers to access and update product data and 3) Catalogue Service, which enable buy-side applications to retrieve catalogue and product information in standard format. The eProCon Integration Service exchanges product information using the proprietary eProCon Specification, which was especially crafted to optimize the communication process between the existing services. The specification is composed to three main data elements which can carry information about companies, products and documents. For IAI-IFC 2x compatibility, elements include property definitions, property sets, classification and other elements that match the IFC model concepts. The Update and Catalogue services on the other hand use the standard XML/B2B catalogue interchange format BMECat, which is an enriched data protocol and widely supported by business applications. BMECat can similarly carry information on properties (features), hieratical classification systems and varied document types that make it ideally suited for both purposes.

The Provider abstract layer encapsulates the service functional parts: a) an adapter/provider framework to achieve retrieval and mapping from native data repositories to the required application protocol and b) delegation framework that enables delegation according to the requesting application protocol.

The adaptor/provider framework dynamically incorporates components through an external configuration file that enables adoption and support for different business protocols, versions and integration strategies. The configuration into separate functional units aimed for easier scalability, load balancing and future expandability.

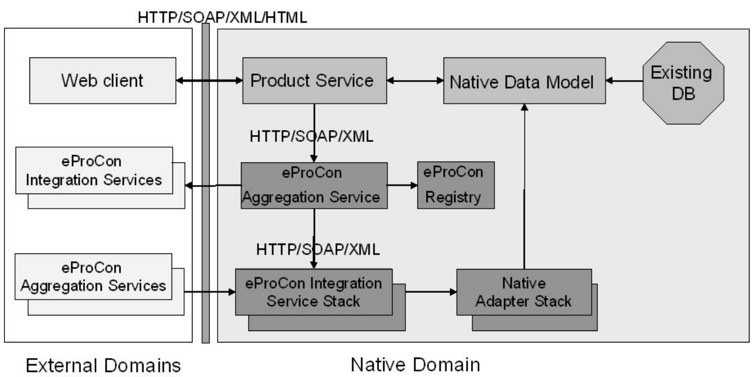

Figure 5: Implementation of the Integration platform

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The implementation architecture of the eProCon integration platform in existing information services environments is shown in Figure 5. Development aimed for easy transition of the native product services to the Nordic virtual service. The architecture provides for, besides the integration services, an aggregation service that handles transparently request forwarding between the individual Nordic services enabling users to search across the Nordic Domain.

3.3 *GDL Objects Way to Re-usable Product Information*

Intelligent design objects are important to Architects and Engineers because they accelerate work, make project management easier and allow them to design instead of just drafting. As product modeling technology is getting more mature and more widely accepted in the industry the requirements for smarter "3D objects" are surfacing instead of drafting in 2D or 3D. A building element like a window needs to be able to carry intelligence or building construction knowledge about itself. Intelligent building objects behave parametrically. Parameters are rules embedded in the object that govern its appearance and behavior. A window might have parameters that allow the architect to define its height, width, number of panes, material and frame style. Similarly a wall might contain parameters to define its composition, surface, finish, height, and connection to other walls, columns, floors and ceilings. The internal logic of the intelligent object also knows about manufactures business rules and is an integrated part of the object component. For instance a window knows that available sizes delivered follow a modular system and no sizes can be used in between.

GDL technology (GDL) is an intelligent object technology, a base technology to be integrated into tools. GDL is a container for product data that understands the logic of the product being described (virtual product), can evolve into 3D geometry, 2D geometry and a property specification and can include information from external sources such as databases and Excel sheets or from the web. GDL objects can describe simple components or very advanced products. GDL contains all of the information necessary to completely describe building elements as 2D CAD symbols, text specifications, and 3D models for calculations and presentations. Building product manufacturers can define their entire product families efficiently, as parameters can be constrained to pre-set values to reflect available product styles.

One of the significant features of GDL objects is that they can export IAI IFC files, and can be dragged and dropped into e.g. CAD systems equipped with GDL support - the GDL ActiveX control - the key component for exchanging and transmitting object information between applications and systems. The GDL-AXC is in it self a mini CAD system that can be used in web applications or regular application for accessing GDL objects. It provides for visualization, configuration and CAD drag and drop import.

3.4 *Smart Product Information – Taking the Next Step*

While GDL object provides a holistic method for re-usable product information including full geometry directly in design systems its main drawback is that although publicly open and free it is still a proprietary technology and continued support remains uncertain for that reason. Besides, creating GDL objects requires special skills in the scripting language that can be seen as a drawback for wide up-take, especially by SMEs with limited skills, but complex product ranges.

"Product Sheet" as a type of product documentation has been in use by the Nordic building centers and is widely recognized by the industry as reliable, quality information about product ranges. This type of product documentation has also been agreed on by the information providers and for many SMEs it is the only available information they provide for industry practitioners.

The idea of the eProCon consortium is to expand on the notion of the Product Sheets to transition to smarter product documentation or "Smart Product Sheets". For this purpose W3C Scalable Vector Graphics (SVG) (W3C-SVG) is being tested as the enabling technology. SVG is an open XML-based language for representing two-dimensional graphics and adding interactive elements through linking, events, and scripting. Scripting also enables access to external data sources and inclusion of ActiveX/Applet Objects such as the GDL object viewer. Consisting only of XML and scripts they can be dynamically generated by any middle tier software or web service.

During testing, product configurators have been produced that promise interesting results. One of the benefits the SVG provides over the currently used Product Sheets is allowing manufacturers to maintain their distinctive market values and differentiating product characteristics by introduction of personalized templates while still maintaining a set of standard information currently available in existing Product Sheets. Smart Product Sheets can be seen as the dynamic media necessary to bring together the varying information types required by the industry and for serving information into applications.

The initial vision for a Smart Product Sheets includes:

– Smart, aware of its re-usable content and context
– Information content dynamic, pulled form different sources in the building centre (and outside)
– Presentation having different media types

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- Interactive and self configurable
- Smart in presenting data to the viewer in right amount and according to viewer interests and profile
- Smart in presenting in right format and context based on viewer device e.g. product card for handheld devices.
- Personalized to manufacturer taste and marketing strategy.

4 RESULTS AND CONCLUTIONS

The paper presented a solution for integration of building product information services in the Nordic countries into a single virtual service and extension of these services to add value for product manufactures when advertising information about their products.

To date, the project has produced first versions of the specifications for both integration services and product portal pilots. Also, first prototype implementations have been demonstrated. Currently, the project is working towards finalizing the specifications, taking into consideration the first implementation experiences, as well as bringing the prototypes closer to commercially viable level, and at the same time testing ideas for new content type presentations, "smart product sheets".

GDL provides a key technology for product information to become re-usable in design systems. During the project, generic design object and parameter population from middleware to generate manufacturer specific object was developed as well as a GDL object broker for storing GDL objects centrally in relation to the information services. This enables them to make GDL objects available in their systems through links with minimal effort.

The co-operation between the Nordic Building Centres is based on a common business model agreement, which stipulates how manufacturers can make their product information known in the virtual service in different Nordic languages and classification systems e.g. when a Finnish manufacturer wants to make his product information available in Swedish and classified according to the Swedish national classification system. The Business model in a way circumvents the problem of multiple classification systems that exist in the Nordic countries and the language barriers between the countries, but yet makes it possible, from the user point of view to be seen as a single virtual service.

Naturally, a further study and development work of the proposed platform is still needed especially in the area of multi-lingual organization of information across Nordic boarders. Even if the Nordic countries have the political will and backing to push forward, the lack of major players in the industry to take the lead in initiatives of this kind will always be an obstacle in advancement of standardizing product information for the construction industry, dominated by SMEs. Currently, business value and market demand will be the drivers – the technology exists but economic motivation of local market information providers is not as clear.

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Prototype of semantic interoperability between different modalities of 2D-CAD design

C.A. Jacoski
Technological Center of Regional University of Chapecó - UNOCHAPECÓ, Chapecó, SC, Brazil

ABSTRACT: The diffusion of specific computational tools for Architecture, Engineering and Construction (AEC) has generated a great amount of digital data in the last years. However, it is necessary for the sector to promote a standardization of such data so that they can be shared among the participants and partners of a design project. Trying to correct the problem of information exchange and mainly of data interoperability, a research project was carried out within design offices in the south of Brazil, identifying the problems and quantifying losses according to the lack of interoperability. For generation of information starting from the CAD design and as a way of enlarging the communication among the partners, a study was held about the use of the IFC classes (Industry Foundation Classes) – a pattern used to transfer data among design modalities. The result was an application of syntactic conversion of attributes of the IFC classes for XML, to attest the viability of technical integration and to transfer information to a web-based environment. As a result of the investigation, a prototype was elaborated for transferring information from CAD design to web-based applications. By using IFC classes, a program was developed in Java language for the syntactic and semantic exchange, with the automatic conversion of the information for standard XML. It was observed that the decrease of interoperability problems, checking the viability of technical integration of the design with the shared information through the web.

1 INTRODUCTION

Many studies carried out in the research area of civil construction indicate that the fragmentation of the productive chain is one of the major problems in this particular area. Studies such as those proposed by Aouad (2000), Construction Task Force/UK (1998), Banwell (1964) and Higgin & Jessop (1964), for example, reveal that a great number of communication problems in project design are often caused by lack of coordination, low efficiency, poor quality, and isolated corrective measures. Latham (1994), in his "*Review of Construction Procurement*", has confirmed the same findings in which certain working practices have a negative effect on the relations between agents, and as a result, these practices may increase costs and lower the quality of construction products.

The findings of the aforementioned studies show how difficult it is to solve these long-standing problems which occur in various different countries, each one with their own specificities. In order to overcome these difficulties, structural solutions in the area are necessary along with the integration of agents participating in the construction processes and their adaptation to current computer tools available on the market, thus softening such difficulties during the interchange process of information between agents.

Nicolini et al. (2001) points out that nowadays there is an emerging consensus not only on diagnosis, but also on what needs to be done in order to find an effective solution to the relations between agents in the productive chain. A more relational and consistent way must be created in order to foster collaboration in the activities along the chain, thus reducing interruptions in the process usually caused by poor communication, fragmentation of the industry and of a disintegration culture (i.e. agents acting as adversaries).

Today’s approaches for exchanging electronic and paper-based project information (e.g. standardized semantic models, software wrappers, and electronic or paper-based sharing of visualizations and documents) do not respond to the information interaction challenges of project teams.

Future research and applications will show to what extent standard-based product models combined with computational mechanisms – which infer information not explicitly available from a product – can support the specific information needs of the project (Haymaker et al, 2000).

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Be that as it may, actions become necessary in the investigation of the existing specific problems in the sector. In this paper, I would like to explore the problems related to the exchange of information between participants in a design project, focusing on the interferences between the types of design.

2 INFORMATION EXCHANGE IN THE DESIGN PROCESS

Information exchange is essential for the production of a quality design. Many actions taken by companies and researchers aim to enable an adequate integration of designers with the use of computational tools.

However, research still needs to formalize the modeling, sharing and exchange of scalable, testable, and sound information to support decision making in project teams (Liston et al. 2001):

- The current information exchange mechanisms need to be complemented with an approach that responds to the needs of project teams.
- Interactive multi-user, multi-application, and multi-device user interfaces need to be designed.
- The effectiveness of project teams in making decisions needs to be measured to assess the power and generality of the information exchange mechanisms and the user interfaces.

By observing the new conditions for the integration of agents in the process, this relationship can be extended to other participants in the productive chain. According to Murray et al. (2001), many advantages can be obtained from the Inter-relationship between agents. The involvement of the contractor, for example, in the design elaboration process can add improvements to the process as whole in at least two ways:

- The first one has to do with the fact that the contractor can provide information that eliminates future unnecessary costs.
- The second one is related to the fact that designs usually lack significant detailing, and in this sense the contractor can provide information that can be used to extend constructability, thus contributing to the improvement of the quality of the project.

The increase of productivity, which is always the main focus in the design process, can be achieved through a rigorous analysis of the requirements in the initial phase of the project, the incorporation of the difficulties found in subsequent phases, and the rigid control over the modifications until the end of the building process, enabling a reduction of time in the design phase and in the number of requests for modifications. In this sense, knowledge management, which maintains a symbiotic relationship with the advances in computer technology, can become a great ally in searching and extracting information from databases by means of computational tools.

The ever-growing use of Information Technology (IT) as an integration instrument has opened up new possibilities for improving data flow between the participants of a design process, reducing errors, improving coordination, maintaining the integrity of data, and as a consequence improving the quality of design (Faniran et al, 2001).

One of the most important benefits offered by IT to the civil construction area is the automation of processes (Love and Ganasekaran, 1997). According to Aouad (2000), various factors interfere with the possibility of integrating technologies of information in the construction industry such as the fragmentation of the productive chain; lack of standardization in the exchange of information between systems; lack of transparency in the processes; poor quality in the management of industries, companies and projects.

Many studies have focused on the improvements that have been achieved in the processes: (i) through the integration in 2D and the modeling in 3D (Anumba, 1989), graphical and non-graphical data (Anumba and Watson, 1991), integration of databases (Brandon and Betts, 1995), the use of interfaces and data structure (Anumba e Watson, 1992; e Li et al., 2000), the development of web-based environments for the integration of projects, among others.

Despite the steady growth of research in IT, there are still lots of questions that need to be answered in the construction sector (Love et al, 2000). Various IT-based projects implemented in the construction sector are cited by Love (1998): COMBINE, COMMIT, ICON, SPACE, RISESTEP, CIMSteel, CONCUR, GEN, VEJA, RATAS, ISO-STEP, IAI/IFC. Design projects of network integration in the construction sector are presented by Faraj, et al (2000): Project ATLAS, COMBI, OSCON, OPIS, plus the aforementioned COMBINE, ATLAS, RATAS.

The question of language is pointed out by Cutting-decelle et al. (2001), in the LEXIC project which suggests the use of a particular language system to solve the problem of meaning among the terms used in construction. In this sense, the PSL (Process Specification Language) created by the National Institute of Standards and Technologies (NIST), in order to standardize the language of process specification, thus serving as an inter-language tool for minimizing issues of interoperability between applications and processes.

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3 REQUIREMENTS FOR STANDARDIZED INFORMATION

The increase of information generated by computational tools (e.g. CAD) in design projects has created a growing concern about how this information should be transferred automatically [In the case of if searching an effective interoperability, if it not only needs a syntactic equivalence enters the entities represented for the systems, but also the equivalence of concepts and meanings of these entities]. Many efforts have been made in order to contemplate standards in adjusting "common Projects" for the community that uses the same parameters of data. Some works offer systems based on the concept of ontology. In the case of the organization of ontology, some basic characteristics must be taken, as the follow:

- Open and dynamic: To adapt it to the changes of the associated domain, having to be automatic;
- Scalable and interoperable: It must be easily scalable for an ample adaptable domain and the new requirements;
- Easy maintenance: It must be at the same time dynamic and of easy maintenance for specialists;
- Consistent Semantically: It must keep the coherent concept and relationships;
- Independent of context: The ontology does not have to contain very specific terms in a certain context, because it deals with sources of data of wide scale;

One of the first semantic standards for the construction area was developed in 1986 by the AEC STEP group, which presented a proposal of indefinite and open standard (with the contribution of Jim Turner and Wim Gielingh (Tolman, 1999)). Through a model of general reference, called GARM (General AEC Reference Model).

More recently the efforts to develop the STEP, together with the spreading of the IFC created by the International Alliance for Interoperability (IAI – 1995), represent the most recent efforts of standardization in the construction sector.

Despite the present efforts, many difficulties have to be faced when one of the standardization systems are implemented, some of these difficulties are described as follows:

- The uncertainties regarding the data obtained from the transference and integration of software information;
- The necessary communication between the industry and the standardization is inefficient;
- Existence of small project teams, with focus on the different types of customers, thus limiting the standardization of solutions;
- The size of the companies is an important factor, therefore the standardization in small companies is relatively easy if compared with great companies having great volumes of procedures;
- Some questions, for example: the incompatibility of the hardware and the interoperability of software enter the chain of participants.

4 THE RESEARCH IN DESIGN OFFICES

The current research has investigated the problems related to the use of information among the participants in a design project, suggesting solutions based on recent technologies (it is important to stress that the 2D design was the only one used).

Resultant of this investigation consolidates a suggestion of information parameters to a protocol of distributed information among the agents of the design.

This study has contributed to the identification of the information necessary to manage interference problems among design projects, suggesting how these data can be modulated and used with the aid of computational tools and the Internet. The use of a standard in the transferring of information led to a model, which is adapted to the existent procedures in the process design and increased as innovation the resources of the IFC classes.

Also as way to present and defend the necessity of incorporating new procedures and tools for the integration of the design process, the internal processes of the offices which were investigated and the knowledge they accumulated and registered were collected, not the mention the accumulation of information regarding the following points:

- Problems resulting from lack of interoperability;
- Activities of manual detailing;
- Problems of data exchange;
- Difficulties of quantification and budgets;
- Stoppage for revision of projects;
- Extra time with mitigation and expense with modification of design.

During the research process in the design offices, the following mechanisms were considered:

- Structure of the collection of data, identifying the significant internal questions;
- Instruments of work: the analysis of documents and processes of each office;
- Characterization data of the office through a structuralized spread sheet;
- Accompaniment of the diverse stages of design, with control of cost, time, modifications and deficiencies of the project;
- Dataflow of the process, identifying the activities carried out and the main procedures adopted; the Interview structuralized with specialists, searching to absorb the intellectual capital of the company.

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The observation of the design process was carried out having as its basis a division of the stages, for each modality of design: architectural design, structure, HVAC, electric.

Inside the process, the existing elements of information and relations were identified with the agents in the development of the design process.

Each occurrence of data exchange, use of information for another participant, or any action affecting productivity was identified and refined in a quantitative spreadsheet. The results are presented below:

Table 1. Loss in design (2D) due to lack of interoperability

Design modality	Loss in design (%)	General
Arquitectural	31	**22 %**
HVAC	24	
Eletric	19	
Structure	16	

In view of the identified losses, a computer program (translator) was created to help to eliminate the losses detected in the research with an exchange of information between the participants making use of web. The functioning of the software is identified as follows.

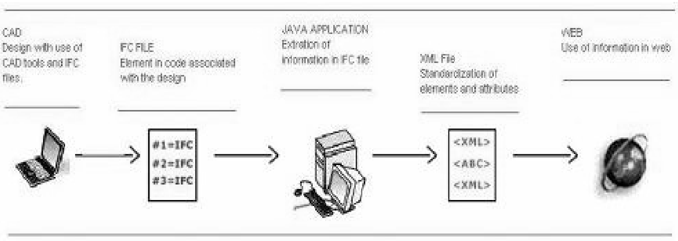

Figure 1. Caption Development process of software to resolve communication problems in design.

5 CONCLUSIONS

The solution presented in this paper shows that it is possible to transfer information automatically from a drawing environment (CAD) to a web-based environment, through literal information (i.e. using transcribing language XML of classrooms IFC).

This type of syntactic conversion of attributes of IFC language for use in XML can become a valuable tool for some of the processes in building design. As previously shown, some standards are already being developed and they lack exactly the association of IFC classes with standard XML.

The experiment has confirmed the possibility of using simple tools, as the prototype developed herein, to solve problems that still represent a dilemma to the development of the design process.

Moreover, the software (translator) developed demonstrates the practical viability of the technical integration through the web, resulting in an experience that offers significant advantages to the process of exchange of information in design.

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Experiences with 3D and 4D CAD on Building Construction Projects: Benefits for Project Success and Controllable Implementation Factors

J. Gao & M. Fischer
Civil and Environmental Engineering, Stanford, USA

T. Tollefsen & T. Haugen
Faculty of Architecture and Fine Art, Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT: From our experience of a wide range of questions that A/E/C professionals are asking, the AEC industry is facing the challenge to determine the benefits of 3D and 4D CAD and what it takes to implement this advanced technology. This paper focuses past experiences of using 3D and 4D CAD on building construction projects.

By reviewing a collection of A/E/C projects from the United States, Norway, and elsewhere, the authors demonstrate: 1) 3D CAD allows improved design, team collaboration, and smooth project execution; 2) 4D CAD enables the exploration and improvement of the project execution strategy, facilitates improvements in constructability with corresponding gains in on-site productivity, and makes possible the rapid identification and resolution of time-space conflicts. These experiences acknowledge 3D and 4D CAD as a key driver and a primary enabler for better design of Product, more cohesive Organization, and more efficient Process (POP) that lead to project success.

This paper also illustrates the real implications of working with 3D and 4D CAD. A detailed case study on the Pilestredet Park Project in Oslo, Norway demonstrates: 3D and 4D CAD is not simply a question of investment but depends more on appropriate planning and managing the implementation, i.e., understanding what you can and want to do, identifying right timing, people, data, tools, and putting 3D and 4D models in the right process to reap the benefits. This outcome will enable facility managers and A/E/C service providers to make informed judgments about the appropriate controllable factors in implementing 3D and 4D CAD.

1 INTRODUCTION

One of the challenges of adopting 3D and 4D CAD ("time" is the fourth dimension added on the 3D CAD) in the construction industry is the uncertain payoff. Until AEC firms are convinced that the benefits are real, relatively few of them will embrace 3D and 4D CAD. For example, the industry guest speakers for the Stanford Construction Engineering and Management Program frequently discuss why some firms take the initiative to invest in 3D and 4D CAD and others do not. Two main explanations for the decision made have emerged: a visionary leader and the threat of intense competition. Therefore, companies adopt state-of-the-art 3D and 4D CAD based on their strategic analysis of its benefits. To fill the gap between strategic vision and operational reality, we need multiple case studies of actual uses of 3D and 4D CAD on a variety of projects as well as the reported benefits from the uses of models. Multiple case studies can be one of the most cost-effective methods for learning from all the experiences of pilot projects, and for passing these experiences on to implement 3D and 4D CAD more efficiently on future projects. If these cases demonstrate the wider applicability of 3D and 4D CAD to AEC companies, then the case studies may well become an important strategic tool for evaluating the effectiveness of IT and justifying investments in IT (Schwegler et. al. 2001).

One of the challenges in implementing 3D and 4D CAD is that its use is often limited to taking advantage of the tools' visualization power to help win bids. Using 3D and 4D CAD as a marketing tool to gain a competitive edge will not be sustainable in the long run. In the long term, companies will need to figure out how to deploy such visual models effectively and efficiently across the duration of their projects (Fischer and Kunz 2004). This requires the identification of the key controllable factors in an implementation plan.

Bazjanac (2002) pointed out that "it will probably first take a new generation of consultants to show industry the benefits of changing the work paradigm, and a new generation of educators to teach future professionals how to do it before 3D and 4D modeling of buildings becomes wide-

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spread." This paper, by reporting on empirical results, aims to take a step in that direction. The first part of the paper reviews 3D and 4D applications on twenty-one A/E/C projects from the United States, Scandinavia, and East Asia. The authors synthesized the various modeling purposes on these real projects and the reported benefits from the uses of 3D and 4D CAD for different modeling purposes. The second part of the paper details a case study on the Pilestredet Park Project in Oslo and identifies the appropriate controllable factors in implementing 3D and 4D CAD.

2 VARIOUS USES OF 3D AND 4D CAD AND REPORTED BENEFITS ON CASE PROJECTS

The multiple case studies involve twenty-one construction projects, on most of which researchers and students at the Center for Integrated Facility Engineering (CIFE) at Stanford University participated in the process of 3D and 4D modeling and documentation. All case studies are fairly recent, discussing the benefits and implementation of 3D and 4D CAD in the late 1990s and early 2000s (see Table 1). The observation on these case projects showed that the implementation of 3D and 4D CAD and the benefits derived therefrom are heterogeneous with respect to modeling purposes and project phases. Appendix A summarizes the various uses/purposes of 3D and 4D CAD as well as the reported benefits (as manifested by case examples) in different project phases.

All design and construction projects follow a general process that proceeds through certain phases from inception to completion, with minor variations depending on the requirements of the project. The phases in the design and construction process that are most common to engineering design and construction projects are: Conceptual/Schematic Design; Design Development, Detailed Design, Construction Documents, Preconstruction (proposal/bidding/procurement) and Construction. To improve the existing process using 3D and 4D CAD, we need to look at each phase and determine specifically how this new technology can benefit AEC projects.

2.1 3D and 4D CAD used in the Conceptual/Schematic Design Phase

In the conceptual/schematic design phase, 3D CAD is used for client briefing. Modeling the facility in 3D "walk-through" helps the owner to visualize the scope of the facility. In Case 5 for example, the architects cut sections and other views from the ArchiCAD product model and generated more than ten virtual walkthroughs at different phases of the design in support for spatial visualization and communication with the clients and end-users.

At this stage, 3D CAD is also used in a virtual reality environment to support conceptual design reviews for the required sightlines, acoustics, or lighting/interior finishes so that the best functional space can be provided for end users' needs. 3D

Table 1: An Overview of Case Projects

Case #	Case Projects
1	McWhinney Office Building, Colorado (1997-1998)
2	Sequus Pharmaceuticals Pilot Plant, Menlo Park (1997- 1999)
3	Experience Music Project, Seattle (1998 - 2000)
4	Paradise Pier, Disney California Adventure, Los Angeles (1998 - 1999)
5	Helsinki University of Technology Auditorium-600 (HUT-600), Helsinki (2000 - 2002)
6	Baystreet Retail Complex, Emeryville (2000 - 2002)
7	Genentech FRCII, South San Francisco (2001 - 2003)
8	Walt Disney Concert Hall, Los Angeles (1999 - 2003)
9	Hong Kong Disneyland, Hong Kong (2001 - 2005)
10	Pioneer Courthouse Seismic Upgrade and Rehabilitation Project, Portland (2003 - 2005)
11	MIT Ray and Maria Stata Center, Boston (2000 - 2004)
12	Banner Health Good Samaritan Hospital, Phoenix (2002 - 2004)
13	California Academy of Science Project, San Francisco (2003 - 2006)
14	Terminal 5 of London's Heathrow Airport, London (2003 - 2007)
15	Residential Building in Sweden, Stockholm (2002 - 2003)
16	Pilestredet Park Urban Ecology Project, Oslo (1997-2005)
17	GSA Regional Office Building, Washington DC (2004-2007)
18	GSA Jackson Courthouse, Jackson, Mississippi (2004-2007)
19	Samsung LSI Fab Facility, Kiheung, Korea (2004-2005)
20	Camino Medical Campus, Mountain View, CA (2004-2007)
21	Fulton Street Transit Center, New York City (2002-2007)

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models help to resolve functional issues before construction starts.

In the schematic design phase, the owner often initiates 4D CAD for strategic project planning. Especially for a large-size project executed by multiple prime contracts, 4D models help the owner strategically plan the project milestones and determine the optimum contractual work packages. In Case 4 for example, the owner successfully used the 4D visualization to determine the contracting packages by visualizing the break-up of project scope into various contractual "chunks" in the context of the 3D model and by seeing the progression of these contractual 'chunks' over time in the context of the 4D model. The 4D model was also used for phased handover, i.e., how to manage the scope and sequence of bid packages so as to close the gaps as work was handed off from one party to another. On another project (Case 9) from the same owner of Case 4, the 4D model coordinated the smooth process of handing over the preliminary site from the local Department of Public Works to the owner's construction team before the deadline.

2.2 3D CAD used in the Design Development Phase

In the design development phase, 3D models shift some of the project team's efforts from producing traditional outputs (e.g., design documents) to more value-adding work (e.g., exploring more alternatives). For instance, on Case 5 the architects reported about 50% time savings in the design documentation phase as a result of object-oriented libraries and catalogues, parametric properties, knowledge reuse, and various automation tools. Furthermore, the 3D models modeled three design and two life-cycle alternatives. The savings potential through life cycle cost comparisons was in the 5 to 25 % range of the project's life cycle costs.

During the development of a building project, changes that stem from design discrepancy checking are constantly made to fine tune the design. Traditional methods typically do not facilitate change effectively. The creation of design documents can be laborious and require a vast amount of low-value drafting tasks including manual checking of work. On the project (Case 5), the model checking system in 3D CAD supplemented the designers' personal skills by automatically highlighting design errors (e.g., collision of building components). Moreover, Case 20 demonstrates that general contractors can be involved early in the design development phase to validate the design, to make sure that the construction methods and techniques are considered during the design process, and to give feedback to the architect.

2.3 3D and 4D CAD used in the Detailed Design Phase

In the design development documents, many of the systems that must be included - mechanical, electrical and structural - are shown schematically, but not in detailed depictions of the manufactured items that go in the building and the systems that tie into them. The GC distributes these documents to the different subcontractors that are involved in the project. The subcontractors submit back to the GC the information associated with their proposed product, which entails specific work plans and shop drawings. The GC often initiates 3D and 4D CAD to coordinate the detailed design process. The subs are responsible to provide 3D models that are constructible (for example, if a slab will be poured in five sections then the model should represent the slab as five distinct objects.) The GC then puts together a 3D coordination model and uses the collaborative weekly work planning meetings to assign 3D objects to the activities to create a 4D simulation. The 3D coordination model establishes an interface between the different systems involved in the project and can be used to check the accuracy of the design. The 4D simulation can ensure that the works carried out by different subcontractors do not interfere. In Case 14, using 3D models for design coordination made it easier to spot and to dramatically reduce the number of design errors. Onsite RFI's were reduced by 80%. On another project (Case 2), none of the change orders in this project resulted from unexpected design conflicts among the MEP work. There were 60% fewer requests for information because many of the issues were resolved through the detailed design coordination process rather than the RFI process. In addition, the use of 3D models enables the creation of a collaborative project management context among subcontractors whose interests are often conflicting with each other. It is primarily because in a 3D environment, subcontractors are able to see potential consequences of actions prior to taking them. This lowers risk and cost for the subcontractors because the 'unknowns' are less looming.

2.4 3D CAD used in the Construction Documents Phase

3D CAD expedites the production of construction documents. 3D models allow the generation of elevations and plans in a single step as well as modifications to one model. During the construction documents phase of Case 11, 2D plans extracted from the CATIA model were detailed in AutoCAD to create contract drawings and specifications. As new data was created in this phase, it was imported back to the CATIA model, where

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attribute information was added to design elements.

In addition, 3D modeling in Case 14 was used to synchronize drawing production with material procurement. The concrete contractor faced an extremely congested site that accommodated only three day's worth of materials in support of construction. The batch size of drawings from 3D models was aligned with the batch size of the work packages on site. A small batch size of shop drawings and frequent orders reduced the lead-time on materials from 10 days to 3 days.

2.5 3D and 4D CAD used in the Preconstruction and Early Construction Phase

Bills of materials can be exported from 3D models to support the cost estimating and procurement process. This quantity takeoff information is extremely valuable in estimating the cost of the building as well as in estimating exactly how much material and labor will be needed in construction. In Case 2, the GC reduced the estimating effort by 25% through using "3D plus cost" integration. In Case 5, automated cost estimating led to an 80% reduction in time to generate cost estimates (including model analysis and creation of alternatives), as well as to a cost estimation accuracy of +/-3%.

Dimensions of prefab components can be exported from 3D models to automate the fabrication process. In Case 3, the 21,000 eccentrically shaped metal shingles that form the outer shell were cut by lasers guided by data generated directly from the modeling software. This ensured that fabricated panels would line up precisely on site and no or little field-fitting would be required.

3D CAD can also be used for site dimension control during the construction process. Taking Cases 3, 8, 11 for examples, laser surveying equipment linked to CATIA 3D models enabled each piece to be precisely placed in its position as defined by the 3D model.

At the proposal stage, 4D models can be used in presentation to help the owner visualize the future and demonstrate that the GC has the best approach for executing the project. Following the experience on Case 12, 4D models helped the GC in winning two major hospital expansion projects and a project for the construction of a new hospital with the same client.

4D CAD can be used as part of the bidding process to demystify the design and make construction bids closer in range. In Case 4, the owner's estimate and GCs' bids were very close. The bid results were within +/- 2.5 percent of the budget.

4D CAD can improve schedule reliability and executability in the preconstruction phase, which enables a smooth progression of construction activities on field. As demonstrated by all the 4D cases, the 4D modeling process makes it very clear where complete scope and schedule information exists and where additional thinking about the missing information apart from 3D models and original schedule is needed. Meanwhile, by requesting clarifications during the 4D modeling process, the project team can often clear up some logic bugs in the schedule while there is still time for such adjustments without detrimental impacts on the project. Early discovery of conflicts also increases the accuracy of the schedule.

4D CAD can also be used for constructability review in the preconstruction phase to detect potential site logistical challenges and accessibility problems. On Case 20, the 4D model helped work through different scenarios of logistics and sequence planning so that decisions about logistics could be made quickly. One example of the decision that had to be made is how the underground parking structure would be integrated with the office building. The scenario shown in the 4D model was much clearer than that shown in the 2D drawings. The use of 4D models increased the number of RFIs during the preconstruction phase. However, by having 4D model, the GC expects to reduce the number of RFIs in the construction phase.

4D CAD can assist in trade coordination weeks before work starts on field. For the purpose of construction coordination in 4D, no activity should be longer than 10 days. Therefore, a 4D coordination model should reach the level of detail at which the day-to-day operations of the various subcontractors (i.e., when each of the subcontractors would be working in each zone) are represented. For instance, in the detailed model in Case 11, the geometry was broken down by individual metal panels, corresponding to each day of construction. During the construction phase, viewing a 4D model with trade management personnel elucidated work flow and provided visual justification of the general contractor's work logic. Bringing various subcontractors together to view the 4D model helped participants to predict which areas would be congested and enabled the general contractor to coordinate activity in the staging areas for the trades and resolve certain conflicts in the virtual model before they became real problems. In addition, 4D coordination models help focus the subcontractors' attention on the project and foster collaboration between them. In Case 8, the project's general superintendent estimated that for every hour he spent working on the schedule, he needed about six hours to communicate the schedule. The 4D model enabled him to reduce that time while increasing the amount of subcontractor feedback and commitment.

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To reap the full benefits of 3D and 4D CAD as delineated in the above review of the multiple case studies, we need to identify controllable factors in an implementation plan. The following example details key controllable factors of 3D and 4D CAD implementation, i.e., the why (modeling purposes), when (timing), who (stakeholders' involvement), what (modeled scope and level of detail in data model), how (software tools and work/information flows), and how much (estimated time and efforts).

3 AN EXAMPLE: THE PILESTREDET PARK URBAN ECOLOGY PROJECT IN OSLO, NORWAY

The objective of the Pilestredet Park Project [1] was to (re)develop and construct urban ecological housing and office buildings, which fulfil a broad set of quantified environmental goals. Approximately half of the original floor space were demolished (55,000 square metres), and there have been built around 85,000 square metres of new construction, plus around 55,000 square metres of renovation to existing buildings (Butters et al. 2002).

3.1 Modeling Purpose

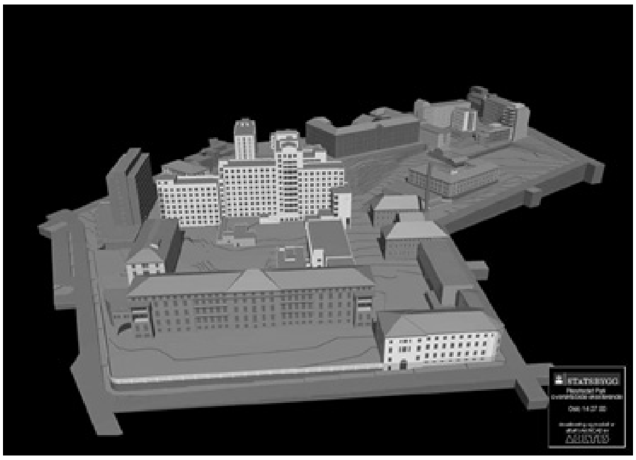
Given the strict environmental demands, no-one really knew how this was going to be done or how it would work out when the project started. The initial step for the owner (Statsbygg)[2] was to set up interdisciplinary expert teams, with resource people and consultants from different fields, to discuss and define the main ecology criteria. On the basis of these preliminary studies, the Urban Ecology Program was formulated. Having thus far outlined the background, the existing situation, the intentions and goals of the project and a total construction schedule given within 5 years, the owner realized that they might better visualize and "communicate" this large urban project within own staff, among involved architects, planners, consultants, public, neighbours, constructors and the municipality by using 3D and 4D models.

3.2 Timing

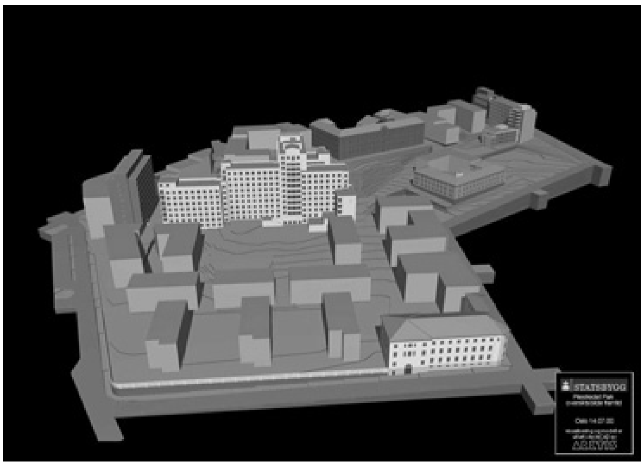
A 3D model that modeled the site and buildings was built in half a year in the schematic design phase. Simultaneously software developers were working with the 4D coupling module (API), and as the first samples of the API arrived 4D models were established in beta testing. About a year after the3D/4D initiative was taken, the requirements to the 4D model were fulfilled and videos and pictures were produced and used in the following planning, demolition and construction process (Kvarsvik 2004).

3.3 Stakeholders' Involvement

Statsbygg initiated the 3D and 4D modelling in 1998. There has been firm backing for the project right up to the very top of the organization both to go through with an ambitious urban ecology initiative and the 3D and 4D effort. The Graphisoft supplier in Norway, Arktis AS, built the 3D model. Graphisoft in Hungary achieved the contract to develop a program (called API) linking the 3D model to the schedule. A broad range of participants, including Statsbygg's own R&D director, Faculty of Architecture and Fine Arts at NTNU, the Pilestredet Park Project Manager, Oslo Municipality, and the R&D department of a large Norwegian constructor, were represented in the technical board



Before



After

Figure 1: 3D illustrations from the Pilestredet Park Project in Oslo, Norway

[1] Total reconstruction of an abandoned hospital area in the center of Oslo, 70,000 square metres urban site, with an agglomeration of hospital buildings from 1870 to 1990.

[2] Statsbygg – The Norwegian Directorate of Public Construction and Property

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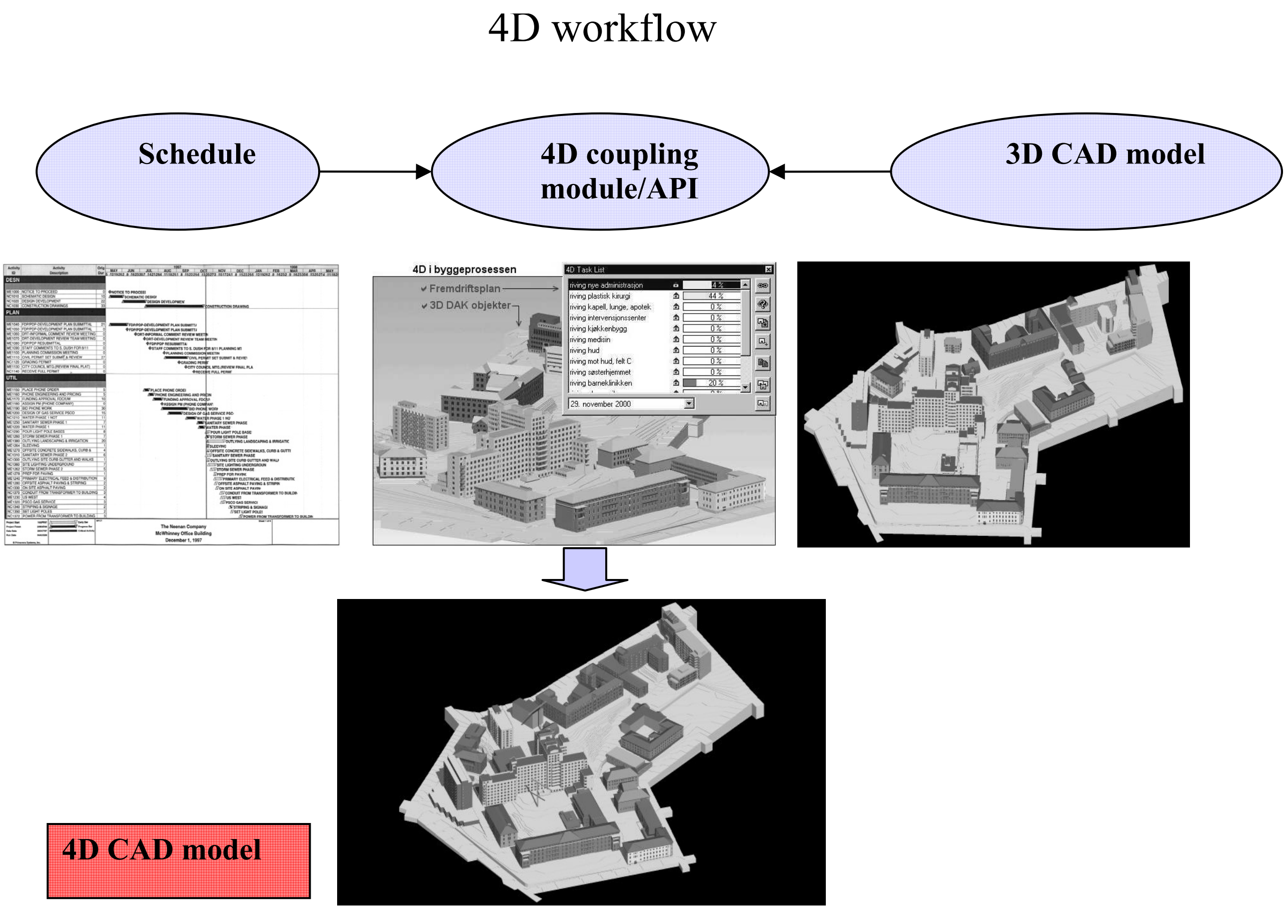

Figure 2: 4D illustrations from the Pilestredet Park project in Oslo, Norway. This figure illustrated the connection and dependencies between the 3D CAD software and the project schedule for the purpose of 4D modeling. Each floor in every building had specific dates for the start and end of construction, and the activities are color-coded for the visualization in 3D-movies. (Statsbygg 2001)

3.4 Modeling Tools

The requirements/specifications were established for the project in the first phase (Kvarsvik 2003):

1 The 3D model should represent the complete scope of the project that includes the site and buildings (exterior shell and interior floors). At that time, this was the largest 3D model built in Norway (onshore).

2 A coupling module (API) should be developed to enable the link between the construction schedule and the 3D model (Figure 2). The API had to be a part of or operated from the CAD tool.

3 The construction schedule has to be linked to the 3D model to produce a visual construction plan, i.e., a 4D model. In the construction schedule, each floor or object in each building must have dates for the start and end of construction.

4 The 3D model must be easy to use so that the professionals in the project management with limited modeling skills can utilize 3D and 4D tools on the job.

After establishing the modeling specifications, Statsbygg looked for suitable software solutions that could be operated within the project team. After market research, interviews and testing of a few existing 4D softwares, Statsbygg chose Graphisoft's ArchiCAD "Virtual Model" (a database) and Microsoft Project as the two programs used in the project. ArchiCAD was chosen because it is an object-oriented "intelligent" software (i.e. the objects can carry information). Microsoft Project was chosen because this was the most-widely used scheduling software in Norway at that time.

3.5 Modeled Data

- The different activities were colour-coded. In the Pilestredet Park Project, five different types of activities were illustrated: Build – (blue); Demolish – (green); Restore – (orange); Temporary (provisional activities on site, e.g., rigging, cranes, staging, etc.) - (light blue); Freeze (closed-off) - (red).
- The 4D model had a low level of detail which only modeled exterior shell and interior floors for every building

Modeling Workflow:

- The activities were defined, developed and edited in the scheduling program.
- Working with the 3D model in ArchiCAD the Construction Simulation API was started, and the schedule was imported. The activities could also be defined, developed and edited directly in the Construction Simulation tool (Kvarsvik 2004).

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– The correct links between the 3D model and the activities were worked out by Statsbygg in the API.
– Statsbygg focused on how to improve the information flow and the communication among actors throughout the complete building process. Statsbygg tested and visualized the status of the project (the whole project or part of it) by a certain date or a particular construction phase, either in the elevation or the plan or in the 3D or 4D.

3.6 *Cost and Effort*

In collaboration with Statsbygg, Graphisoft developed their 4D "Construction Simulation" tool by analyzing and testing it in the Pilestredet Park Project. Two years after the project started, Graphisoft released "Construction Simulation" in the ArchiCAD 7.0 edition in 2001 world wide, which was an extremely short period from R&D to a commercial product. Statsbygg paid about 160,000 Euros to Arktis and Graphisoft for building the model, developing the API, and supporting the software in the Pilestredet Park project. One person in Statsbygg was in charge full-time for managing, operating and testing the 4D building model.

3.7 *Benefits of Supporting Product, Process and Organization*

3.7.1 *Process*

1 In a great number of meetings with participation of many people from different levels of organizations, the 4D model enabled project stakeholders to get a rapid insight and overall view of the challenges in the project.
2 On an urban site in the middle of Oslo, the 4D model played an important role in planning and managing the site. It illustrated different issues related to the building process with special respect to logistics in the phase of site demolition, i.e., the administration of storing, process and transporting material in and out of the site. Taking another example, Kvarsvik (Kvarsvik 2004) said in an interview that since all demolition materials were to be crushed and processed on site, the 4D model got project participants to realise the impact of different locations of the crusher on the surrounding areas and take steps to minimize the noise and dust from the demolition process.
3 Statsbygg maintained that more benefits would have been achieved by building the 3D and 4D models earlier in the project, when the old hospital area was considered to be demolished and planned for new use. In this way, the 3D and 4D models would have given quick feedback of different development scenarios to the planners.

3.7.2 *Organization*

The most obvious benefits of using the 3D and 4D model manifest themselves in working as a communication tool to engage all the stakeholders like architects, planners, consultants, builders, authorities, public communities. The 3D and 4D models gave Statsbygg insight in terms of cultivating an open and democratic culture in the project team for planning and building this project.

1 The 3D and 4D models gave the project team the input for important and future-oriented solutions, which supported the team spirit.
2 Kvarsvik also said that using 3D and 4D models attracted young and clever professionals.

3.7.3 *Overall Business Performance*

There are a number of benefits associated to costs. Experiences from the Pilestredet Park project showed that the 3D and 4D model contributed to lower the project costs on the following accounts.

1 More easily visualizing the project scope and soliciting insight to the project goals contributed to better communication and information flow, which allowed the accomplishment of project goals.
2 Detection of interferences during the design process provides opportunities for quality assurance in the construction phase (i.e. on site).

4 CONCLUSION

Experiences from the reviewed case projects demonstrated the benefits of 3D and 4D CAD for various modeling purposes in different project phases. These experiences acknowledge 3D and 4D CAD as a key driver and a primary enabler for better design of Product, more cohesive Organization, and more efficient Process that lead to project success. The case study on the Pilestredet Park Project in Oslo, Norway indicates that 3D and 4D CAD is not simply a question of investment but rather of appropriately planning and managing the implementation, i.e., understanding the appropriate *modeling purposes*, identifying the right *timing*, *people*, *data*, *tools* for doing it, and putting them in the right *workflow*. These are key controllable factors in the implementation process for realizing the expected benefits. Next, we will further look into how an appropriate control of these implementation factors can be translated into more benefits and what kind of metrics can be used to measure the implementation and benefits of 3D and 4D CAD.

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Appendix A: Various Uses/Purposes of 3D and 4D CAD and Reported Benefits on Case Projects

	Project Phase	Modeling Purpose	Benefit (Product, Process, Organization)	
3D	**Conceptual/ Schematic Design**	**Briefing of project scope**	**Org. (communication)**	Enable project players to better understand project scope
			Case Example	(2) (3) (8) (11) (4) (5)
		Evaluation of design forms vs. functions	**Product**	Improve quality of functional design
			Case Example	(5) (18)
			Process	Expedite evaluation of functional design
			Case Example	(5) (18)
	Design Development	**Analysis of system options**	**Process**	Enable development of multiple design alternatives early
			Case Example	(5) (11)
		Design discrepancy (constructability) checking	**Product**	Improve design accuracy, reduce design errors and inconsistency
			Case Example	(5) (11) (20) (21)
			Org. (communication)	Enable designer better understand field-related design issues
			Case Example	(11) (20) (21)
	Detailed Design	**Detailed design coordination (MEP subs, fabricator, etc.)**	**Product**	Improve design accuracy, reduce design errors and inconsistency
			Case Example	(2) (3) (7) (8) (10) (11) (14) (20)
			Process	Expedite detailed design coordination and shop drawing approval process
			Case Example	(2) (7) (14)
			Org. (coordination)	Engage CM/GC and subs earlier and more in the design phase
			Case Example	(3) (8) (11)
				Enable a collaborative project management context among GC and subs
			Case Example	(2) (3) (7) (8) (10) (11) (14) (20)
	Construction Documents	**Drawing production**	**Product**	Improve quality of design output
			Case Example	(14)
			Process	Expedite production of construction documents
			Case Example	(3) (5) (8) (11)
				Synchronize shop drawing production with material procurement
			Case Example	(14)
	Preconstruction	**Automated quantity takeoff**	**Process**	Expedite cost estimating/procurement process; Improve estimation accuracy
			Case Example	(2) (5) (7)
	Construction	**Automated prefabrication**	**Process**	Expedite fabrication process; Improve installation accuracy
			Case Example	(3) (8) (11) (14)
	Construction	**Site dimension control**	**Process**	Expedite site layout process; Improve surveying accuracy

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	Project Phase	Modeling Purpose	Benefits (Product, Process, Organization)	
4D	**Schematic Design**	**Strategic project planning**	**Process**	Expedite work packaging
			Case Example	(4)
				Facilitate phased handover
			Case Example	(9)
				Support evaluation of multiple construction strategies
			Case Example	(9) (13) (15)
			Org. (communication)	Engage many project participants in project planning
			Case Example	(4) (16)
				Facilitate visualization of project scope and insights to project goals
			Case Example	(4) (16) (20)
	Preconstruction	**Proposal**	**Org. (communication)**	Show contractor's capability to execute the work
			Case Example	(11) (12)
	Preconstruction	**Bidding**	**Process**	Make construction bids closer in range
			Case Example	(4) (11)
			Org. (communication)	Brief bidders of owner/GC's intention
			Case Example	(4) (11) (12)
	Construction	**Permit approval**	**Process**	Expedite permit approval process
			Case Example	(8) (11)
	50% Construction Documents - Construction	**Master scheduling and construction sequencing**	**Process**	Improve schedule reliability and executability
			Case Example	(1) (3) (4) (7) (8) (9) (11) (19) (6)
				Synchronize facility operation and construction
			Case Example	(12) (17)
			Org. (communication)	Facilitate communication of the required sequence per specification
			Case Example	(10)
				Facilitate communication of construction status to end users
			Case Example	(12)
			Process	Enable early detection of potential site logistics and accessibility problems
			Case Example	(1) (3) (4) (5) (6) (8) (9) (10) (11) (12) (13) (14) (16) (19) (20) (21)
	50% Construction Documents - Construction	**Constructability review**	**Org. (communication)**	Externalize and share project issues
			Case Example	(1) (3) (4) (5) (6) (8) (9) (10) (11) (12) (13) (14) (16) (19) (20) (21)
			Process	Enable early perceptions of work scope and interference between trades
			Case Example	(2) (3) (7) (8) (11) (14) (19) (20) (21)
	Construction	**Trade coordination**	**Org. (coordination)**	Facilitate coordination between GC and subs
			Case Example	(2) (3) (7) (8) (11) (14) (19) (20) (21)

Automatic comparison of site images and the 4D model of the building

P. Podbreznik & D. Rebolj
University of Maribor, Faculty of civil engineering, Construction IT centre, Maribor, Slovenia

ABSTRACT: A method for automatic comparison of on site building images and the 4D model is proposed. The process and the main system modules on the path from real images to a reconstructed geometry model are explained. Finally, the decision about the geometry modeler is argumented and the semantic links between the reconstructed geometry model and the 4D model are explained.

1 INTRODUCTION

A 4D model includes a product and a process model, where information about the product as well as about the process is integrated [4]. Project management applications are widely used in construction and are also an important part of the 4D model environment. One of the recognized problems in project management in the building phase is the comparison between the schedule plan and the realization. This is generally done by inspecting the building process on site, which is a time consuming and inaccurate process and as such a hindrance in the project information flow.

In the paper we are proposing a solution based on the automatic construction of a 3D geometric model from 2D images. To perform automation of the building process inspection, the fundamental parts of the building object, the fundamental elements, have to be recognized on 2D images. The system gets 2D images directly from the construction site by using web cameras. Fundamental elements are then used in a 3D reconstruction process to build a specific 3D geometric model, which is compared with the product model component of the 4D model. The project manager can see differences between both models and accept changes to the 4D model, and the schedule plan respectively.

The solution concept is depicted on figure 1. With the proposed automation we can significantly improve the information flow in the construction process. Failures and differences between the planned and realized activities discovered earlier will decrease costs caused by false or missing information. A product model with recorded changes can be used as a source for the realization plan of the building.

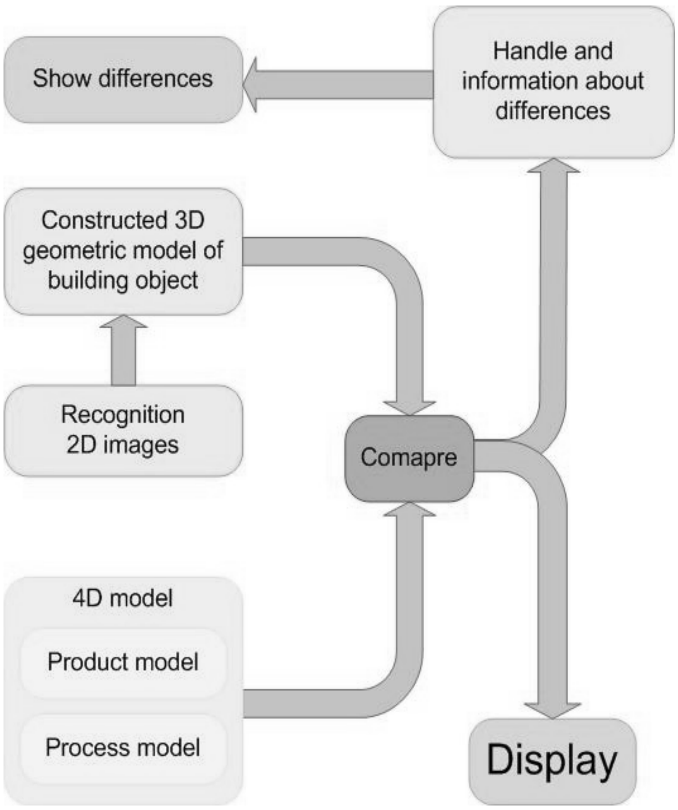

Figure 1: Base shame of application

2 4D MODELS

Construction of buildings is probably the oldest engineering activity, which has caused the evolution of building methods, materials, improved methods for designing, etc. In the early days of mankind human beings built more or less by trying and learning on

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failures. With time enough experiences and knowledge has been collected to try more complex buildings. However, they had to put their ideas to some form of plans. At the first phase planning was organized as a sketch, which was linearly evolved with pretentiousness of buildings and schedules. The civil engineers had to divide the building plans into two parts, which we today address as:

– product models, and
– process models.

Each of them could be independently presented as individual object in the building process.

2.1 *Product models*

Product models are the most important concept to make complete and integrated representation of the whole building, which includes:

– 3D geometry model,
– building properties (acoustic, thermal, luminosity, materials . . .),
– connectivity of different professional aspects (mechanical, electrical engineers . . .),
– environment for inter-operability.

Most often civil engineers made their virtual buildings with different modeling tools or 3D geometry models, which had different solution to represent the virtual building with building properties as a computer file [5][3]. How data is structured and formatted was depending on modeling tools and their support for different export formats. Most often it has been impossible to reuse the same file in different modeling tools and engineers lost useful information when they recompiled files between different formats.

One solution suggested common data structures, which would enable exact definitions for:

– geometry for fundamental elements,
– relationship between elements,
– linking elements with the corresponding activities
– topology,
– properties of each element or object.

Exchange structures evolved and in 1994 a standard has been accepted for the description of data to be exchanged between applications (STEP[5] – Standard for the Exchange of Product model data). With STEP it is possible to describe any product model, independent of its complex geometry and property structure. For practical use STEP has to be divided into many engineering branches (civil, mechanical engineering, ship building, etc.), which could be described with different application protocols. Each application protocol implements specific engineering area and has its own code (AP203, AP209).

The STEP's main problems are complex definitions for elements and relationships between them, and its impractical high abstraction level. Therefore a solution has been proposed in form of predefined elements, which are ready to be used. IFC[3] - **I**ndustry **F**oundation **C**lasses, is a collection of element definitions for the civil engineering area, and is based on STEP.

2.2 *Process models*

Process models are more abstract than product models, since they describe activities. In the scope of a 4D model, a process models defines the product model in time. Process models have been constructed from different methods and define the schedules in different ways. Gantt charts have mostly been used in scheduling tools, but couldn't represent clearly all overlapping tasks across the building process.

The method Line of balance could be another possibility to represent task sequences and conflicts between them. This method enables an efficient representation of task overlapping and supports simple activity management and schedule.

2.3 *Constructing 4D models*

Integration of both models, with links between activities from the process model and elements from the product model, represents a definition of the product model in time. Applications, which enable linking of objects from both models, are called 4D tools.

With 4D tools [4] site managers can quickly check accordance of geometry of the product model with the real building situation, and scheduled tasks with activities from the building site.

3 3D GEOMETRY MODELERS

Today CAD tools are the basic assistance for engineering design. Each engineering area has its own specific requirements and appropriate specific CAD tools. Civil engineering CAD tools provide functionality to construct the product model and are based on the geometry model, which is the core structure. The CAD tools can be divided into several components:

– geometry kernel to construct geometry model and set topology,
– specific modules to set properties for geometry elements,
– calculation modules (structural analysis e.g. FEM, thermal calculations etc.)
– representation modules (e.g. VR)

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– modules for data exchange,
– user interfaces: (GUI - graphical user interface, API - application program interface, scripts).

3.1 *Geometry kernel*

A geometry model [12] consists of specifically organized data structure with relationship between objects in the model. Data structure is depending on geometry representation or geometry modeler with various geometry kernels respectively - depending on the requirements. Each engineering branch has to handle specific geometry problems, which would be solved in specific ways. For that reason many geometry representations exist and gives many possibilities to construct geometry models. The main geometry representations are:
– spatial occupancy enumeration,
– constructive solid geometry - CSG,
– boundary representation - B-rep.

3.2 *Product model construction*

4D tools usually require a geometry model and a schedule to import. How a product model is built with a CAD tool depends on the tool characteristics, but designers always have to separate geometry object into parts, which can be linked with activities in the process model. This is the basic concept of constructing product models and CAD tools have to have the modules to enable parts separation. Other modules are needed for object description and set properties for fundamental elements.

Module for object description includes libraries with fundamental elements (column, wall, slab …). These elements usually have full description with permanent settings and functionality name like bear wall, indoor wall. Designers or constructors have possibilities to make their own elements with custom description and settings and save them into libraries. The possibility to build fundamental custom elements with properties and setting depends on CAD tools.

3.3 *Data exchange modules*

Designers and constructors build geometry models, set properties and separated the building objects into different parts and finally build a product model. CAD tools save the product model into specific file types, but mostly also enable exporting into other types too. Often it is necessary to save the product model into STEP of IFC files to keep the complete structure and data information.

3.4 *User interface – UI*

Direct communication with the machines like computers is a very difficult task, especially for non-professionals. Any kinds of interfaces [1], which establish the convenient communication between users and machines, are much more user-friendly. Software companies have professionals to design user interfaces because it is very important how they are organized and how they communicate with the user and application site. Software designers have many possibilities how to improve interaction between the user and the application and choose convenient type of interface.

The first computers haven't had user-friendly interfaces and usually they had been text oriented without colors and visualization effects. The main problem for graphical effects, in the past, was memory, which disables software engineers to make attractive interfaces.

3.4.1 *GUI - graphical user interface*

With hardware and software development the interfaces became more and more complex and useful for general users to work with the machines. The user interfaces became graphical oriented and relieve usage with command suggestion to user.

3.4.2 *Application program interface – API*

API's interfaces are suitable for advance users, programmers and software designers to use application functionality as components or procedures call. Programmers could used API as a core of application and develop some additional functionality or as components to include existing modules and use them as an add-on.

Both methods are used very often today, because they make it possible to include a lot of knowledge very quickly and simply. Flexibility and suitability depend on environments, which could be adopted for different types of professionals. CAD tools have their own environment with specific language to call the procedures, which enable data manipulation, computation, visualization etc.

The most interested for computer engineers are APIs in different programming languages, but API has to support language wrapper for each programming language. C++, C, Java, Python are often supported in nowadays engines and reach high performances of the final application.

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4 CONSTRUCTING GEOMETRY MODEL FROM IMAGES OF BUILDING SITE

The construction of the geometry model as a process is illustrated on figure 2 and has the following basic phases:

- building site images input,
- pattern recognition,
- include knowledge about 4D model,
- construct geometry model.

The main difference between conventional automatic object recognition and the proposed method is the existence of the 4D model, which can be referenced to solve conflicts or ambiguities in the recognition process. In this way the 4D model is both used as a knowledge repository and as the model to be analyzed and updated according to the real situation.

4.1 *Images of building site*

The choice of method to get correct images as an input to application is difficult, because we have to consider many parameters that enabled us to make geometry construction successful. If we want to simplify reconstruction process from 2D shape to 3D object it would be necessary that each single camera has:

- defined fixed position,
- fixed zoom,
- defined time intervals between image sequences, which enable elimination of temporary objects from the final image,
- the same exposure time settings,
- exact geodetic position and heading.

4.2 *Pattern recognition*

After successful input of all necessary data (images, product model and schedule) the process of pattern recognition can start. The results are classified into object define classes depending on algorithm shapes criterions. At this point it's necessary to make the first connection with information from the product model, which serves as a reference model across the geometry model construction process.

At the beginning we will focus only to very simple building elements like bear walls, columns, etc. We have to assure enough quality of recognition and then make algorithm improvements [10][11] for more complex building elements and more details that accompany the building process.

Application calibration has to be realized in artificial control environment with small models, built of wood or paper. Images from those circumstances are clear without any noise signals like fog, temporary equipments, shadows etc. To make real images it is necessary to analyze the real images from building site (figure 3) and gain the mathematical characteristics, which have to be included into clear images to become suitable for input.

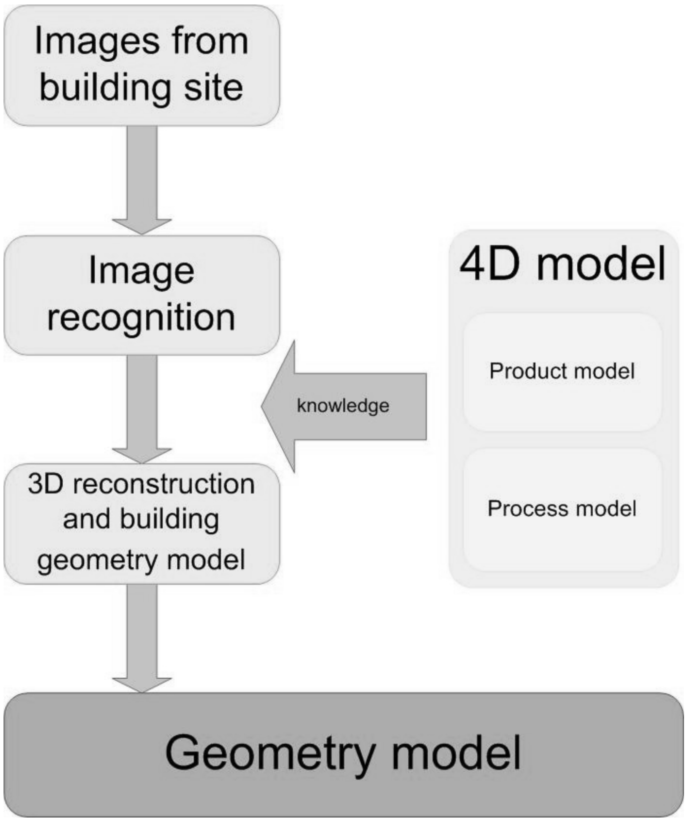

Figure 2: Construction phases

Figure 3: Image with noise

In previous chapter we mentioned the image sequences that help to eliminate temporary objects from images of the building site. It is not necessary to be double, could be triple or more. The idea is to exclude differences between images and reject all dynamic objects.

4.3 *Constructing the geometry model*

One of the requirements is the exact definition of the position and heading of each camera. This re-

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quirement simplifies the process of 3D reconstruction [2][7] and enable us to put recognition objects to coordinate system with correct object dimensions and relationships to other objects. Geometry model have to have the reference links between elements from 4D model and reconstructed elements, which enables us to make comparison between both models. To construct the geometry model we decided to use Open CASCADE [8][9][6] modeler, because it has a lot of useful features:

- it is under LGPL license,
- support many language wrappers (C, C++, C#, Java, Python),
- support OpenGL rendering,
- enable programming with different libraries for graphical user interfaces (Java, TCL, Tix, QT, FLTK, MFC),
- improve mash algorithms,
- enable combining visualization with other tools, specially with VTK -
- Visual ToolKit,
- it could be commercial oriented,
- useful documentation, e-learning, on-site training session, technical support, . . .

5 CONCLUSION

This paper presents the global concept to control the building activities on building site. In the first phase we established the base platform with 4D models and on the other side a geometry model. Open CASCADE geometry modeler can import product model data in STEP format, and construct its own data structure, which can be reused further. In the same way geometry modelers enables constructing our geometry model with all necessary settings and export it to many types of files.

The second phase is the pattern recognition, 3D reconstruction and finally construction of the geometry model, which will be compared with the imported product model. Finally we will implement a module with useful visualization, which offer building managers a simple control over the building process.

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4D Project Planning and H&S Management

A. Ciribini & G. Galimberti
Dipartimento di Ingegneria Civile, Università degli Studi di Brescia, Italy

ABSTRACT: A The European Client Organisations must face huge responsibilities by 92/57/EC Directive when the Health and Safety Management System has to be built in. Moreover, Public Client Organisations are trying, in different ways, to cope with such duties in modifying their Project Execution Plans over time so to update project schedules and reports complying with H&S Plan-related measures. The researchers have performed a detailed analysis which should allow Project Sponsors and Project Managers to deal with Time Management following a safety-oriented approach.

1 INTRODUCTION

1.1 Type area

The EC Directive 92/57 (concerning H&S Management on Construction Sites) has been enforced in Italy in 1996.

The Directive, due to come in force in 1992, and postponed several times, was vainly expected to cause a huge impact from a legal point of view, despite all the serious attempts and efforts made by H&S Specialists in changing their own attitudes.

However, new practices have been introduced during the design and construction stages: appointed by Client Organisations, H&S Coordinators suddenly became driving players within the building and construction processes.

Project Planning and Control-related tools were reckoned apt to improve the H&S performances on construction sites.

When appointing a H&S Coordinator, the Client believed to be allowed to transfer him the risks to be born.

The H&S Managers and Coordinators, unfortunately, are often forced to waffle on about the legal meaning of the Directive's words rather than solve bad real practices.

Moreover, following the new approach, H&S Coordinators were trying to look at Spatial Factors which could affect the behaviours of the crews and equipments on site.

Unfortunately, a 3D-based design approach was needed, but designers usually prefer 2D CAD models in a scantly consistent way.

Indeed, they did not realise that 3D models could support a better H&S Planning practice.

The largest amount of available CAD techniques (80%) involve a 3D model to be prepared, whilst a Design Team could gain a huge profit in detecting conflicts.

Spatial Planning had to be undertaken by Client's Designers, during the pre-tender construction phase, through an agreement with Client's H&S Consultants, waiting for the contribution of the Building Contractor.

Likewise, General Contractors and Specialist Package Contractors should not be left with the main executive powers about H&S Management.

Otherwise, they could act as the ultimate owners of the decision-making process concerning the construction site-related occurrences, whilst being not allowed to negotiate prior to tendering.

Unfortunately, a few Contractors are used to apply the 4D CAD techniques or the Spatial Planning-oriented tools, too.

On the other hand, any late delivery caused by poor suppliers could barely trouble the whole and rigid Project Schedule: the H&S Planning System is to be improved from such a viewpoint, too.

Therefore, 4D Planners could visualize the sequencing of the work packages to be performed (and the components to be built or cast) whilst Spatial Analysts will optimise the space use on site.

The widespread of the subcontracting (reaching three or four tiers) is troubling a manageable process.

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The parcelling out of the decision-making points causes a fragmented way of doing on site.

Because of changing working conditions on site, Client Organisations should be careful in devising the Breakdown Structures (PBS, WBS, OBS, ABS, RBS, CBS) during the design stages, waiting for a further investigation to be provided by the Contractor prior to the commencement of the works.

One major difficulty is to be found in structuring the sub-contracted work packages following a stated approach, as well as in the United States-widespread CSI classification system.

The Main Contractors are seldom able to find a viable sequence of starting as far as Subcontractors are asked to perform their tasks from the spatial point of view.

Otherwise, OBS, ABS, and WBS should be timely structured by H&S Coordinators so to be later verified and modified by Contractors and Subcontractors.

When taking into account such a purpose, the 2006 Winter Olympic Games Agency (a large Awarding Organisation) prepared a set of guidelines (concerning such topics and matters) to be closely followed by designers.

Such an approach encompassed spatial locations, physical components, schedules of rate, and activities.

Nonetheless, that is sometimes easier said than done: also the Design Teams are seldom able to realise the consistent sequencing of the activities to be included into the schedules.

It is important to consider contractual conditions because many activities are to be performed by different Contractors, following different payment criteria.

Coping with unreliable and unfinished schedules, Contractors are neglecting their duties: in other words, master plan schedules and look-ahead plans are often meaningless.

Eventually, the Pre-Tender H&S Plan issued by the H&S Coordinator sounds to be not consistent with the Construction H&S Plans provided by Contractors and Subcontractors.

The Spatial Planning should be linked with the productivity rates, so to balance working areas and physical advancements on site.

The traditional CPM method does not consider the effects of overcrowding: crews involved in non critical tasks might impair the completion of other critical activities.

Within a Dynamic Spatial Planning-oriented framework the space, conceived as a driving resource, mitigate the risks concerning the productivity's loss.

H&S Coordinators and Managers have to remember that reducing a task durations does mean to cause overlapping activities and overloaded working spaces.

It must be better to make efforts to avoid this conflicting conditions through a timely analysis of the forecast locations of the crews and equipments.

2 4D PROJECT PLANNING AND H&S MANAGEMENT

The H&S Management has widely to deal with working areas and space conflicts, trying to realise crew workflow directions, space requirements, and spatial buffers between activities (the so-called safety lags).

The H&S Coordination lies, above all, in realising physical flows on construction sites over months and years.

Sequences of crews (workflows and production rates) could be optimised from the point of view affected by work locations.

The H&S Planning should not neglect the space occupation rates: it happens that available and delivered resources could not be used due to an interference.

Shortages of space availability are often causing hazards or increase the risk levels, as well as planning and construction phases are quite often separated.

Moreover, the concurrent configuration of many tasks will increase the meaning of critical space.

Building Contractors are more and more seeking at reducing the time span through a huge compression of the task duration.

In so doing, working areas become overloaded and overwhelming activities could engender hazards and casualties. 4D models seem very useful in realising and avoid the overlaps.

Whenever criticalities are dealing with spatial constraints rather than time management, 4D Project Planning and its dedicated tools seem to be very useful.

Spatial constraints (due to overcrowding and restricted accesses) have to be considered also when looked to Procurement Planning.

Indeed, walkways, plant/equipment routes, procurement paths, storage areas and space requirements are the main factors to identify criticalities.

While some methodologies, as Last Planner and Critical Chain Scheduling, seek at manage activities to be started following short-term review of the allocated resources and the use of shielding tasks, the spatial loading has to be looked at with special care.

Likewise, a bad resource usage could engender hazards and casualties because of space conflicts and overloads.

Resources need space to be stored and to be handled, but, unfortunately, such a space-demand is often un-

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derestimated as scheduled activities are linked each other following the CPM time-oriented constraints.
Delivered supplies could really affect the viability of the project schedule, when Contractors and Subcontractors are bearing the transferred risks.
Indeed, the authors were focused upon space (and safety lags) as driving resource to prepare and fill a H&S Plan.
When trying to reduce the original risks (leaving only the residual ones), H&S Coordinators (Planning Supervisors and Principal Contractors) evaluate spatial parameters to ascertain the sustainable thresholds.
They have to define the restricted areas and regulate the shared resources, considering a dynamic layout planning of the construction site.
Critical Space Analysis will be conceived in a tied way with the time sequencing of the scheduled activities. Genetic algorithms and stochastic search techniques have been employed to find the best resource distribution profiles, taking into account the potential space conflicts.
Equipment Performance simulators have been proposed, too.
A recently proposed multi-constraint scheduling (concerning with space, contract, resource, and information) tool could help to solve a lot of problems from the H&S Coordinator's point of view.

3 4D MODELS

It is a very hard task to define a close logic of the construction schedule because of a large amount of unknown variables. It has been acknowledged that a set scope of works to achieve should require a comprehensive realization of resource assignments.
Above all, spatial implications affecting the storage and handling systems could become very critical.
Moreover, a shortage of working areas often affect the sequencing of the tasks to be performed.
Therefore, a dynamic approach to the site layout and to the scheduling should be consistent with the routing of materials and gangers.
Considering constraints coming from the site surveys should provide the Planner with the ability to highlight the correct sequencing of the activities to be performed.
The main difficulties lie with the change management that is affecting the refurbishment works.
Moreover, such works could be performed on different floors during the same lapse of time.

4 4D PROJECT PLANNING

The traditional and widespread software packages are only able to allow Project Planners to look mainly at the resource curves and profiles, without spatial constraints.
Moreover, even if it could be possible to deal with space availability as a standard resource, H&S Coordinators and Project Planners themselves prefer to avoid to do it in a selfish way of thinking.

The Authors have listed a set of stages to be complied with when considering Project Scheduling and H&S Planning:

1 Analysis of working areas and paths;
2 Allocation of the working areas and plant/equipment to the listed activities;
3 Allocation of storage areas to the needed resources;
4 Control of the potential space overloads;
5 Review of the Project Schedule and the resource profiles;
6 Introduction of the safety lags (between activities);
7 Review of the driving resources;
8 Analysis of the site layout to be designed;
9 Linking of the H&S measures and specifications to the working areas and 3D objects (parts to be built and site equipments);
10 Site induction through the reviewed 4D models;
11 Management of the H&S site meetings through the 4D models;
12 Update of Project Scheduling and H&S Planning through the 4D models.

When tendering on a competitive base, Building Contracting Firms are often preparing their bids in a short time, because of the legal rules, providing unreliable bids.

Moreover, the lump sum contracts could cut dramatically margins of gain, urging the Contractor to recover such edges, in spite of their Subcontractors.

Such Subcontractors will be scarcely involved in the Project Planning and H&S Management .

A tender to be awarded on a lump sum criterion implies a detailed design.

The amount of the contract price to be spent in H&S measures will be sacrificed, too.

In Italy the H&S Coordinator has to fill the completion certificates only after the assessment of the H&S-related costs committed by Contractors.

During the tender stage, planners are often bored by temporary works, which need an accurate estimation.

Although H&S Coordinators seek at stimulate the best practices in the H&S Management, they are not succeeding in changing the usual way of thinking of the self employers, gangers and foremen.

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The authors applied 4D CAD Techniques to building and construction projects, from the parking building to the hydraulic infrastructures.

The construction of a set of check dams in a mountain river proves that the morphology of the landscape could affect the availability of working areas.

It was featured by heavy slopes and restrictions in accessing, so that spatial constraints could not have been taken into account with traditional scheduling methods.

5 4D PROJECT CONTROL

4D models, prepared during the pre-construction stage, could be used in monitoring and controlling performed works.

Planners and H&S Coordinators should analyse and make comparisons amongst the original schedule and the updated ones.

When a delay occurs, it is easy to find missing objects, which are showing dropping productivity rates or others events.

Planners at every opportunity do not risk to be noted for consistency: frequent changes always pose a problem and weaken the dependability of the H&S Plan.

It is generally assumed that project schedules, as have been known for several years, cannot possess a power that practical experiences struggle to match.

As the Planners and H&S Coordinators undertake the hazardous task of owning a proactive approach to unforeseen events, the focus will remain on realising dynamic flows and physical conflicts due to changed relationships or risky overlaps.

Despite complaints from many H&S Coordinators, there is unfortunately little likelihood of a major adjustment in the behaviours of Contractors and Subcontractors.

When works are progressing and closely monitored, 4D Project Planning is promising to bring a new style in searching for a safe trade off between the needs of H&S Coordinators and Contractor's Representatives.

If works are behind of schedule, the collision about between H&S Coordinators and Site Managers could be bruising for the fulfilment of the contract to be signed. 4D Project Planning provide the possibility to analyse and visualize different ways to amend the original schedules.

Otherwise, the full reliability of the updated H&S Plan will remain a distant goal.

The fist task will be to avoid superseded documents and schedules to be available on site.

The toughest effort to be made will be handling Project Schedules and H&S Schedules so to increase the awareness of the gangers and the crews.

The induction of newcomers on site is more powerful and learning curves seem to be crucial.

Several choices could loom during the site meetings (when discussing and debating about time changes) and the outcome will spread on site.

An oddity could happen: the most important factor, the spatial availability and usage, is neglected, although the safety-related results are set to become more and more required by the Large Client Organisations.

Everything else will pale compared with the difficulty of reduce and mitigate H&S-oriented risks.

6 CONCLUSIONS

H&S Planners and Coordinators need to deal with spatial constraints and resource usage.

These topics are hardly debated in the Client Organisations and Contractors.

And even if they were, it is unlikely that H&S Coordinators and Managers would be able to change the figures concerning hazards and casualties without effective criteria and tools.

In Italy, spending on H&S-focused Project Scheduling is low compared with a British average.

There are many reasons for this, from low revenues to unskilled Planners.

The large Building Contractors are only required from their Clients to provide a detailed schedule including chiefly tasks to be performed.

Clients are neglecting the procurement issues and the resources to be allocated.

They reckon that any uncertainty will affect the original schedule or believe that too many accidents will trouble the forecast CPM-related Plan to envisage a proactive way.

Moreover, 4D Models will compel Clients and Contractors to act as partners instead of counterparts, in a cooperative contractual framework.

Unfortunately, Clients and Contractors are used to think in an adversarial manner, so they prefer to stay with the rooted behaviours.

Following such an approach, H&S Coordinators are forced to look at single Work Package to be performed over the time, lacking of the awareness of spatial conflicts amongst the Subcontractors and badly assessing the potential hazards due to the supplies' shortage, handling and storage.

The H&S Managers belonging to Contractors and Subcontractors try to hide what they feel as boring.

Nonetheless, 4D Techniques deserve credit and attention to be paid.

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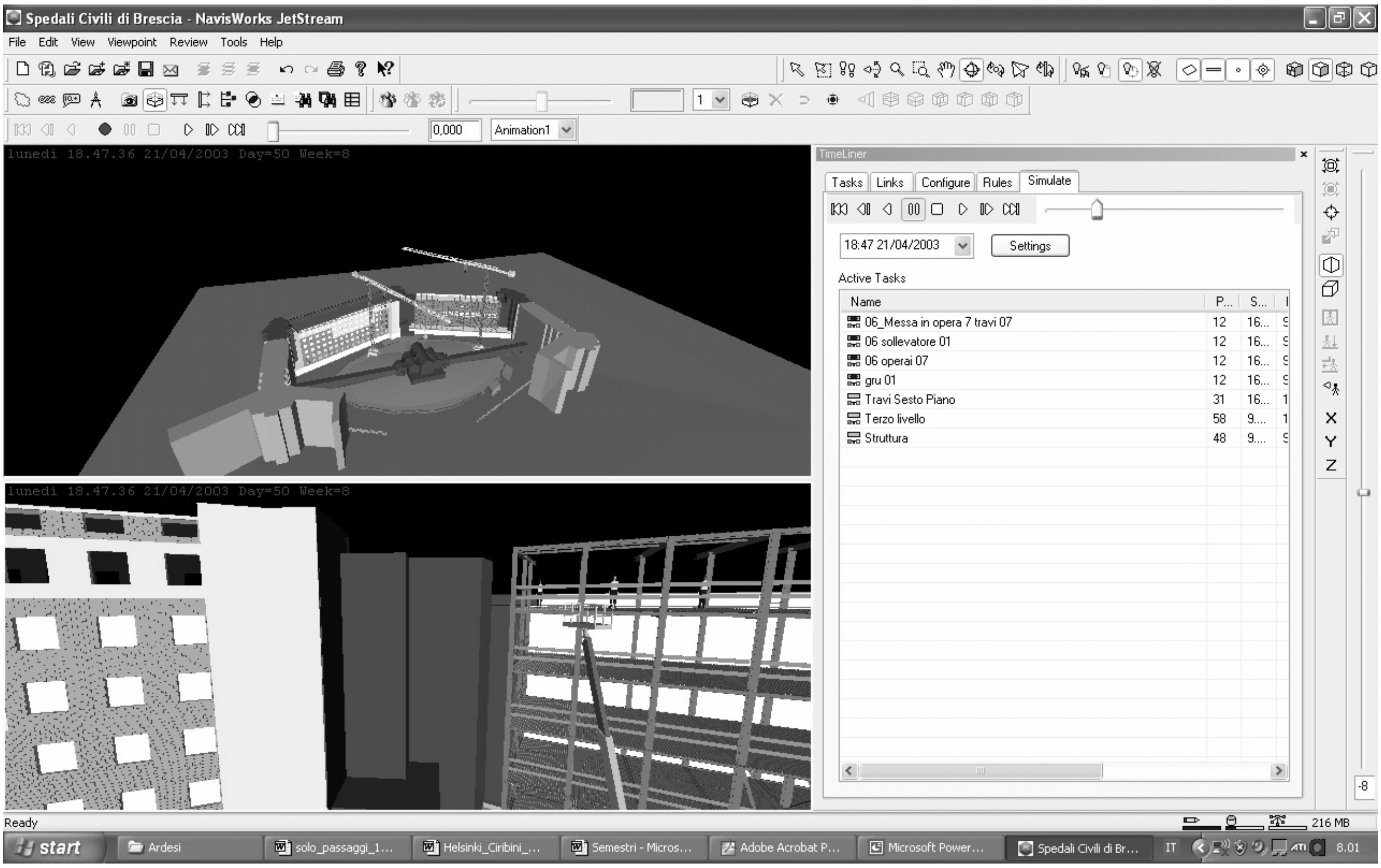

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Using 4D in a new “2D + time” Conceptualization

L. Rischmoller
Director, School of Construction, Faculty of Engineering, Universidad de Talca, Curicó, Chile

E. Valle
General Manager, VAIN-ARM, Santiago, Chile

ABSTRACT: This paper describes a system that combines a 2D digital board that shows dynamically in rows and columns arranged in a special layout, starting and finishing dates of subcontractors work linked to the fourth dimension, time, coming from construction schedules. The system is the result of a research project whose objective is to improve planning, scheduling, and controlling the work of subcontractors of finishings in building projects. The system will be tested on case studies projects for planning, scheduling and controlling the work of subcontractors. It is expected that the systems will act as a powerful real time Visualization, Planning, Analysis and Communication Tool in the case studies. Despite the 3D case studies models were very useful for constructability and other purposes, the traditional 4D approach that combines 3D + time was not very useful when dealing with construction works that remained mainly “hidden” within the project 3D model. Applied to the case studies, the digital board shall provide different ways to display, communicate and understand information about resources, costs, dates and relationships coming from a traditional CPM network using 4D in a new 2D + time conceptualization.

1 INTRODUCTION

1.1 *4D Modeling*

4D models have traditionally been conceived like adding the temporal dimension to 3D CAD models, i.e. linking a 3D graphical model to a construction schedule, through a third party application (Collier and Fischer, 1996, McKinney et al., 1996), providing the ability to represent construction plans graphically (Williams, 1996). Recently the definition of a 4D model has expanded its scope to include activities from the design and procurement also linked to the components in 3D CAD models (Fischer and Kunz, 2004).

1.2 *A new conceptualization of 4D*

In this paper it will be presented a conceptualization of 4D models that does not include a 3D CAD model as an obligatory requirement, but considers a 2D digital board that shows dynamically in rows and columns arranged in a special layout, starting and finishing dates of subcontractors work linked to the fourth dimension –time– coming from construction schedules.

The system aroused from the application of “typical” 4D models to three case study projects (two building repetitive project and a subway station), in which components in the 3D CAD models related to certain finishing construction works carried out by subcontractors remained “hidden” once the main structure of the project was displayed as a 3D model.

The system combines commercially available software tools, that allows different ways to display, communicate, understand and mainly update in “real-time” information about resources, costs, dates and relationships coming from a traditional CPM network using 4D in a new “2D + time” conceptualization. The new approach has led to the creation of prototypes of the proposed system that will be validated in two of the case studies where research about “typical” 4D is carried out. It is expected that planning, scheduling and controlling the work of subcontractors will become improved using the proposed system as a powerful real time Visualization, Planning, Analysis and Communication Tool.

2 HIDDEN 3D CAD ELEMENTS

2.1 *4D-PS applied to non-industrial projects*

In collaboration with two construction contractors in Chile, research projects to adapt the 4D Planning and Scheduling (4D-PS) work process (Rischmoller et al, 2000) to be used in building repetitive projects and in a subway station are currently underway.

The main change respect to the original 4D-PS approach is related with the responsibility for the 3D model development and the stage of the project in

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which the 3D modeling and construction schedule development efforts are carried out. The original 4D-PS work process was designed considering that the 3D modeling effort is carried out by the project engineering department in parallel with the construction schedule development during the project design stage.

2.2 *Adapting 4D-PS*

The current 4D-PS adaptation, considers that the design of the project is finished before starting the 3D modeling and construction schedule developing efforts. The design of the project is received by the construction contractor as 2D drawings developed using AutoCAD software.

The research team using Architectural Desktop (ADT) software develops 3D models of the projects divided in "pieces" according to the construction plans and schedules developed by the contractors using MS Project software based in the 2D drawings project design. A new construction schedule is developed using Primavera Project Planner (P3) software ensuring that the "pieces" in the 3D models will match with the activities names in the P3 schedule. The new P3 schedule is also loaded with the material quantities take off coming from the ADT 3D model. Finally 4D models are produced linking de ADT 3D models and the P3 schedules using the SmartPlant Review software, which is also used review the 4D model as well as navigating through the 3D model before starting the 4D modeling efforts.

2.3 *Building repetitive projects*

4D models have been developed for a contractor specialized in low income building repetitive projects. The floors of these building projects are repetitive and sometimes the projects include several similar buildings. Based on the project 2D drawings, once one type of floor has been modeled in 3D, it is copied as needed to assemble one or more 3D building models. The level of detail for the 3D model of every typical floor is high (e.g. including wall paper, paved floor, interior doors, stuccowork, etc.) (Figure 1).

The visualization of the 3D model led to a better understanding and communication of the needed construction works for every typical floor.

A construction schedule was developed in parallel to the 3D modeling effort taking into account the expected match between construction activities with the 3D CAD model elements in order to expedite the 4D model development process. In this way 4D models of some building projects were developed expeditely.

When revising the 4D models it was realized that once the main concrete structure (i.e. walls and slab) of every floor was finished, the 3D elements inside the building became hidden. In every project executed by the contractor composed of five to twenty five stories buildings, the ability to visualize the construction sequence associated to the hidden objects in the 3D/4D model was null in every 4D model developed. The same occurred for an individual building seventeen stories tall.

The 3D models developed during the research were very useful to obtain the material quantity take-off of the projects and to support planning of mainly finishing construction works in individual typical floors. However, the elements in the 3D model mainly related to finishing construction works –the hidden 3D elements– were not very useful to review and analyze the complete construction schedule when included into 4D models.

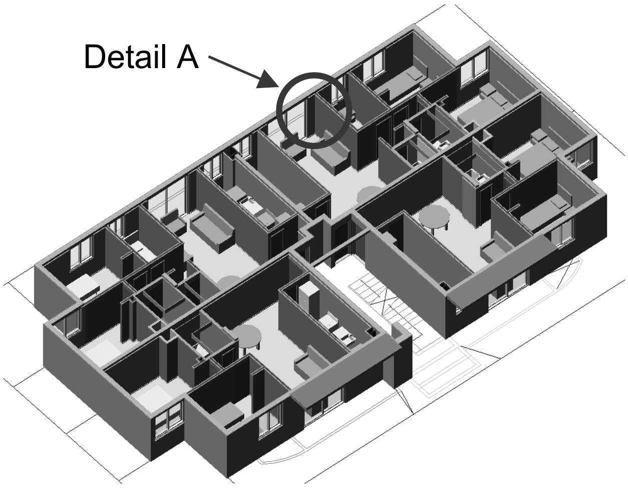

Figure 1. Detailed 3D model of a typical floor

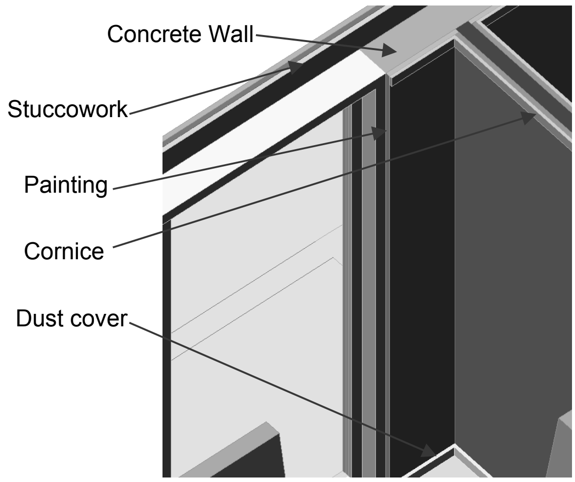

Figure 2. Detailed of a typical floor (Detail A Figure 1)

2.4 *Subway station*

In another research project a similar approach to that used in building repetitive projects was applied. The project consisted in 4D modeling a subway sta-tion in which the scope of the 4D models did not in-clude finishing works, but it was limited to the con-crete walls and slabs of the subway station. Even finishing construction works of the subway station were not 3D modeled, it was corroborated that once the main structure of the project is complete, there are several

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construction works that would have be-come hidden if they would have been 3D/4D mod-eled (Figures 3 and 4).

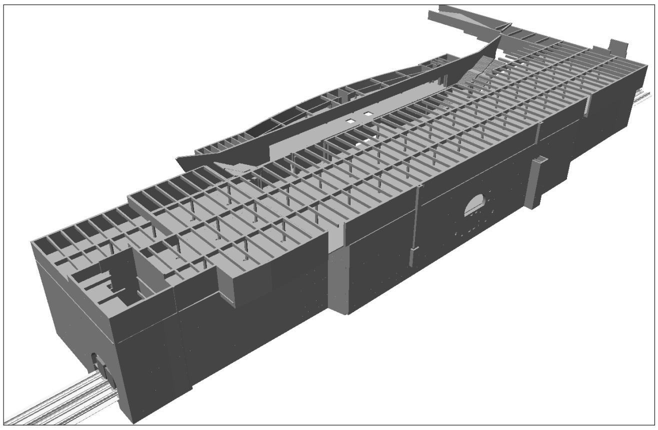

Figure 3. Subway Station, finishing construction works be-come "hidden" by the walls and slabs

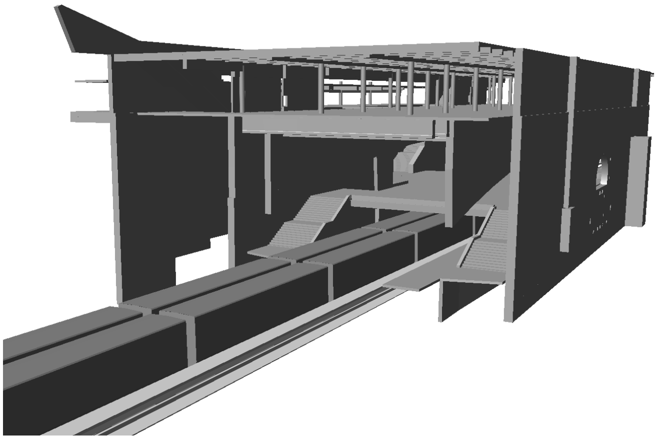

Figure 4. Subway Station, finishing construction works be-come "hidden" by the walls and slabs

3 TRADITIONAL JOBSITE BOARDS

3.1 Jobsite boards

Using black or white boards or panels at the jobsite to try to support construction plans and schedules communication and control is not uncommon. These boards are sometimes very good structured showing a good relationship between the construction activi-ties, the dates these activities must be executed, and the location in the project where these activities must be carried out (i.e. the horizontal as well as the vertical division of the project). Maintaining these boards however demands manual intervention which makes it difficult to keep them with updated infor-mation as the project progresses. These boards are also stationary and it is the people who has to get near the board in order read its information rather than moving the board (i.e. a printed copy) where the people is, as needed.

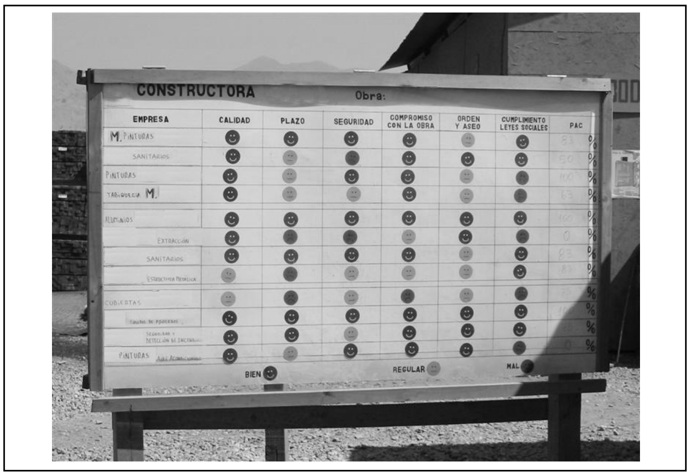

Figure 5. Board at the jobsite

4 THE DIGITAL PLANNING AND SCHEDULING BOARD

4.1 Temporal dimension of 3D hidden objects

According to the experience with the application of 4D modeling to the case studies, it was concluded that the temporal dimension of some "3D hidden elements" was not being effectively useful to con-sider 4D models as the powerful Visualization, Planning, Analysis and Communication Tool it promises to be. Since 4D modeling benefits are not in doubt, in order to solve this "problem" the new approach –the digital planning and scheduling board (DPS Board)– presented in this paper was devel-oped.

4.2 Finishing construction schedule

The repetitive nature of the finishing construction works in building repetitive projects led to presume that a typical gannt chart would be easy to develop, understand and used to control the finishing works in the project. Construction schedules using MS pro-ject software had previously been developed by the case studies contractor intending to support planning communication, reporting of advance and construc-tion execution improvements. These schedules con-tained several 100 activities for a typical project with hundreds of arrows trying to depict the rela-tionships among the different activities (Figure 6). These schedules proved to be pretty long to be rap-idly understood, communicated and even printed to be useful to the rest of the projects participants. Fur-thermore, trying to maintain the schedule updated once the project begins and reschedule the project when needed, proved to be a task so tedious that us-ing these schedules was soon disregarded.

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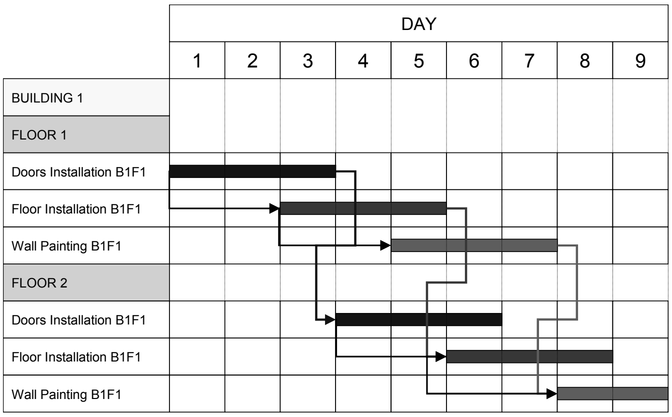

Figure 6. Fragment of a long finishing construction works schedule

4.3 *Replacing 3D elements with cells*

Based in the idea of typical white boards used at the jobsite of several construction projects, the information about the finishing construction works of the building repetitive case studies was structured in a matrix whose rows contained cells representing repetitive construction activities grouped by the different project elevations (i.e. floors). The columns of this matrix reflected the horizontal division of the projects, in some case by buildings (i.e five buildings of five stories each building) while in other case by floors (i.e. the seventeen stories unique building)

This matrix was drawn using ADT software considering that each cell of the matrix shall be linked to one or more construction activities in the construction schedule. Different layers, colors and files combined with the Xref manger feature from AutoCAD were used to achieve this goal. Figure 7 shows an outline of the matrix: the DPS Board.

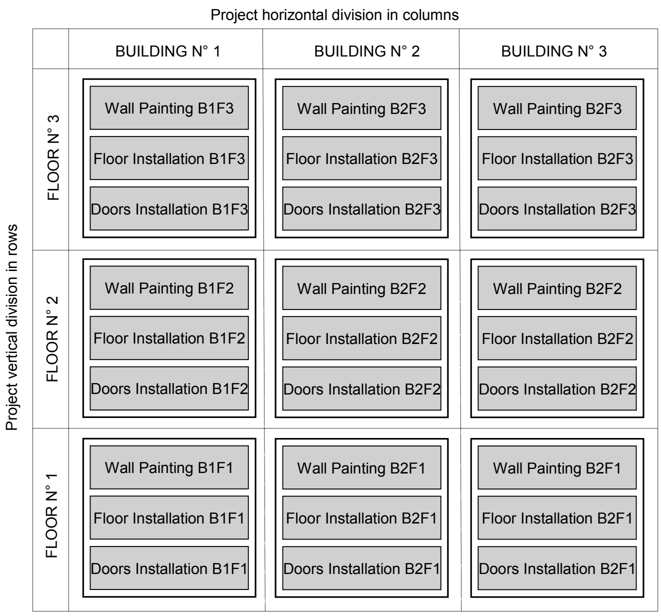

Figure 7. Outline of part of the digital planning and scheduling board (DPS Board)

4.4 *Linking the construction schedule with the 2D elements*

Once the DPS Board is constructed, the activities in the construction schedule are linked to the cells in the DPS Board in the same way that 3D elements in a 3D model are linked to construction activities. In this way, and despite the third geometrical dimension is not considered, since the 4th dimension of time coming from the construction schedule is included, we consider the result as a 4D model.

Several prototypes of 4D models using the DPS Board have been constructed proving its functionality from the software tools perspective. The cells in the DPS Board are turned on or off controlled by the activities in the construction schedule. Each cell has a color code associated, and equal activities executed in different location are the same color. A different color tonality is also used according if an activity has not started, is in progress or it is finished.

In collaboration with a building repetitive projects contractor in Chile, these prototypes are being prepared to be validated as Visualization, Planning, Analysis and Communication Tools in two case studies, from the construction management perspective.

5 BENEFITS

5.1 *Expected benefits*

The expected benefits of the application of the DPS Board shall be to some extent similar to those obtained from a “typical” 4D modeling application (Fischer & Kunz, 2004; Rischmoller et al, 2002; Heesom & Mahdjoubi, 2003). The geometry of the elements considered in the DPS Board is simplified to cells instead of the accurate representation provided by 3D model elements. However, for elements that become “hidden” into 3D models, the DPS Board offers different ways to display, communicate and understand information about resources, costs, dates and relationships com-ing from a traditional CPM network using 4D in a new 2D + time conceptualization. In this way the DPS Board provides an alternative to consider the relationship between the spatial and temporal aspects of some construction project elements which otherwise would be very difficult to take into account (i.e. “typical” 4D modeling).

The quantitative as well as the qualitative benefits of the application of the DPS Board will be measured and contrasted with the expected benefits at the case studies currently underway briefly presented in this paper.

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5.2 *Further research*

Further research applying the DPS Board to other kind of projects shall contribute to validate the approach presented in this paper. A customized arrangement of cells structuring a suitable horizontal and vertical division for other kind of projects shall be carried out in further research. The cells in the board could represent repetitive or non-repetitive activities grouped in work packages. Defining a work package as a group of activities which have in common either location, tools required, execution processes or other characteristic of similarity (e.g. doors installation, painting, etc…). Figure 7 shows a general representation of the DPS Board that could be adapted to other kind of projects during further research.

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Manipulating IFC model data in conjunction with CAD

M. Nour & K. Beucke
Chair of Construction Informatics, Bauhaus University, Weimar, Germany.

ABSTRACT: The IFC model is used as a means of information exchange between AEC software applications. Currently, workflow aspects based upon IFC models still reside in a gray area between applications. This paper reports ongoing research work on a new approach that uses an online dynamic continually updated construction product data source for IFC based Building Information Models (BIMs). It focuses on different algorithms for parsing, interpreting and writing STEP ISO 10303 P-21 files. In between these stages various instantiation, deletion and updating process on the IFC model take place. The paper also investigates the ability of current software applications to work on the IFC model in a sequential order and points out some workflow management problems that were encountered during this process.

1 INTRODUCTION

The paper focuses on the operations that are needed to carry out on the IFC model in order to introduce product data from an external source to the model. An important objective of the undergoing research work is to supply the IFC model with information about construction products; not only life cycle information but also information allover the lifecycle of the product. Another objective is to enable carrying out operations needed to modify and keep the IFC model up-to-date. Among these operations are the instantiation of new property sets, property definitions, and classifications of construction products. Moreover, it is more often than not required to carry out changes to the model like changing the values of the above-mentioned aspects or even deleting them. This is envisaged to respond to the changes that a construction project undergoes in the design, specification and value engineering stages and hence can be used for procurement aspects like conduction of parametric searches in electronic product catalogs. Furthermore, this is considered to be the means by which the construction product's life cycle properties could be mapped to the IFC model all over the life cycle of the product itself. An important goal in this process is not to cram the IFC model with all the available life cycle information for each product in the construction project. However, the goal is to supply and support the model with up-to-date information from a continually updated data source (Nour et al, 2004). This implies that only needed information is mapped and instantiated in the model. In this way, the size of the IFC model and its exchange format (STEP ISO 10303-P21) can be minimized i.e. a fat free communication model can be reached. This model exists in parallel to its life cycle information and can reference and import any of its contents according to the user's (client's) need.

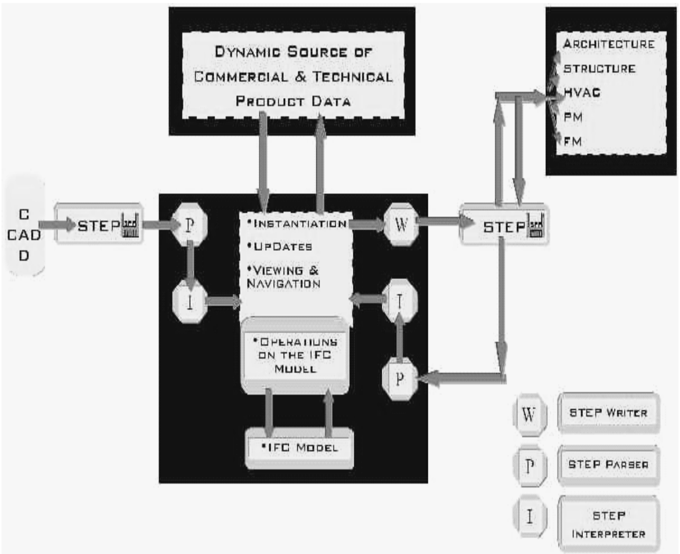

Figure 1.1 An Overall view of the operations on the IFC model

Figure 1.1 shows a map view of this research work, where the whole system consists of distributed platforms represented in a source of dynamic construction product data and a user (client) side represented in the CAD software and other multidisciplinary applications. The core of this system is the operations undergone on the IFC model. This in-

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cludes importing the model to a space where new data can be instantiated, and old data can be updated or deleted. At the end the model can be exported to an arbitrary number of multidisciplinary applications. In other words, this means that construction product data can be mapped -from a relational model- to the IFC object oriented model and newly instantiated or merged to it. The latter is done in two main scenarios. First is when the user or specifier needs to define the search parameters of the product and second is later during the whole life cycle of the product whenever a need for product data or updates arises. The paper begins with a brief description of the STEP ISO 10303-P21 parser, then moves to the IFC2x Interpreter, where various alternatives for the interpretation process are discussed. It shows how various modifications and updating operations that are performed on the model in addition to exporting the model in the form of a STEP ISO 10303 P-21 file and finally some workflow management aspects that were encountered.

2 STEP ISO 10303-P21 PARSER

A major problem facing the implementation of IFC in university research projects is the process of parsing STEP files and the instantiation of the IFC Model, which is defined in EXPRESS ISO-10303-P11. In industry contexts, there are several EXPRESS based object oriented databases that are capable of reading, updating, writing and mapping STEP files. However, the costs of such relatively new technologies, at the time of writing this paper, are extremely high.

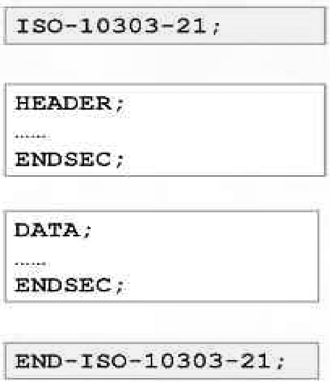

Figure 2.1 Constituents of a STEP file, Nour 2004

For many researchers, IFC is considered to be not more than a means for data exchange between commercial software applications. It was found that one of the biggest barriers standing between researchers and the IFC model is how to push the model itself from the theory in the IAI[1] documentation to the practice of implementation. In the meantime, the tools that can facilitate the instantiation of the model and manipulating its elements are extremely expensive. Since the research work is entirely independent of any commercial software application, it presents therefore a simple approach to parsing (STEP ISO-10303-P21 2004) files using available parser generator technologies.

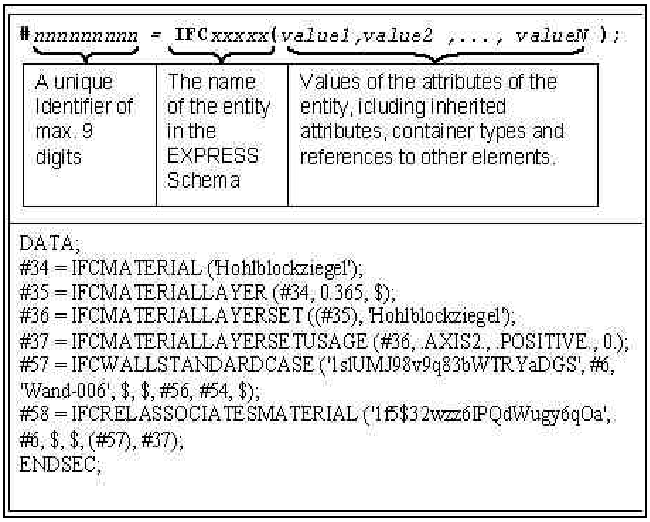

Figure 2.2 The Analsis of the STEP file, Nour 2004

The first step in developing the parser is identifying the structure of the STEP file, then defining the grammar. The first step was determined as a result of the analysis process of the STEP physical file's main constituents that are shown in figure 2.1, starting with the HEAD section and moving to the body or DATA section and ending with the END_ISO_STEP statement. The second step is done by writing down a grammar of the step file. The ifcElement starts with a line number identifier and the '=' sign, the name of the Element 'IFCxxxxx', open bracket, the argument list, a closing bracket, then an EOC (End Of Line Command) symbol which is the ';' symbol as shown in figure 2.2.

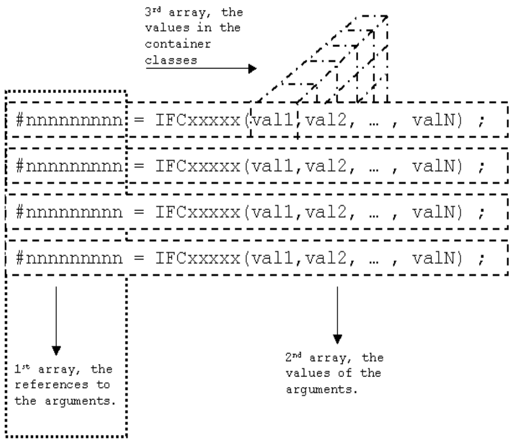

Figure 2.3 The instantiated three arrays from the parsing process

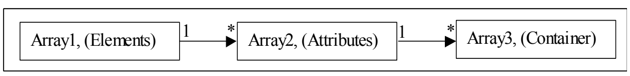

Figure 2.4 UML for the output 3D Array, Nour 2004

At the end of the parsing process a three dimensional array is obtained, as shown in figures 2.3 and 2.4. The first dimension of the array contains all the

1 IAI International Alliance for Interoperability, www.iai-international.org/iai_international/

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IfcElements (1st array), each IFC element points to an array containing its arguments (2nd array) and finally some argument values are references to container classes or other elements by them selves, i.e. They are represented through the third optional dimension (3rd array). Now the code should have already been parsed and is ready for interpretation by Java.

3 IFC2X INTERPRETER

The interpreter tries to map the IFC2x model entities to Java classes. The fact that STEP is a kind of serialization of objects defined in EXPRESS cannot be ignored. This more often than not results in many problems like the absence of some attributes in the STEP file, e.g. the optional, derived and inverse EXPRESS attributes. Moreover, Java is a programming and modeling language, whereas EXPRESS IS NOT a programming language. There are lots of differences that can be pointed out between the two languages.

Among these differences are the support for multiple inheritance, different types of container classes, logical, optional and Inverse attributes. STEP physical files are tightly bound to the EXPRESS schema they were written against. Because the ordering of attribute values is determined from the EXPRESS schema, changes to the schema may cause problems with files written against the original version. In the context of this paper only important issues that are encountered through the process of creating the interpreter are very briefly discussed.

A first step in mapping EXPRESS entities to Java classes is building an SDAI (Standard Data Access Interface). The SDAI is a STEP API for EXPRESS defined data. The SDAI protocols contain a description of the operations and functionalities that should be satisfied by the mapped entities. The SDAI is described by several ISO standards documents. STEP Part 22 (ISO 10303-22 SDAI, 1995) contains a functional description of the SDAI operations, while Parts 23 (ISO 10303-P23, 1995) and 24 (ISO 10303-P24, 1995) describe how these operations are made available in the C++ and C language environments. Bindings for CORBA/IDL and Java are also available. As a general rule, all mapped EXPRESS entities should implement the SDAI interface. The only purpose of this interface is the definition of rules that the generated Java classes must implement to get access to the inner attributes (Loffredo, 2004). There are two main types of bindings available:

SDAI Late Binding — In this approach, no generated data structures are used. Only one data structure is used for all of the definitions in an EXPRESS model. The Inner attributes are usually collected in a container class, e.g. Vector or List. Moreover, access to the objects is provided at runtime (ibid).

SDAI Early Binding — An early binding approach makes the EXPRES S information model available as specific programming language data structures for each different definition in the EXPRESS model (Schwarz, 2004). For example, an early binding such as the Java SDAI would contain specific Java classes for each definition in the IFC2x Schema. One major advantage to this approach is that the compiler can do extensive type checking on the application and detect conflicts at compile time. Special semantics or operations can also be captured as operations tied to a particular data structure. Early bindings are usually produced by an EXPRESS compiler. The compiler will parse, resolve, and check the EXPRESS model, then passes control to a code generator to produce data structures for that model. EXPRESS entity definitions are usually converted to Java or C++ classes where type definitions are converted to either classes or typedefs, and the EXPRESS inheritance structure is mapped onto the Java / C++ classes. Each class should have access and update methods for the stored attributes, possibly access methods for simple derived attributes, and constructors to initialize new instances. It should be also noticed that Java does not support multiple inheritance. At any rate, this problem is not encountered in this work due to the fact the EXPRESS definition of the IFC model does not use any multiple inheritance.

Another Approaches — The early and late bindings are not the only possible approaches. In the scope of this work a mixed approach is implemented. This approach provides the advantages of an early binding (compile-time type checking and semantics as functions in a class) without the complexity introduced by modelling a huge number of classes in the IFC model (there are more than three hundred and seventy leaf classes, in addition to eighty nine defined types, twenty three select types and one hundred and seventeen enumerations). It should be mentioned that in the the early binding approach there is a restriction to predefined classes. This means that if we need to interpret Ifc2x compliant STEP files, we have to model all the elements of the IFC2x model to Java classes. At the meantime, if we need to change to IFC2x2, then we have to do the same again with the whole model to produce new Java binding classes. A mixed binding takes advantage of the observation that applications rarely use all of the structures defined by the IFC2x EXPRESS Schema. The subset of structures that are used, called the *working set,* can be early-bound, while the rest of the Schema is late-bound (idem, 2004). All data is still available, but the application development process is simplified. The number of classes and files that are needed are reduced dramatically, resulting in quicker compiles, simpler source control, and more rapid development.

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In the scope of this work the mixed approach is implemented, in the early binding parts (working classes) a more labour-intensive approach has been used to hand-generate an early binding for the IFC2x model. Such a binding is not 100% compliant to the IFC EXPRESS model, due to the fact that there are EXPRESS data types that can not be mapped 1:1 to Java data types in addition to the strong rules that are imposed by the EXPRESS language.

Although this approach might provide a simplified programming interface, there are some drawbacks to be aware of. Aside from the increased labour involved in defining and implementing the binding, this method requires that the user should understand the EXPRESS schema API completely, and be able to predict how it will be used. (Loffredo, 2004).

3.1 *Mapping Express Data Types*

The EXPRESS language includes TYPE and ENTITY declarations, CONSTANT declarations, constraint specifications and algorithm descriptions. Only EXPRESS primitive data types, TYPE, ENTITY and aggregations declarations, are mapped to the exchange structure (STEP-P21). Other elements of the language are not mapped to the exchange structure and consequently are not mapped to Java types. Table 3.1 shows the mapping from EXPRESS to STEP and Java types. The first two columns in the table are taken from the ISO 10303-21 Specifications. The third column is developed by the author.

Table 3.1 Mapping EXPRESS to STEP & Java

EXPRESS element	mapped in to STEP-P21:	Mapped into Java
ARRAY	list	List
BAG	list	List
BOOLEAN	boolean	boolean
BINARY	binary	binary
CONSTANT	NO INSTANTIATION	NO INSTANTIATION
DERIVED ATTRIBUTE	NO INSTANTIATION	NO INSTANTIATION
ENTITY	entity instance	Class
ENTITY AS ATTRIBUTE	entity instance name	Reference to object
ENUMERATION	enumeration	Class
FUNCTION	NO INSTANTIATION	NO INSTANTIATION
INTEGER	integer	integer
INVERSE	NO INSTANTIATION	NO INSTANTIATION
LIST	list	LIST

EXPRESS element	mapped in to STEP-P21:	Mapped into Java
LOGICAL	enumeration	Class
NUMBER	real	double
PROCEDURE	NO INSTANTIATION	NO INSTANTIATION
REAL	real	double
REMARKS	NO Inst.	NO Inst.
RULE	NO INSTANTIATION	NO INSTANTIATION
SCHEMA	NO INSTANTIATION	Package (early binding)
SELECT	As an entity	Class (early binding)
SET	list	Set
STRING	String	String
TYPE	As an entity	Class (early binding)
UNIQUE rules	NO INSTANTIATION	NO INSTANTIATION
WHERE RULES	NO INSTANTIATION	NO INSTANTIATION

The EXPRESS Type, Enumeration and logical values are mapped to Java classes that try to immitate the behaviour of the EXPRESS entities. However, there is a drawback that modelling the rules and ristrictions imposed by the EXPRESS modelling language is not fully achievable.

3.2 *Interpreting STEP ISO 10303 P-21*

After parsing the STEP file, a three dimensional array - described earlier – is obtained. The following algorithm describes the process of interpreting the parsed code to IFC2x Java classes, where a mixed early and late binding approaches are used together. The author did not build an EXPRESS compiler that automatically does the mapping between EXPRESS entities and Java classes but depended on a good understanding of the IFC2x model in manually creating the mapping.

Step One — is the building of Java classes that are mapped from the IFC2x EXPRESS Schemas' entities i.e. an early binding approach. This is done for about more than seventy seven working classes and more than three hundred and twenty abstract and super classes. Each IFC EXPRESS Schema is mapped to a Java package and each mapped class implements the SDAI interface that provides the functionalities that insure reaching the inner attributes of the class.

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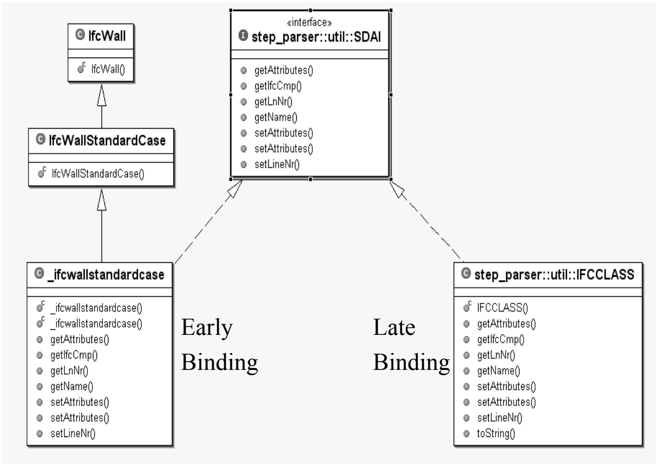

Figure 3.1 UML Diagram showning the implementation of the SDAI interface for early & late bindings and the separation between the IFC model and its implementation

In the early binding approach the EXPRESS entities are mapped to Java classes with no implementation, only as attributes. The implementation is then determined by a subclass that takes the name of the superclass preceded by a "_" as shown in the UML diagram in figure 3.1 This keeps the Java Ifc2x model pure and away from the influence of any implementation. This is envisaged to enable other researchers to use the model and provide their own implementation without any limitation to the author's use of the model. The figure also shows the use of both early and late binding approaches at the same time. Both approaches implement the SDAI interface.

In the late binding approach, one class is used for all EXPRESS entities. This class contains an attribute that is an array that contains all the attributes of the EXPRESS entity. This approach does not perform any attribute type checking on the countrary to the early binding approach that performs a type checking at run time and throws a class cast exception, whenever an incompatibility is encountered.

Step Two — Sorting the parsed array in an ascending order according to each element's identifier number is done by changing the array to an ArrayList and building a comparator class that is capable of sorting the list. The interpreter iterates over the parsed array of elements. If the element iterated upon already exists in the IFC2x model (early binding), then a new instance is created with the given parameters. If not, it will be instantiated as a late binding class. In both cases, before the instantiation takes place, the interpreter iterates over the arguments and makes an argument checking for each element in the 2nd dimension of the array i.e. the attributes of the IFC STEP entity. If it is a "$", then it is substituted by a null value. If it is a "#nn", then the identified element is sought from an identifiers HashMap that keeps references to the interpreted IFC2x Java objects and uses the STEP numerical identifier(#nnn) as a key. If it already exists i.e. already interpreted, then a reference to it replaces the identifier and if not, then it is added to a remainings list, where it will be later referenced to the correct element at the end of the interpretation process. In case where the argument is a container class (a Set or a List and so forth), the interpreter iterates over its elements (in this case as the 3rd dimension of the Array) and treats them as normal arguments. In general, if the argument is not an identifier, a "$" or a container class, then the value of the argument is taken as a parameter for the construction of the new instance of the Ifc2x Java class, bearing in mind the mapping rules between EXPRESS data types and Java data types. At the end of the interpretation process, the elements in the remainings list are re-instantiated, where any identifier reference should be replaced with a reference to an element (IFC2x Java Object) obtained from the identifiers Hash Map. In this way, any violation to referencing conventions is rectified. In other words, the instantiation of such argument is postponed till the end, where the references to the elements already exist in the identifiers HashMap. At the end of the interpretaion process we should already have an array of Ifc2X Java objects.

4 VISUALISATION OF THE IFC MODEL

After interpreting the parsed STEP file it is visualised in the form of a tree that represents the project hierarchy of the IFC model. This enables the navigation through the model and exploring its entities.

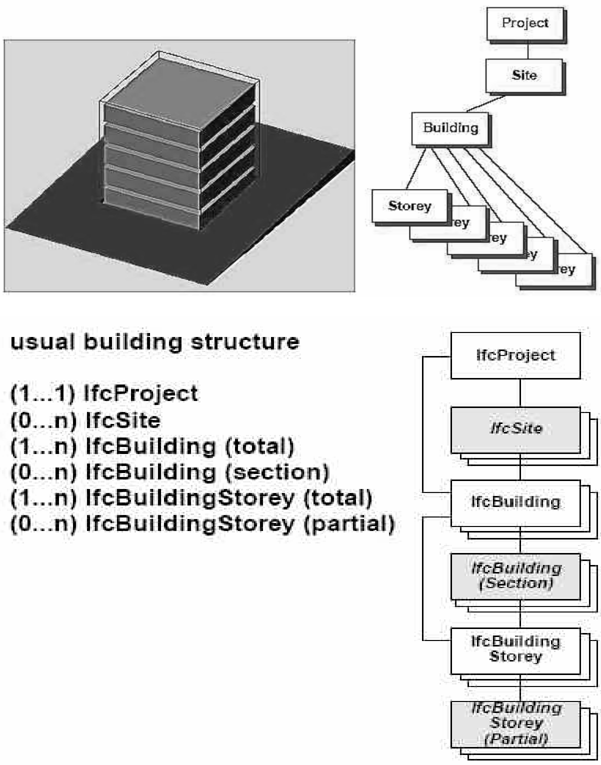

Figure 4.1 The Project hierarchy in the IFC model, IFC2x Model Implementation Guide (IAI, 2002).

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This also facilitates the selection of construction products in the IFC model and carrying out various processes on the model such as any instantiation, modification or deletion of the products' properties and so forth.

Figure 4.1 shows the hierarchical structure and spatial arrangement of the IFC model. The root of this tree is the Project entity, where it is a single unique object that contains zero or more sites. Each project contains one or more buildings and each building contains one or more stories. The mandatory and optional levels of such a tree structure are shown in the same figure. Whereas the IfcProject, IfcBuilding and IfcBuildingStorey are mandatory levels for the exchange of complex project data, the IfcSite and IfcSpace represent optional levels (which may be provided, if they contain necessary data).

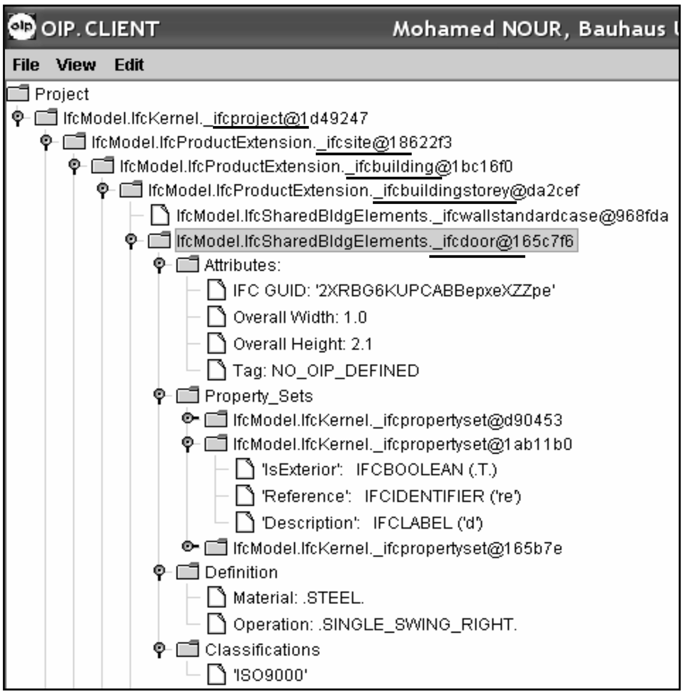

Figure 4.2 The IFC Project Tree hierarchy

Figure 4.2 shows the navigation tree in the software application, starting from the project instance moving down to the construction product instance. The project tree is extended to include other aspects such as the product's attributes like the dimensions of a door or a window, the construction materials included in such elements and so forth. In other words, the attributes that contribute to the construction of parametric searches in electronic product catalogs are included. It could be navigated through these parameters as desired by just expanding the product's tree node. And hence enables carrying out information queries and updates on the selected elements in the information model.

5 OPERATIONS ON THE IFC MODEL

In the scope of the research work the operations needed to be done on the IFC model are limited to the instantiation, updates and deletion of construction product properties in addition to exporting the modified model in the form of a STEP ISO 10303 P-21 file.

5.1 *Instantiation of new property sets and classifications*

In general and as shown in figure 5.1, before carrying out any instantiation process to a property set, property definition, a classification or even a new construction material, we should find first the elements (IfcBuildingElement) in the IFC model to which the new instance is related. In the scope of this research work, this is envisaged to be done by selecting a product from the project's tree view. Once we have a selected product, then we can query the model to find the objectified relationship classes instances (IfcRelxxx) that link the product with other parts of the model – like a cross reference table in a relational database- and consequently add to the

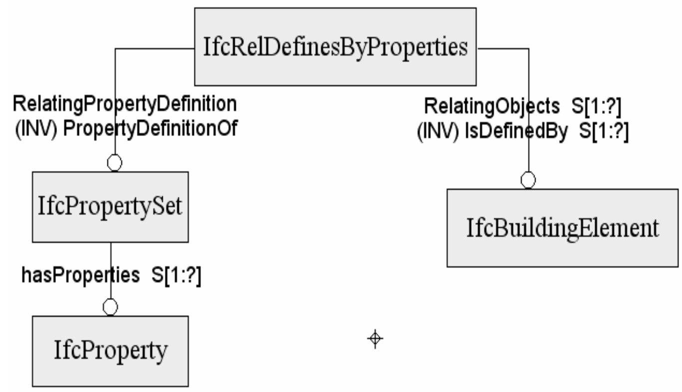

Figure 5.1 An EXPRESS-G diagram showing the relation between properties & construction products through the definition relationship

product an arbitrary number of new properties classifications or materials. Furthermore, this enables carrying out any required update or delete operations on the model.

The instantiation process is done in this way due to the fact that the IfcPropertySet and IfcBuildingElement EXPRESS entities are both linked to the IFC relation by inverse attributes – as shown in figure 5.1 - that are absent in the STEP file. Thus, searching the relations is the only means through which the property set and the construction product could be matched together.

The process of adding a new property to a product begins by searching the model and examining if the product is already linked to a property set that this property belongs to or not e.g. PsetDoorCommon which is one of the many published property sets in the documentation of the IFC2x model. In case this property set is found, the property is simply added to the property set. If the property set does not exist then a new property set and a new relation instance are instantiated from scratch, linked to the product and the property is added to the property set.

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In both cases of instantiation of the property sets and the constituent properties, new instances of the properties themselves are created with the necessary parameters, added to the property set and then added at the end of the instantiation process to the array (ArrayList) of IFC elements. It should be mentioned that figure 5.1 is an EXPRESS-G diagram that represents an abstraction by the author that ignores inheritance of the EXPRESS entities and some of the attributes. This is done for clarification reasons and to make the diagram as simple as possible.

5.2 *Updates*

The updates to the model are carried out in the same manner like the instantiation. During the navigation in the project tree, a product is selected, a query in the model is executed to find its attributes and properties. Once the values are changed from the user interface as shown in figure 5.2, the new values replace the old ones.

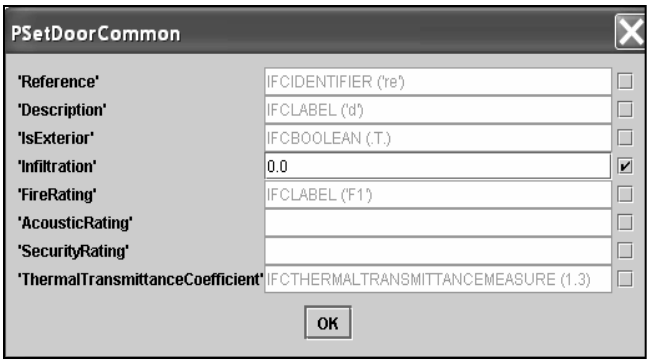

Figure 5.2 The GUI used for the updates

5.3 *Deletion*

Deletion is done either by blanking the text filed in the GUI or deleting the property explicitly. It is important here to mention that it is not only necessary to delete the references to and from the deleted object, but it also important to delete the object itself. This is done by changing the array of elements to an ArrayList, removing the deleted element and then returning the array back again.

5.4 *EXPORTING STEP ISO 10303-P21 files*

Exporting the model in the form of a STEP ISO 1030-P21 is easily done once the model is converted to a tree structure according to its relationship references and not according to its project hierarchy as it was done earlier in the visualization process. To build this tree the Java JTree and DefaultMutableTreeNode classes were used. At the root of the tree are always the aggregation relationships that have references to different parts of the model and acts as the aggregation elements. On the other hand, elements that have no references to other elements are situated at the leaf ends of the tree. The more the element has references, the more it is nearer to the root of the tree.

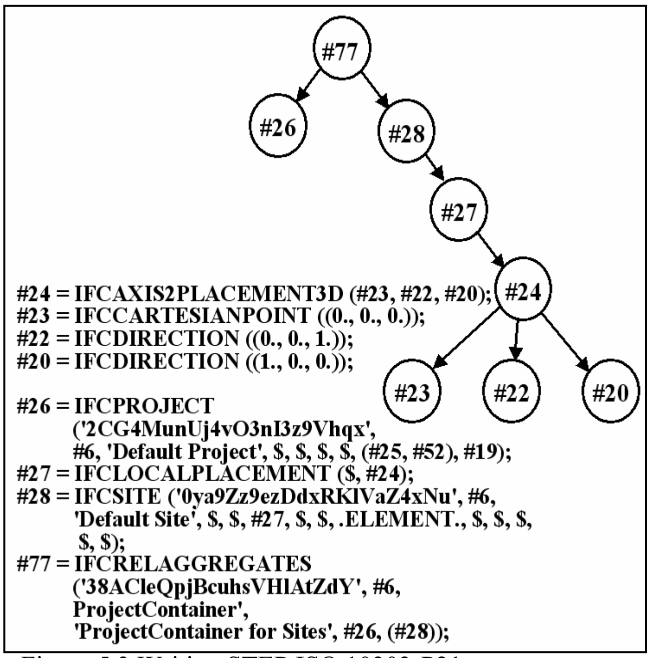

Figure 5.3 Writing STEP ISO 10303-P21

Figure 5.3 presents a simple example that shows the way to build such a tree. The STEP writer iterates over the array of elements and each of the element's arguments, where the Java Types are mapped to STEP. All elements are allocated new identifier numbers according to their position in the tree. From figure 5.3 we can notice that elements with an identifier #xx references another element with an identifier #yy, where xx > yy. The STEP writer iterates on the IFC model elements and their arguments and replaces the null attributes by a "$" and the references to other elements by their newly allocated identifiers. Furthermore, the same procedure is done with elements residing inside collections or container classes together with adding extra parenthesis as shown in #77 and its reference to #28 in figure 5.3.

One major problem during the building of the tree was the mutation of the nodes. In the IFC model tree a node can be referenced from more than one parent node, thus the node jumps from the old position to the new position. However, the nodes should keep their position where they are first referenced, i.e the old position. Hence, the major task to overcome this problem was to prevent the referencing of nodes that have already been referenced before. This was done by keeping a record of the referencing in a hash map and to allow referencing only in cases where the node has never been referenced before.

After building the tree structure, the HEADER part of the STEP file is instantiated, and the tree is traversed in a post order recurring manner, where the leafs of the tree are iterated upon before the parents and hence given a smaller identifier number and written first to the STEP file.

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6 WORKFLOW MANAGEMENT ASPECTS

The IFC model is mostly used for the transfer of information from one software to another. There is always a gray area between software applications that enables the information to be mapped from one software application to another. However, there are more often than not functionalities that are supported by one software and not by the others. This often results in inevitable information loss; when the model is saved by an application that imports an IFC model and does not support the functionalities of the software that originally produced it. Further more, some times it has nothing to do with functionalities, the software serializes the model to IFC according to the information content of its objects and ignores the information that was originally imported within the model. This is exactly the case that the author encountered when the IFC model was instantiated by product data and re-imported by CAD software (ArchiCAD 7.0, Students version and ADT 3.3) the software could show the newly instantiated information as in figure 6.1, but when asked to re-export the model, the software serialized its objects to a STEP file and took no care of the extra information in the model. Hence, the IFC model loosed its advantage as an independent non proprietary building information model that is capable of transmitting multidisciplinary AEC information.

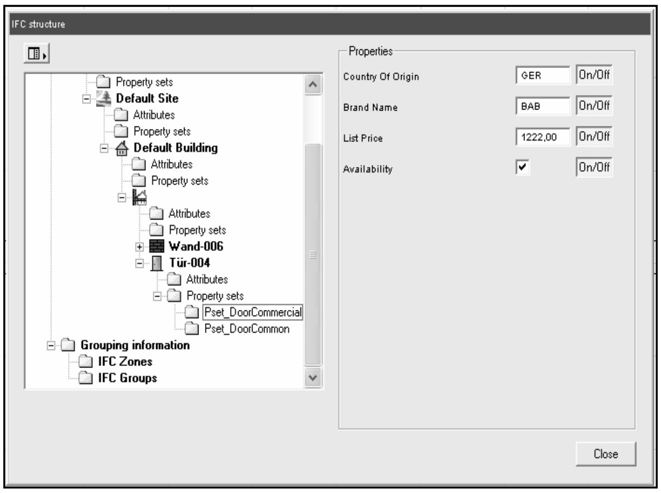

Figure 6.1 A snap shot from ArchiCAD 7.0 showing the Instantiation of the Property Set Pset_DoorCommercial

7 CONCLUSION

The paper has discussed various steps necessary for the implementation of the IFC model in scientific research using simple programming techniques and away from using relatively expensive commercial software. The paper showed an algorithm for parsing STEP ISO 10303-P21 files and its interpretation to IFC2x Java classes, in addition to carrying out instantiation, updates and deletion operations on the model and finally exporting the model in the form of a STEP physical file that can be used by AEC software applications.

Some shortcomings of the CAD software applications were encountered in the process of exporting the imported model. The shortcomings are represented in the loss of information that was originally imported into the model, despite the fact that the CAD software could read it and represent it in its own environment. It is worth also mentioning that the lost information does not relate to the functionalities of the importing CAD software. It is most probably commercial information that is related to construction products. In other words, only the information that is related to the imported software is exported.

If the above mentioned shortcoming is rectified by AEC software applications - which will happen no doubt sooner or later – this would give a real technical push to the use of Building Information Models and its ability to be worked upon by multidisciplinary AEC software applications.

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Efficient verification of product model data: an approach and an analysis

V.A. Semenov, A.A. Bazhan, S.V. Morozov & O.A. Tarlapan
Institute for System Programming of the RAS, Moscow, Russia

ABSTRACT: In the paper an approach to verification of product model data is developed and discussed. The general approach encompasses all the variety of data and constraints assumed by EXPRESS language and provides for efficient solutions to verify product model data both completely and incrementally under single and multiple updates caused by insertion, deletion, and modification operations. The implementation methods are also of the paper subject. The methods are oriented on static analysis of specifications, compilation of optimized codes for the integrity checking and maintaining procedures and their efficient runtime execution. In the paper a performance analysis is conducted to compare the developed OpenSTEP Checker application with available similar programs and to form some qualitative criteria for efficient verification of product model data in various application contexts. The results are given in conformity to IFC standard that is of principal importance for achieving semantic interoperability in the architecture, engineering, and construction.

1 INTRODUCTION

The STEP is a family of emerging international Standards for the Exchange of Product Model Data developed by the ISO Technical Committee 184 "Industrial automation systems and integration" (ISO 1994). The STEP provides standardized mechanisms to specify information models using the EXPRESS language as well as to exchange and to share model-driven data in the ways neutral to potential software platforms and applications. Since such data are usually generated and shared by different applications, some integrity constraints may be violated, data consistency may be falsified and application interoperability may be destroyed. Therefore, STEP-compliant applications and distributed systems must incorporate some mechanisms to ensure that integrity constraints are always satisfied and the shared data are consistent and meaningful for all the stakeholders involved in joint multidisciplinary projects.

The tasks of integrity enforcement attracted much effort in the area of database management systems, particularly in the deductive and relational database communities (Pacheco 1997). The issues of integrity checking and maintenance of object-oriented data were also investigated (Mayol & Teniente 1999), but in some restrictions imposed on the information models, integrity constraints and update operators, not enabling expansion of the results into the verification tasks relating to general EXPRESS schemata.

In the paper the approach to verification of product model data is developed and discussed. The general approach encompasses all the variety of data and constraints assumed by EXPRESS information modeling language. In particular, it allows such constraints as referential integrity, cardinality constraints, attribute domain and object domain constraints, uniqueness and global rules. The approach provides for efficient solutions to verify product model data both completely and incrementally under single and multiple updates caused by insertion, deletion, and modification operations. Complete verification is usually employed to guarantee consistency of the information accumulated in persistent data stores or exchanged between interoperable software applications. Incremental verification allows to manage the information consistency more effectively if the data updates have local and latent character. In particular, this is the case if common multidisciplinary data are shared among separate software applications involved in distributed collaborative transactions (Ramamritham & Chrysanthis 1997).

The approach implementation issues are also of the paper subject. The presented methods are oriented on effective static analysis of EXPRESS specifications, compilation of optimized codes for the integrity checking and maintaining procedures and their highly efficient runtime execution.

Realization of the complete verification is rather straightforward. It is based on translation of constraint predicates given by declarative specifications

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of information schema into some imperative language and corresponding execution environment.

Realization of the incremental verification is more sophisticated as it must guarantee acceptable localization of all the potential violations caused by possible data updates. The fundamental means of the developed incremental method are reconstructed dependency and inference graphs permitting to interrelate EXPRESS constraints and possible data updates in pre-compile time and to significantly reduce the search space for the integrity checking procedures executed at runtime (Semenov et al. 2004b).

Being realized in a strong way, the incremental verification enables to detect potential violations without performing costly evaluations of all the constraints imposed by an information schema. Nevertheless, it requires additional expenses on analysis of established inference relations between constraints and updates and may result in lower total efficiency. In the paper a performance analysis is conducted to compare the developed OpenSTEP Checker application with functionally similar programs and to form some qualitative criteria for efficient verification of product model data in various application contexts. The results of analysis are given in conformity to emerging IFC standard (IAI 1999) that is of principal importance for achieving semantic interoperability of software applications in the architecture, engineering, construction, and facility management industry domains.

2 OBJECT-ORIENTED METAMODEL

2.1 Formal model

So, we define an object-oriented data schema as a structure $S = \langle T_S, \prec, Attr_S, Func_S, Rule_S \rangle$ with the following meaning:

- $T_S = T^D{}_S \cup T^{\overline{D}}{}_S \cup C_S$ — a set of data types of the information schema consisting of basic types $T^D{}_S$ mapped into basic semantic domain *D*, derived types $T^{\overline{D}}{}_S$ mapped into multi-valued constrained semantic domain $\overline{D}$, and object types C_S;
- $\prec$ — a partial order on T_S reflecting the generalization/specialization relations induced to employ an inclusion polymorphism;
- $Attr_S$ — a set of attributes and constants. Each attribute $a_C \in Attr_S$ defined by the object type *C* is represented by a pair of operation signatures $a_C : C \mapsto T$, $a_C : C \times T \mapsto C$ for functions accessing the attribute value of the type *T*. Defining an attribute $a_C \in Attr_S$ of the type C' establishes an association relation between the object types C, C' with the corresponding role a_C;
- $Func_S$ — a set of imperative methods $f \in Func_S$ with a generic signature $f : T_1,\dots,T_n \mapsto T'_1,\dots,T'_m$, where the input and output data types $T_1,\dots,T_n$, $T'_1,\dots,T'_m \in T_S$ may be basic, derived or object types. For schema functions $f \in Func_S$ the signature is reduced to $f : T_1,\dots,T_n \mapsto T'$. Derived attributes of objects $f_C \in Func_S$ can be represented by the specialized signature $f_C : C \mapsto T'$;
- $Rule_S$ — a set of semantic rules $r \in Rule_S$ imposing integrity constraints upon object-oriented data. They may limit the number, kind and organization of objects as well as impose relationships among their states. The rules are represented by the predicate signature $r : T_1,\dots,T_n \mapsto logical$. Depending on data types $T_1,\dots,T_n \in T_S$ of the schema the scope of the rules may be expanded into separate data, object instances and whole object populations.

In a way quite similar to the algebraic specification approach (Richters & Gogolla 1998), we provide a signature $\Sigma_S = (T_S, \prec, \Omega^D{}_S \cup \Omega^{\overline{D}}{}_S \cup Attr_S \cup Func_S \cup Rule_S)$, where $\Omega^D{}_S$, $\Omega^{\overline{D}}{}_S$ are sets of operations defined on basic and complex derived types. The signature formed by such way describes all of the types and the operations belonging to the information schema *S* as well as contains the initial set of syntactic elements upon which the expressions $Expr(\{var_T\} \mid T \in T_S)$ with variables indexed by the types can be defined.

A set of interrelated objects defined by the information schema *S* with attribute values and associations established among them constitutes the state of an object-oriented model M_S. In conformity with our discussion, M_S is a product model data defined by some information schema *S*.

A named subset of objects of the model M_S relating to the same type $C \in C_S$ is referred to by object population $p \subset M_S$. Let $C(p) \in C_S$ is an object type assigned to the population *p* of the model M_S. The set of all the objects of the model M_S belonging to the same type $C \in C_S$ is called by type extent $ext(M_S, C)$. Obviously that if the types $C_1 \in C_S$, $C_2 \in C_S$, and $C_1 \prec C_2$, then the subset relation $ext(M_S, C_1) \subseteq ext(M_S, C_2)$ takes place for the derived type extents. Moreover, for any population *p* of the model M_S such as $C(p) \prec C$, the relation $p \subseteq ext(M_S, C)$ is always true.

For the purposes of clarity we explain further the introduced formalism and consider shortly syntax and semantics of the EXPRESS language that is of great importance for specification of arbitrary product model schemas using the general object-oriented notation.

2.2 EXPRESS data model

EXPRESS introduces basic data types {*Real, Integer, Number, Boolean, Logical, String, Binary*} $\subseteq T^D$ of usual semantics. Complex types $T^{\overline{D}}$ and object types *C* are defined using {*Bag, Set, List, Array, Enumeration, Select, Defined*} and {*Entity*} declarations correspondingly. These metatype constructions permit to

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define different sorts of aggregates, enumerations, selections, classified objects as well as to derive nested data types with hierarchically imposed constraint sets from already defined ones.

Simple data types are *Boolean*, *Logical*, *Number* (including particular subtypes *Real* and *Integer*), *String*, and *Binary*. Interpretation of the simple types is usual, but we extend each set with a special value *?* denoting the undefined value. A type $T \in T^D$ is mapped to a semantic domain D by a function $I : T \mapsto D$ as follows: I (*Boolean*) = {*true, false*} $\cup \{?\}$, I (*Logical*) = {*true, false, unknown*} $\cup \{?\}$, I (*Real*) = $R \cup \{?\}$, I (*Integer*) = $Z \cup \{?\}$, I (*String*) = $A^* \cup \{?\}$, where A is a finite alphabet, A^* is a set of all sequences over the alphabet A, and I (*Binary*) = $\{0,1\}^* \cup \{?\}$. The *String* and *Binary* variables may have fixed or varying sizes with limits defined by corresponding derived types.

Repertoire and semantics of the operations defined on the simple types is well understood. These are arithmetic operations on numeric operands of *Number*, *Real*, *Integer* types and standard mathematical functions; translation of the numbers into string representation and backwards; logical operations on operands of *Logical* or *Boolean* types; concatenation, pattern matching, indexing, subset operations on *String* and *Binary* operands as well as comparison operations defined for all the simple types. Some operations have the same overloaded name symbol and can be distinguished only by looking at their argument types.

Constructed types that may be either enumeration or selection data types extend the set of basic types. The domain of an enumeration type *Enumeration* is given by an ordered set of values represented by unique names $I(Enumeration(a_i, i = 1, \ldots, n)) = \{a_i \in A^*, i = 1, \ldots, n\} \cup \{?\}$. The literal values of the enumeration type are referred to as enumeration items. Ordering of the enumeration items results in comparison operations.

A selection data type *Select* defines a derived type represented by a list of the other underlying types. The selection instance is an instance of one of the types specified in the selective list. Therefore the selection data type is a generalization of its underlying types and its value domain is the union of the underlying type domains $I(Select(T_i, i = 1, \ldots, n)) = I(T_1) \cup \ldots \cup I(T_n) \cup \{?\}$.

A *Defined* data type is an user extension to the standard data types available in EXPRESS excepting that it enables to define additional semantic constraints imposed upon specified data. Therefore the defined type is always a concretization of its underlying type and its value domain $I(Defined(T)) = I(T) \cup \{?\}$.

Object types are defined by declaring their explicit, inverse, derived attributes and local rules. Generalization relations between object types are established via simple and multiple inheritance mechanisms. The inherited object type shares all the attributes and rules encapsulated by its parent supertypes, but can redefine them by specializing attribute types and imposing more restricted semantic constraints upon object states.

On object types the following common operators are defined. The relational operators = and <> are intended to compare the real states of objects. Unlike deep comparison operators, the operators :=: and :<>: permit to identify objects themselves. For a given object the function *rolesof* returns a list of qualified names of associations in which it takes part. The function *usedin* returns a set of objects connected with a given object via an association given by its qualified name. Availability of these functions in the language repertoire makes possible the navigation over object-oriented models via associations in both directions.

Multi-valued expressions in EXPRESS are described by aggregation metatypes *Array*, *List*, *Bag*, and *Set*. So, *Array* data type is a fixed-size structure where indexing of the elements is essential. Optionally, arrays can admit that not all of the elements have a value. *List* data type represents an ordered collection of like elements. A list can hold any number of elements allowing or, optionally, not allowing their duplication. *Bag* data type is a collection of elements in which order is not relevant and duplication is allowed. And, finally, *Set* is a collection of elements in which order is not relevant and where duplicate elements are not allowed. The number of elements in lists, bags, sets may vary, depending on their limit specifications.

Set operators +, -, * are defined to union, to difference, and to intersect collections of compatible types T_1, T_2. Relational operators, including subset and superset operators <=, >=, are intended to establish relations of equality and generality between collections. Pairs of relational operators =, <> and :=:, :<>: are semantically equivalent for all the aggregation data types except for aggregates of objects with differences pointed above. The membership operators *value_in* and *in* test a given element for membership in an aggregate by value and instance equivalence. The *query* expression evaluates a logical condition individually against each element of an aggregate and returns an aggregate containing the elements for which the logical expression evaluates *true*. The indexing operator *[]* extracts a single element from an aggregate. Operations *sizeof*, *hiindex*, *loindex, hibound, lobound* return the number of elements in an aggregate, the upper and the lower indices of array elements, the upper and the lower bounds of lists, bags, sets correspondingly. The *insert* and *remove* operations are defined additionally to simplify manipulations with lists.

Aggregation, selection, and defined types may be nested allowing the construction of more complex multidimensional structures that cannot be avoided

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in such non-trivial information models as STEP application protocols (ISO 1994).

EXPRESS provides for predefined abstract data types *Generic, Aggregate, BagOfGeneric, SetOfGeneric, ListOfGeneric, ArrayOfGeneric* that can be used to specify functional methods in generic manner. Being defined on *Generic* type some operators can be applied also to any data. These are the function *exists* that tests whether a given variable has defined state, the function *nvl* that returns alternative value if a variable is in undefined state, and the function *typeof* that forms the set of all type names the given value belongs to.

2.3 EXPRESS constraint model

In addition to declarative part, the EXPRESS language provides for imperative constructions necessary to specify the integrity constraints imposed upon object-oriented data. The semantic constraints are defined in the form of rules that can be conditionally categorized into three groups.

The first group is related to rules defined for separate data items and imposed upon them:

- limited width of $data \in String$, $data \in Binary$: $length(data) \le n,\ \ n > 0$ for strings and binaries of varying length or $length(data) = n,\ \ n > 0$ for data of fixed length;
- limited number of elements in aggregates: $lobound(aggr) \le sizeof(aggr) \le hibound(aggr)$ for lists, bags, and sets $aggr \in ListOfGeneric \cup BagOfGeneric \cup SetOfGeneric$, and $sizeof(aggr) = hiindex(aggr) - loindex(aggr) + 1$ for arrays $aggr \in ArrayOfGeneric$;
- nonidentity of elements in unique aggregates: $aggr[i] :\ne: aggr[j]$ for all indices such as $i \ne j$ and $i, j = 1,\dots, sizeof(aggr)$ in sets and unique lists $aggr \in SetOfGeneric \cup ListOfGeneric$, and $i, j = loindex(aggr),\dots, hiindex(aggr)$ in unique arrays $aggr \in ArrayOfGeneric$;
- defined elements in non-optional arrays $aggr \in ArrayOfGeneric$: $exists(aggr[i]) = True$, where $i = loindex(aggr),\dots, hiindex(aggr)$;
- domain rules for a defined data type $data \in Defined(T)$: $rule_i(data) = True, i = 1,\dots, n$, where the rules $rule_i$ are given by logical expressions. The value domain of the defined type *Defined*(*T*) is formed as a domain of the underlying type *T* except for the values violating at least one rule.

The second group consists of the rules assumed or defined by separate object types and shared by their instances. The following constraints are covered by this group:

- type compatibility of object attributes and assigned values $obj.a = val,\ \ obj \in C$: $value\_in(type(obj.a),\ \ typeof(val)) = True$. The types must be equivalent or the attribute type must generalize the value type;
- required values of non-optional attributes of objects $obj \in C$: $exists(obj.a_i) = True$, $i = 1,\dots, n$;
- limited cardinality of inverse associations $C_1.a \xrightarrow{\{m:n\}\quad \{p:q\}} C_2.b$ in objects $obj \in C_2$: $p \le sizeof(obj.b) \le q$. If an inverse attribute is specified as a set of objects, an uniqueness constraint $obj.b[i] :\ne: obj.b[j]$ for all the indices such as $i \ne j$, $i, j = 1,\dots, sizeof(obj.b)$ is additionally imposed upon the objects participating in such associations;
- nonidentity of value sets for unique attributes $C.a_1,\dots,a_k$: $obj_i.a_1 :\ne: obj_j.a_1$ *or* … *or* $obj_i.a_k :\ne: obj_j.a_k$ for $obj_i, obj_j \in ext(M_S, C)$, $i \ne j$, i.e. no two objects of the model cannot share the same set of unique attribute values;
- domain rules for objects $obj \in C$: $rule_i(obj) = True$, $i = 1,\dots, n$, where the rules $rule_i$ are given by some logical expressions. The inspected object belongs to value domain if all the domain rules predefined by its types are satisfied. These constraints are used to bound the values of individual attributes and their combinations for separate objects and their groups.

Finally, the third category of constraints available in the EXPRESS language is global rules: $rule_i(ext(M_S, C_1),\dots, ext(M_S, C_k)) = True, i = 1,\dots n$ where the rules $rule_i$ are given by some logical functions with factual parameters being corresponding object type extents. These rules are defined immediately by an information schema and enable interrelate the states of whole object populations.

Notice that the result of verification of any rule is logical one meaning that the constraint may be asserted, unknown or violated. According to the EXPRESS semantics only violated constraints are interpreted as not conforming to the schema. Therefore to be valid the model must contain all valid objects and also satisfy all the uniqueness and global rules with asserted or unknown status. To be valid the object must satisfy all the attribute constraints and domain rules with asserted or unknown status too.

3 VERIFICATION

There are two typical statements of verification problems in conformity to STEP-driven product model data. First one is the complete verification that consists in checking of all the data within an object-oriented model M_S in strong correspondence with all the rules formalized and enumerated below. The second one is the incremental verification reasoning from local and latent character of possible updates in the model M_S.

The single updates may be object deletion $delete(obj)$, $obj \in M'_S$, object modification *modify(obj)*, $obj \in M'_S, M''_S$ and object insertion $insert(obj)$, $obj \in M''_S$, where M'_S, M''_S — preceding and current states of the model. Multiple updates

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are compositions of the single updates. Often, being occurred within transactions, the updates have partial character, which may be effectively exploited for localization of potential violations without performing costly evaluations of all the constraints for the model. Because of complete verification of complex large-scale product model data is a computationally expensive task, the incremental approach may result in higher efficiency and makes the consistency enforcement policy to be applicable in some practice-important cases.

3.1 Complete verification

Complete verification is rather straightforward and can be conducted using the following transparent algorithm:

```
for each Object in Model
    for each Attribute of Object
        Check AttributeRule (Object, Attribute)
    for each domain Rule of Object
        Check DomainRule (Object, Rule)
for each uniqueness Rule defined for type C
    Check UniquenessRule (ext(Model,C), Rule)
for each global Rule defined for types C1,…,Ck
    Check GlobalRule (ext(Model,C1),…,ext(Model,Ck),Rule)
```

It is suggested that the algorithm logs the errors pointing out what rules are violated and for which attributes, objects and type extents. In the first external loop all the constraints related to separate object attributes and object domains are checked. The next loop realizes checking of uniqueness rules defined for some object types. To evaluate the rules the corresponding type extents have to be extracted from the inspected model. In the third loop the algorithm checks all global rules with factual parameters being proper type extents of the model.

3.2 Incremental verification

Here we outdraw the developed method for incremental verification of data defined by the EXPRESS schemata. The method takes into account all variety of the constraints available in EXPRESS and exploits the introduced concepts of dependency and inference graphs. In more details the method is presented and described in our work (Semenov et al. 2004b).

First of all, to effectively analyze data dependencies, transitions between model populations should be defined. Every transition either direct or associative one realizes some relation between the populations and produces some transition function that being evaluated makes the states of the interrelated populations to be consistent. A direct transition $r \in R^D$, $r: p_i \to p_j$ $(i \neq j)$ realizes a subset relation between object populations of compatible types so as if $C(p_i) \prec C(p_j)$ then $p_i \subset p_j$ and if $C(p_i) \succ C(p_j)$ then $p_i \supset p_j$. Every associative transition $r \in R^A$, $r: p_i \to p_j$ (possibly, $i = j$) realizes some association relation defined by the schema for the corresponding object types $C(p_i)$ and $C(p_j)$ in explicit or implicit way. In particular, if a transition realizes an association *role*, then the relation takes form $Use(p_i, role) \subset p_j$, where $Use(p_i, role)$ is a set of all the objects associated with the population objects p_i by the *role*.

A production function for the direct transition $r \in R^D$, $r: p_i \to p_j$ can be defined as $p'_j = p_j \cup obj \in p_i \;\; | C(obj) \prec C(p_j)$. For the associative transition $r \in R^A$, $r: p_i \to p_j$ a production function is formed as $p'_j = p_j \cup obj \in Use(p_i, r)$ $| C(obj) \prec C(p_j)$.

The transitions can be inverted. A production function of the inverted direct transition $\bar{r} \in R^D$, $\bar{r}: p_j \to p_i$ is given by $p'_i = p_i \cup obj \in p_j$ $| C(obj) \prec C(p_i)$. For the inverted associative transition $\bar{r} \in R^A$, $\bar{r}: p_j \to p_i$ a production function can be formed as $p'_i = p_i \cup obj \in Usedin(p_j, r)$ $| C(obj) \prec C(p_i)$, where $Usedin(p_j, role)$ is a set of all the objects with which the population objects p_j are associated by the *role*. Being applied twice, the inversion operation returns the transition in its original state.

Let *S* is an information schema, *P* is a set of populations with prescribed types $C(P) \in C_S$ and attribute subsets $A(P) \in Attr_S$, and $R = R^D \bigcup R^A$ is a set of direct and associative transitions between populations *P*. We call the structure $AG\langle P, A, R\rangle$ where populations *P* are represented by vertices, attributes *A* — by marks assigned to vertices, transitions *R* — by directed edges incident to corresponding population vertices by attributive graph for the schema *S*.

Navigation graph $NG\langle P, U, V, A, R\rangle$ is like an attributive graph $AG\langle P \cup U \cup V, A, R\rangle$, where some population vertices *U* and *V* are interpreted as sources and sinks. In the used graphic notation the source vertices are marked by incoming edges, the sink vertices — by outgoing edges. For the navigation graph the operations of inversion, composition, and reduction can be constructively defined. In particular, inversion of the navigation graph results in inversion of all the transitions *R* and changing places of all the source and sink vertices *U*, *V*.

The navigation graph $NG\langle P, U, V, R, A\rangle$ for the schema *S* gives a declarative query in M_S. Parameters of the query are initial states $u \subset M_S$ of the source populations *U*, and the result is the states $v \subset M_S$ of the sink populations *V* such as all the transition relations are satisfied. The query can be evaluated by means of production functions applied to all transitions of the graph until the population states are not updated.

Although navigation graphs allow cycles, the definition of the query is constructive as it guarantees determinism: the query processing routine is always finished for a finite number of evaluations of production functions and the query result does not

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depend on the way how the transitions were serialized.

The introduced navigation graphs and queries have an important application for analysis of data dependencies caused by imposed constraints. For this purpose a dependency graph $DG_f\langle P,U,V,R,A\rangle$ can be constructed for each method $f \in F_S$ of the schema S.

The method dependency graph is a navigation graph that can be constructed for any method of the schema like procedure, function, derived attribute, domain or global rules in accordance with some formal procedure. The procedure assumes that formal and factual parameters of the method, local variables, regular path expressions having object-related types correspond to the graph vertices P, U, V. At that, local variables and regular expressions are represented by the vertices P, input parameters and factual output parameters of called methods — by the sources U, output parameters and factual input parameters of called methods — by the sinks V. The object-related types mean here object types, aggregates of objects, selections of objects, and proper nested derived types.

Attribute subsets A are formed and prescribed to corresponding vertices P, U, V, if attributes of all the other types are used in the method expressions having object-related types. Transitions in the dependency graph correspond to operations of type casting, set-theoretic operations, calls of methods, and also to separate terms in regular path expressions. For brevity we omit the details and address to the mentioned work, where the procedure has been completely described.

The schema dependency graph $DG_S\langle P,U,V,R,A,F\rangle$ is a graph composed of the dependency graphs $DG_f\langle P,U,V,R,A\rangle$ constructed for all the methods $f \in F_S$ of the schema S. As a result of the composition all the elements belonging to the particular dependency graphs are marked by the method identifiers F and method calls are resolved in the following way. The sinks being factual input parameters of called methods are connected via direct transitions with sources being formal parameters of these methods. The sinks being formal output parameters of called methods are connected via direct transitions with sources being factual parameters of the methods. At that, all the sources not participating in method calls resolution and being sources of verification rules are remaining sources, and all the other vertices are becoming sinks (at more detailed consideration additional categorization of vertices is possible and may be useful).

Being navigation graph and defining queries in the inspected model, the schema dependency graph can be applied to localize the model objects that would participate in verification of separate rules. For this purpose the sources of the analyzed rule $f \in F_S$ have to be initialized by the model objects and a query based on the schema dependency graph has to be evaluated. The result of the query will include all the model objects potentially participating in verification of the rule. Indeed, taking into account static associative and subset relations between object populations and omitting conditional statements, the method and schema dependency graphs result in extended querying and guarantee localization of all the objects participating in the rule verification.

The graph $IG_S\langle P,U,V,R,A,F\rangle$ inverted to the schema dependency graph $DG_S\langle P,U,V,R,A,F\rangle$ is called by inference graph.

By construction the inference graph enables to localize rules that might be violated as a consequence of some updates occurring in the model. To form a navigation query the sources of the inference graph have to be initialized by modified objects. The result of the query evaluation is the model objects accumulated in sinks. Each non-empty sink population gives both objects and assigned rule $f \in F_S$ that might be violated through modifications. It is essential that violations may occur only if some attributes and associations of the modified objects have been changed. The formed attribute subsets A and the constructed transitions R are just those metadata that permit to conduct such analysis. Navigation over the inspected model using the inference graph extends the sets of objects and rules that could be disturbed and, therefore, it guarantees localization of all the rule violations.

Using the assertions above, algorithms for incremental verification can be proposed. Here we present the algorithm applicable to single and multiple updates of all kinds. Modification operations are represented as a succession of the deletion and insertion operations.

```
construct scheme inference graph (SIG)
for each DELETED Object in Model
    for each Attribute' in RolesOf(Object)
       for each not deleted Object' in UsedIn(Object, Attribute')
          Add AttributeRule(Object', Attribute') to Check List
    for each not deleted Object' in Use(Object, Attribute)
       for each Attribute' of Object' inverse to Attribute
          Add AttributeRule(Object', Attribute') to Check List
    for each Source vertex in SIG such as
          Type(Object) in TypeOf(Source)
       Add Object to Source populations
evaluate query
for each Sink vertex in SIG
    for each Object' in Sink populations with assigned Rule
       if (Rule is domain) then
          Add DomainRule(Rule, Object') to Check List
       if (Rule is unique) and (Rule is not in CheckList) then
          Add UniquenessRule(Rule) to Check List
       if (Rule is global) and (Rule is not in CheckList) then
          Add GlobalRule(Rule) to Check List
delete DELETED Objects from Model

insert INSERTED Objects in Model
for each INSERTED Object in Model
    for each Attribute of Object
```

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```
      Add AttributeRule (Object, Attribute) to Check List
    for each not inserted Object' in Use(Object, Attribute)
      for each Attribute' in Object' inverse to Attribute
        Add AttributeRule(Object', Attribute') to Check List
    for each Source vertex in SIG such as
        Type(Object) in TypeOf(Source)
      Add Object to Source populations
evaluate query
for each Sink vertex in SIG
    for each Object' in Sink populations with assigned Rule
      if (Rule is domain) then
        Add DomainRule(Rule, Object') to Check List
      if (Rule is unique) and (Rule is not in CheckList) then
        Add UniquenessRule(Rule) to Check List
      if (Rule is global) and (Rule is not in CheckList) then
        Add GlobalRule(Rule) to Check List

for each Rule(Rule, Object, Attribute) in Check List
    if (Rule is attribute) then
      Check AttributeRule (Object, Attribute)
    if (Rule is domain) then
      Check DomainRule (Object, Rule)
    if (Rule is uniqueness defined for type C) then
      Check UniquenessRule (ext(Model,C), Rule)
    if (Rule is global defined for types C1,…,Ck) then
      Check GlobalRule (ext(Model,C1),…,
                              ext(Model,Ck),Rule)
```

At the first phase the algorithm produces a list of rules that might be violated and have to be subjected to subsequent verification. Elements of the list are triples containing attribute, object, and rule. The list is formed of attribute rules for the inserted objects, cardinality attribute rules for the objects directly associated with the deleted and inserted objects as well as from domain, global and uniqueness rules localized by means of navigational querying. The queries based on the schema inference graph are initialized and evaluated twice: for localization of potential violations caused by deleted objects, then for localization of violations caused by inserted objects.

At the second phase the algorithm verifies suspicious rules that are extracted from the list, evaluated, and logged if some disturbances have been detected.

4 IMPLEMENTATION AND ANALYSIS

The presented approach to verification of STEP-driven product model data provides for implementation methods based on static analysis of the information schema specified at the EXPRESS language, compilation of executable codes for the integrity checking and maintaining procedures and their highly efficient runtime execution.

We foresee significant potential of the approach presented to verify such complex high-scale product data like those of defined by Industry Foundation Classes (IFC). This information standard is developed by International Alliance for Interoperability in conformity to architecture, engineering, construction, and facility management (IAI 1999). Significant resources consumed to control the data consistency are one of crucial points of available product data management technologies and solutions.

We consider three basic aspects and methods to increase efficiency of data integrity checking and maintaining procedures in accordance with the presented approach. These methods have been realized in OpenSTEP Checker: an application built on the general-purpose software platform by ISP RAS (Semenov et al. 2004a).

The first aspect is to exploit so-called early binding formation and implementation of data access interfaces taking into account particular information schemas. It enables to access product data and to evaluate the schema methods (rule predicates, derived attributes, functions, and procedures) with more speed than in the usage of late binding realizations. This advantage is achieved because execution of precompiled imperative instructions is always more efficient than their interpretation.

The second aspect is optimized implementation of the schema methods taking into account of peculiarities of the EXPRESS language. As our experience proves, the performance of the verification procedures can be increased by optimization of:

~ queries given by object identifiers, inverse associations, and subtyping relations;
~ operations on arithmetic and logical operands with extended (unknown) states;
~ identity comparison operations;
~ methods of recalculated derived attributes.

The third aspect is to take advantage of local and latent character of the model updates peculiar to transaction processing. The algorithm presented above enables to effectively control and maintain data consistency during user sessions. Its realization can be combined with two mentioned methods.

To estimate operational costs IFC2x files were used as timing benchmarks for some available verification programs, namely: OpenSTEP Checker, IfcObjCounter v.1.1 by Forschungszentrum Karlsruhe GmbH, Institute for Applied Computer Science (http://www.iai.fzk.de), Express Engine v.3.1.4 developed within an open source project (http://sourceforge.net/projects/exp-engine), and Express Data Manager v.4.080 by EPM Technology AS (http://www.epmtech.jotne.com). Timing measurements were made with data sets generated by CAD systems and ranging in size from 1000 up to 100,000 objects. Complete verification option was checked for all the explored applications. Costs to load data from STEP files were ignored, only verification costs were measured. Because of some programs didn't provide built-in CPU timing capabilities, all times were measured using a stop-watch.

The programs exhibited acceptable $O(N \log N)$ growth characteristic. An asymptotic performance of the IfcObjCounter was significantly slower, so we were unable to complete measurements on data sets with more than 50,000 objects. Its $O(N^2)$ extreme

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behavior and a higher degree complexity might be explained by insufficient optimization of underlying verification algorithms and operations. In particular, verification of uniqueness rules resulted in reduction of the total performance more than 50 times even on small data sets.

Being based on Common LISP, the Express Engine demonstrated much slower characteristics compared with the OpenSTEP Checker. The conducted measurements showed average 30 times performance losses. It may be caused by slow speed of interpretation of LISP instructions and possible complication of implementation of verification programs against applications directly running in execution environments.

The Express Data Manager is quite balanced interpretation system that proceeds with arbitrary data and attended schemas both loaded at runtime. Nevertheless, it yields the pas to the OpenSTEP Checker that employs early binding method to pre-compile widely used EXPRESS schemas and to link the corresponding libraries to the target application dynamically. This method enabled to increase performance of the program more than 3 times.

Thus, the OpenSTEP Checker is the fastest application among the considered ones. Another advantage is a capability to verify the data in an incremental way. As such analysis is connected with additional expenses on evaluation of navigation queries, a priori quantitative criteria for the final efficiency have to be established. To estimate potential benefits of the incremental verification and to establish such criteria, special experiments have been performed. The experiments simulated series of short transactions each of which consisted of single object modification. The whole series covered all the objects contained in the inspected models. The total and averaged (related to the model size) CPU times of incremental analysis and verification were measured.

The experiments detected that the averaged time is roughly proportional to the time required for complete verification of the model. For the selected benchmarks this factor varied approximately from 0.001 up to 0.002. Therefore on short transactions covering a few random objects the averaged performance speedup amounts to hundreds and thousands times. At that, if the transactions include the updated objects participating in a few uniqueness or global rules, the speedup may be drastically reduced up to 10-25. On the other part, the conducted experiments showed that being applied to long transactions covering all the model objects, the incremental analysis might require the CPU resources 3-6 times exceeding the complete verification time. It means that the threshold value for fraction of updated objects at that the incremental method gives benefits may be varied widely enough. Nevertheless, if the fraction of object updates in the model is less than 15 percentages, the usage of the incremental method is quite motivated in most cases.

5 CONCLUSIONS

Thus, the approach to efficient verification of STEP-driven product model data has been presented. The approach combines ideas of exploiting early binding implementation of data access interfaces, deep optimization of verification programs and alternative usage of complete and incremental methods. The conducted timing experiments showed that the efficiency of the consistency checking and maintaining procedures can be significantly increased and the presented approach to efficient verification is realizable and quite marketable. The demo version of the OpenSTEP Checker can be downloaded from the project site www.ispras.ru/~step.

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Supporting State-based Transactions in Collaborative Product Modelling Environments

M. Weise & P. Katranuschkov
Institute for Construction Informatics, Technical University of Dresden, Germany

ABSTRACT: The up to date state and the consistency of shared building model data are of utmost importance for the achievement of efficient model-based collaborative work. However, in engineering design these are not easy tasks. Design activities are typically carried out in *long transactions* that are characterized by the following three subtasks: *check-out* of the needed design data into a private workspace, *making design changes* within the private workspace, and *check-in of a new model state* into the shared model repository to make changes and decisions visible to the other designers. As a result of various existing semantic interoperability problems, in the new model state both actual design changes and data loss have to be considered that cannot be easily distinguished. To help tackle these problems we suggest a *delta-based versioning approach* whose essence is in storing design changes instead of complete design states. This approach is then used as basis to support the three data processing stages of a design step within a collaborative work environment, namely (1) creation of the needed and manageable model subset by removing all irrelevant design data, (2) storing the design changes, and (3) restoring the removed data by an "undo" operation of the first step. In the paper we present the used semantics for describing design changes, their transformation to deltas and the scope and limits of the suggested *undo* operation. At the end we provide an example of the use of the suggested approach with the industry standard IFC model and discuss its potential and needed further research.

1 PROBLEM DEFINITION

Model-based collaborative work is a widely known, well-defined area, tightly associated with coordination and cooperation in design teamwork. Amongst the most challenging problems within this area is the *consistency of shared model data*. It can be subdivided into two inter-related tasks: (1) ensuring interoperability to enable loss-free data exchange, and (2) efficient data management to control parallel data changes, while warranting consistent design states.

1.1 *Interoperability problems in collaborative work*

Interoperability can be treated on several levels. The relevant aspects here are *systemic* and *semantic* interoperability (Katranuschkov 2001). The first focuses on the technical process of accessing/exchanging the data, whereas the second focuses on the meaning of the exchanged data, i.e. how to understand and use the data in the context of collaborative work.

Solutions for systemic interoperability are mainly seen in providing syntactically standardised low level access to the data using an API like SDAI, or protocols like SOAP or CORBA. This allows to replace file based data exchange, which is commonly seen as a bottleneck for efficient cooperation, but does not solve problems related to semantic "misunderstandings" of the data, and does not provide answers how changes done in parallel can be managed.

Semantic interoperability, on the other side, addresses the definition of the used data. It is dealing with product modelling as well as with methods enabling the mapping of data between different product model schemas. Today, it is widely accepted that both techniques are needed in data exchange, but their appropriate combination is still in discussion. The basis of product modelling is commonly provided by a unified *meta model* which is used to formalise domain knowledge. Additionally, a *mapping language* is used to define interdependencies between different model schemas, thereby allowing to combine the knowledge of the *used product model instances* (see Figure 1).

In this context a product model instance is defined as a set of object instances related to a specific product data model which themselves comprise a set of attribute values. Typically, a product model instance will be a subset of the shared building information model (BIM).

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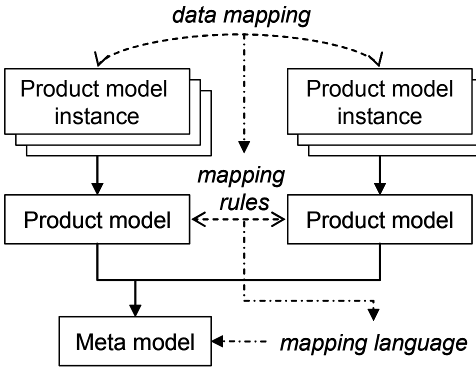

Figure 1. High level concept of semantic interoperability.

1.2 *Data management problems*

Appropriate management of the shared model data is necessary to provide up to date design information and to ensure consistency.

From the viewpoint of database technology, a design activity in collaborative design is typically carried out as a *long transaction* which is characterised by a sequence of three subtasks: (1) *check-out* of the needed design data into a private workspace, (2) making design changes within the private workspace, and (3) *check-in* of a new model state into the shared workspace to make the data changes and design decisions visible to the other designers. However, due to time constraints such design activities are typically carried out in parallel. Consequently, there is a need to synchronize data access. This can either be achieved by restrictive, counter-productive data locks, or else, methods have to be developed to merge the diverging design data at certain coordination time points. In the latter case, beside controlling data access the most challenging task is to regain the consistency of the model data at the coordination points. For the solution of such problems various knowledge-based approaches have been suggested that are capable to partially evaluate consistency or to support certain design decisions. However, in spite of all efforts, these problems are still open.

1.3 *Observations from design practice*

In the last years advanced model-based work started to penetrate design practice. However, even though a number of the above discussed concepts have since been adopted, there are still many short-comings that handicap the realisation of the outlined data sharing approach for collaborative work.

For integration and interoperability issues the ISO 10303 standard (STEP) has been widely acknowledged. Its basic methodology specified in the parts ISO 10303-11 to 21 is being used to define specific product model standards such as CIS/2, IFC, OKSTRA and STEP AP 225. However, these standards are developed with little harmonisation with regard to each other. Their use is currently limited to neutral data exchange between design applications within pre-defined use scenarios. Furthermore, the quality of semantic interoperability heavily depends on the used applications, i.e. their import/export functionality allowing to interact with the shared model data. Consequently, the roundtrip of design data has to deal both with data loss and altered object structures.

Due to many recognised short-comings of file-based data exchange, shared product data environments are starting to be introduced. However, since there is no commonly accepted API to data management environments, design applications are still limited to file-based data exchange. Fine-grained data access as suggested by the SABLE project (Houboux et al. 2005) is constrained by technical aspects such as network traffic and, more importantly, the requirement from design practice to allow off-line modifications. Thus, the concept of application scenarios, i.e. defining model subsets for well defined business cases, is currently the most detailed data access level for practical use. Concurrency control of design changes is mainly realised by simple locking mechanisms or "first come – first served" strategies which consequently reduces the flexibility of the design process. Finally, the problem of data consistency is currently limited to check rather simple constraints defined by the underlying data structure which cannot guarantee the semantic integrity of design changes.

It can be concluded that, even though on theoretical level the concepts for interoperability and data management comprising model definitions, mapping rules and consistency checking seem to be clear and reasonable, they are still not achieved in practice. The reasons for that are multifarious and thoroughly discussed in a number of papers (cf. Turk 2001, Amor & Faraj 2001, Bazjanac 2002, Weise et al. 2004). Thus, in practice we have to deal with only partially integrated data, and this does not seem to be only a temporary handicap. Methods to overcome such practical short-comings are no less important than good product models or sophisticated database and communication tools.

2 SUGGESTED APPROACH

The baseline of our approach is that collaboration must be traceable for the involved designers and that *design changes* are among the most important data in the iterative design process. The essence is that, instead of continuously tracing all design changes (which could only be done on application level and is therefore hardly realistic), we consider only the new model states which include *all* changes done by the designer within a full design step. To do that, we suggest a set of methods allowing to shift change analysis from the actual new data states to the *data changes* (deltas) that have caused these new data

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states. As additional benefit, the suggested methods provide also a basis to reduce data loss in practice.

2.1 *Capturing design steps*

From data management viewpoint a design step can be characterized by (1) the used design data, i.e. the data needed to carry out the design step, and (2) the design changes, i.e. the result of the design step. This reduces the design step to its input and output, the least common denominator for supporting design applications as black-box systems. Figure 2 below shows an example design step of designer D_A who is using three objects for his design changes. Instead of storing a new design state, the changes are stored by using a *minimal change vocabulary*. Hence, we propose version management of design data by using deltas.

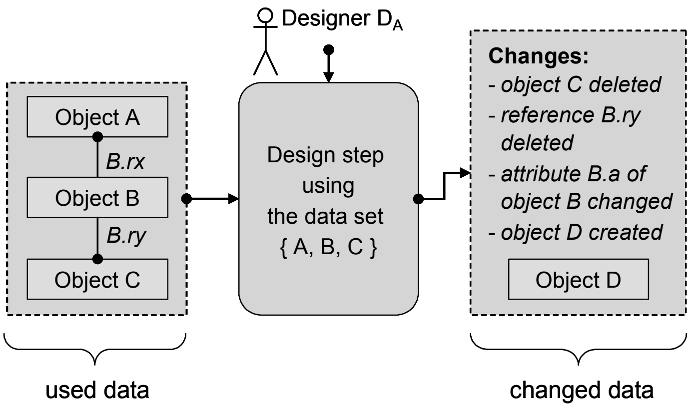

Figure 2. Example of a design step characterized by the used and the changed design data.

Compared to other application areas of version management, such as software and mechanical engineering, we see important differences for design processes in building construction, which hinders the use of available solutions like CVS or Subversion. Additionally, there is lack of methods enabling efficient version management. Therefore, before detailing the suggested delta approach, we discuss requirements for representing design changes and their integration into the overall design process.

2.2 *Requirements to represent design changes*

In order to support different phases of the design process we have to deal with significant changes of the shared product model instance. Such changes are caused both by the nature of design, i.e. the progress from sketch to detailing, and supporting IT processes such as mapping, matching and merging. Thus, the model data cannot be treated as a static object structure, changed only by the values of attributes. We have to deal with a kind of *object evolution*, where objects are sometimes split into other objects, sometimes unified to a single object, or changed to instances of another object type.

To tackle such changes in the object structure we need to extend the change vocabulary. Conceptually, we are dealing with the following types of change information: *basic changes* (creation, deletion, changing of objects and attributes), and *complex structural changes* (splitting, unification and type evolution of objects). Figure 3 shows schematically these types of change information. Additionally, we have to consider design changes carried out in parallel, thereby creating alternative design states, as well as merging of alternatives to regain a unified design solution.

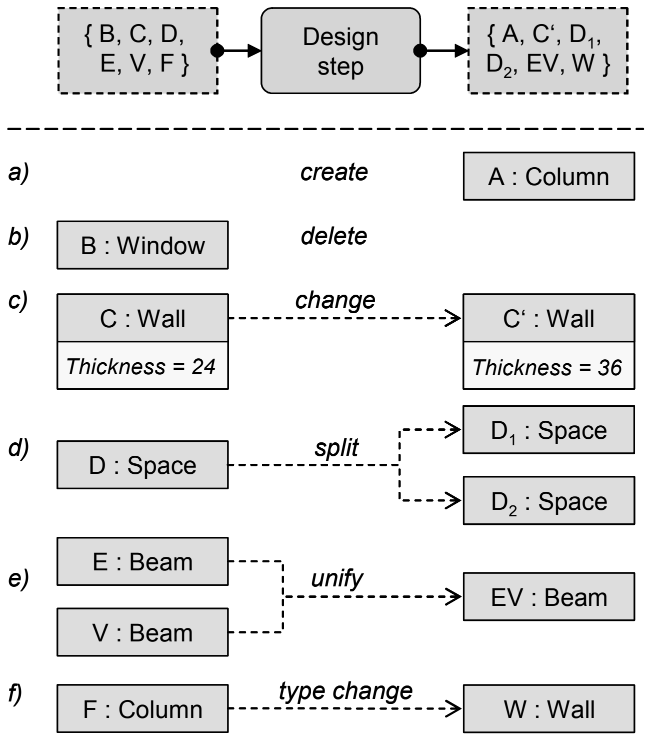

Figure 3. Information concepts needed to represent the data changes in a design step.

2.3 *Integration of change information into the design process*

In our approach, instead of continuous tracking of the changed design data, we only deal with discrete new design states. This requires additional services to identify the data changes. Moreover, a design step is carried out using a *subset* of the shared product model instance which is constrained by the capabilities of the used design application(s) to correctly import and interpret the provided data. This state-based way of working with model subsets results in additional risk for data loss which has to be reduced by the data management approach.

To be able to differentiate data changes from data loss, we divide a design step into three data processing stages: (1) selection of the needed data subset, (2) modification of the data, and (3) re-integration of the changed data into the full shared model instance. Each of these stages will be represented by data changes that can then be evaluated by the other de-

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signers, thereby providing them with as much information as possible to recognise the *intended* changes of the design step. Consequently, the selection of a model subset will be provided by removing all irrelevant design data so that a new design state is created that contains only the requested data. However, with this approach to the creation of a model subset we have to restore the removed data at the final stage. This is done by using a specific '*undo*' operation. Thus, we differentiate between changes applied to the model subset and additional 'adjustments' needed to update the shared product model instance.

These three generalised stages of a design step are illustrated on Figure 4, together with the creation of new sets of model changes at each stage.

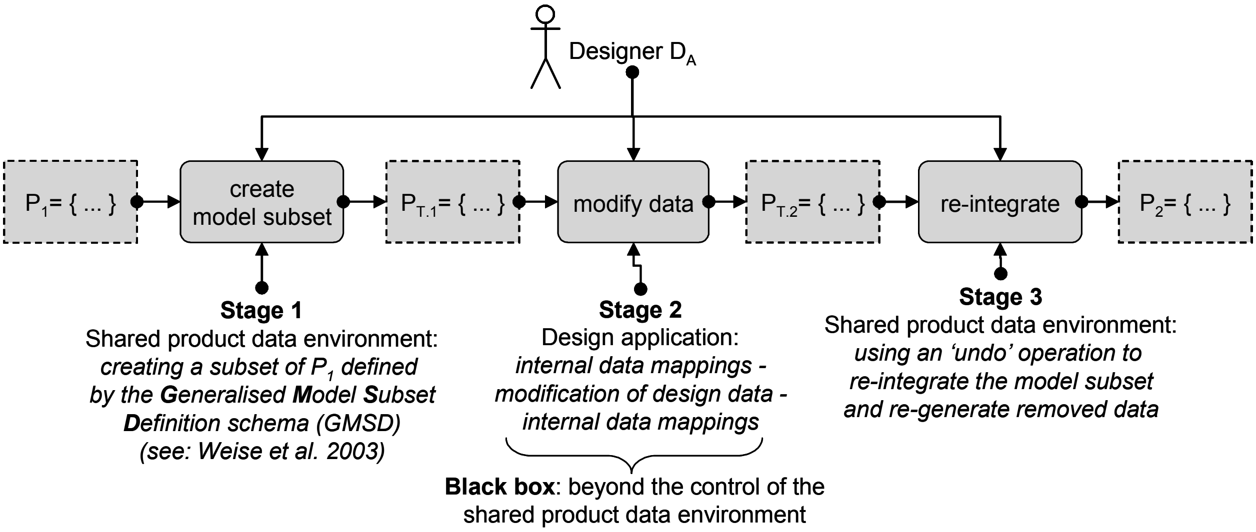

Figure 4. Break down of a design step into three stages with distinct types of data changes at each stage.

To support the described three stages we have developed generic methods for defining and creating model subsets (Weise et al. 2003) as well as for identifying data changes (Weise et al. 2004). Based on these services we are capable to support state-based transactions using a subset of the shared product model instance.

For the principal design step shown on Figure 4 the following high-level operations can be formally defined: (a) create model subset $P_{T.1} \subseteq P_1$, (b) compare $P_{T.1}$ and $P_{T.2}$, leading to the eq. $P_{T.1} + \Delta P = P_{T.2}$ that is solved by our comparison algorithm, and (c) undo (re-integrate), applying identified changes to the design state P_1 so that the updated product model instance P_2 can be derived by $P_1 + \Delta P = P_2$.

However, in the realisation of these operations there are several practical problems that need to be dealt with. In the comparison of design states, due to the problem of missing object identifiers e.g. in IFC, we cannot ensure that the changed design state is described only by *true* changes, i.e. the changes made by the user are not always equal to the detected changes ($\Delta P_{user} \neq \Delta P_{compare}$). Another problem with IFC is that unique identifier are by definition invariant with regard to the object state which is in conflict with the change types d) and e) on Figure 3. Also, by using the suggested *undo* operation incorrect change results can lead to inconsistencies of the updated product model instance P_2. Moreover, the data changes in a new design state may not correspond to the semantic changes intended by the user. For example, if a design application is changing a globally used length unit from *m* to *mm*, it means no semantic change but results in a problem to update the shared product model instance. Consequently, the *undo* operation creating an updated shared product model instance has to be supervised by the designers to correct eventual inconsistencies.

3 VERSION MODEL

In order to capture data changes correctly, we have to deal with *change-based versioning* which has to satisfy the requirements of the defined change vocabulary. However, whilst there are many version management methods existing to date, they are all developed and used in more tightly integrated domains and cannot be readily adopted in an ICT environment for building design due to several critical differences in technical and organisational aspects.

Westfechtel and Conradi (1998) compare software configuration management with engineering data management and outline basic differences and similarities. They identify as a major difference the complexity of engineering data managed in product data models instead of text files. They mention also the problem of integrating different engineering design tools but anticipate standardized data representations solving the problem of semantic interoperability. However, even if a common shared model is agreed, as e.g. IFC, design tools will still be using their own dedicated data models that will not (and cannot) be fully harmonized with the shared model. Shifting the interoperability problems to their responsibility is neither practical nor realistic.

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3.1 *Objectives of the version management*

In our version model we are dealing with well defined configurations of data objects, each describing a product model instance created in the design process. Beside the known advantages of version management for collaborative work, a specific aspect of the suggested version model is to compensate data loss caused by the existing interoperability problem. The objectives are:

- to enable error-free and consistent design steps, including the 3 subtasks: (1) *check-out*, (2) *local data changes* via design tools treated as black boxes from the viewpoint of data management, and (3) *check-in / re-integration* of the data into the common shared model instance;
- to inform the design team about identified changes;
- to provide access to earlier model versions thereby facilitating the management of conflicts via collaborative decisions.

We are not dealing with problems such as configuration management or dynamic composition of object versions to create new design solutions. Since design solutions are always created within the outlined design steps, such issues are not of interest.

3.2 *From objects to object versions*

Each design state can be handled as a product model instance defined by a set of objects, each consisting of a set of attributes. This abstraction provides the basis for the concept of the suggested version model.

$$A := \left\{ a \mid a \text{ is an attribute, representing any data value or object reference} \right\}$$

$$O := \left\{ o \subset A \mid o \text{ is an object defined by a set of attributes} \right\}$$

$$P := \left\{ p \subseteq O \mid p \text{ is a product model instance defined by a set of objects} \right\}$$

If a new product model instance must be derived from an existing product model instance, a new set of objects has to be created. This new object set is defined so that changed objects are replaced by the new object versions. To identify the changed objects we use a version relationship between new and replaced object versions. However, in contrast to other approaches we do not differentiate between objects and object versions. Thus, we define the version relationship as follows:

$$R_{VN} := \left\{ (x,y) \in O \times O \right\}$$

$$R_{VN}(x,y) - \text{ version relationship where } x \text{ is replaced by } y$$

Consequently, we are able to differentiate between the outlined change types by using basic set relational operations as shown on Figure 5. Furthermore, combinations of these change types are possible to represent more complex changes. For example, an object version can be changed by unification and type evolution at the same time.

Let $p, q \in P$ where p is a direct predecessor of q. Then :

created objects : $x :\Leftrightarrow \underset{x \in (q-p)}{\forall} \neg \underset{y \in p}{\exists} R_{VN}(y,x)$

changed objects : $x :\Leftrightarrow \underset{x \in (q-p)}{\forall} \underset{y \in p}{\exists} R_{VN}(y,x)$

deleted objects : $x :\Leftrightarrow \underset{x \in (p-q)}{\forall} \neg \underset{y \in q}{\exists} R_{VN}(x,y)$

split objects : $x :\Leftrightarrow \underset{x \in (p-q)}{\forall} \underset{y,z \in q, y \neq z}{\exists} R_{VN}(x,y) \wedge R_{VN}(x,z)$

unified objects : $x :\Leftrightarrow \underset{x \in (q-p)}{\forall} \underset{y,z \in p, y \neq z}{\exists} R_{VN}(y,x) \wedge R_{VN}(z,x)$

By analysing the object type it is also possible to identify type changes. If the object type is defined as shown below, all data changes caused by type change can be determined.

Let :

$K := \left\{ k \mid k \text{ is a type definition} \right\}$

$R_{OK} := \left\{ (o,k) \in O \times K \right\}$

$R_{OK}(o,k)$ be an 'instance - type' relationship

Then type change of objects is defined by :

$$x :\Leftrightarrow \underset{x \in q, y \in p}{\forall} \underset{a,b \in K, a \neq b}{\exists} R_{OK}(x,a) \wedge R_{OK}(y,b)$$

Figure 5. Representation of the different change types by means of set relational operations.

3.3 *From object versions to deltas*

Generally, replacement of objects is needed if (1) objects were changed by at least one attribute or split, unified or changed in type, or (2) a change is forced by consistency constraints of the version model to ensure integrity of the object states. In all other cases no replacement of objects is required.

As outlined before an object is treated as a set of attributes defining an object state. However, since changed objects are connected to replaced objects via version relationships, they can be represented only by the changed attributes. Whenever unchanged attributes are needed, they have to be determined from the replaced objects by traversal of the object history. The goal of this approach is to manage as few as possible changed objects and attributes enforced by integrity constraints of the underlying version model. Consequently, we try to omit an update of references unless it is not possible to unambiguously resolve referenced objects. The rationale is to avoid propagation of object updates to a huge number of unchanged objects. This *proliferation problem* is illustrated on Figure 6 which shows how the creation of artificially changed objects would be enforced if updates of references are performed in the version model.

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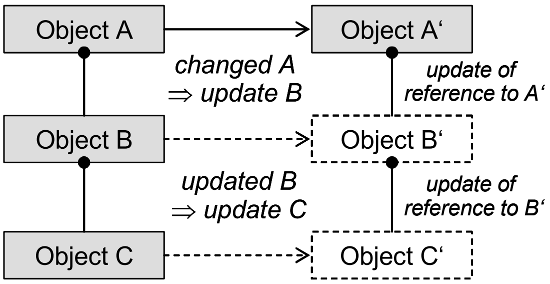

Figure 6. Proliferation of reference updates, as required by the version model.

To ensure consistency of the identified deltas, certain integrity constraints of the underlying version model have to be checked. If a version relationship between objects represents a one-to-one connection, integrity is not violated. Otherwise, the integrity of attribute values and object references that were additionally updated to avoid inconsistencies needs to be verified. Two examples of such cases are shown on Figure 7, where an update of references is only needed for the split Object A.

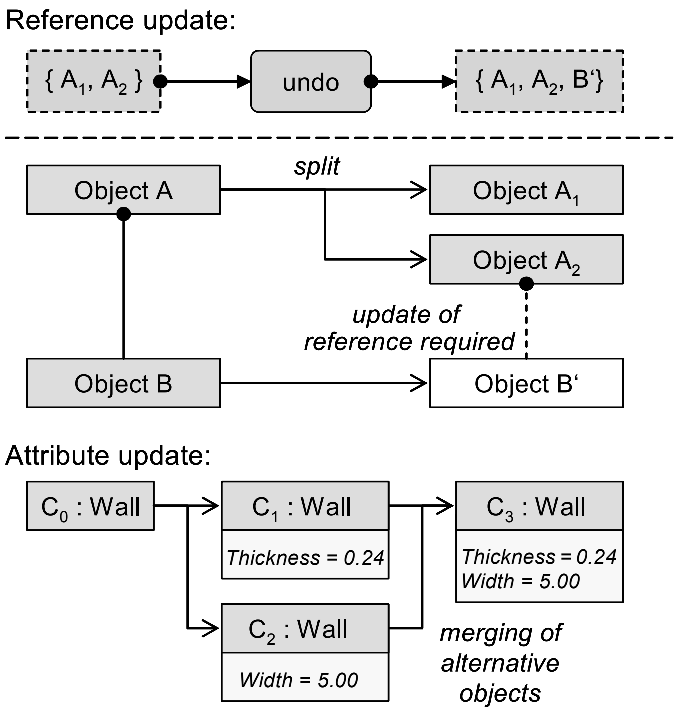

Figure 7. Update of object references and attribute values required by integrity constraints.

As we subsume that integrity of references has to be guaranteed for the changed model set by the used design applications, an update of references needs to be checked only for the *undo* operation. Such a check fails, if the design changes identified by the comparison algorithm are not compatible to the remaining product model data. Hence, the integrity constraints for references are directly related to required design changes.

In contrast to reference updates, adding of attributes is caused by unified (or merged) objects. Since changed attributes are stored in the object, we have to ensure that missing attributes can be calculated independently from the used version path. Thus, delta attributes contained in a unified object are not directly linked to changes, so that they have to be derived by traversing the whole relevant object branch from the beginning. For example, to determine the design changes between objects C_3 and C_1 on Figure 7, all deltas between C_1 and the object branch beginning at C_0 have to be compared with the deltas from C_3. From the deltas stored in C_3 we can then determine the change to the *Width* attribute.

Because of these consistency constraints, the deltas managed by the underlying version model are in general a superset of the data changes. However, the difference between deltas and actual changes is significantly reduced by the suggested structure of the version model. The changes that are an important information for the users can be easily derived from the deltas stored in the object history.

3.4 *Undo operation on deltas*

An attribute value replaced at the stage of creating the used model subset is set to the string *'replaced'* or, in the case of an attribute defining a set of values, to a *subset* of the replaced information. Figure 8 shows the replacement of the attribute *Width* enforcing the creation of a new object version C_1. The idea of the suggested *undo* operation is to invert this process by replacing all attribute values used to define Stage 1 by their former values. Thus, in the updated object version C_3 the value of the *Width* attribute of C_1/C_2 will be replaced by the value of the *Width* attribute of C_0. As long as these *'replaced'* attributes are not changed in the modifications within Stage 2, they can be automatically replaced for all changed and unchanged objects. However, if replaced attributes are defining references to other objects, their integrity is also checked.

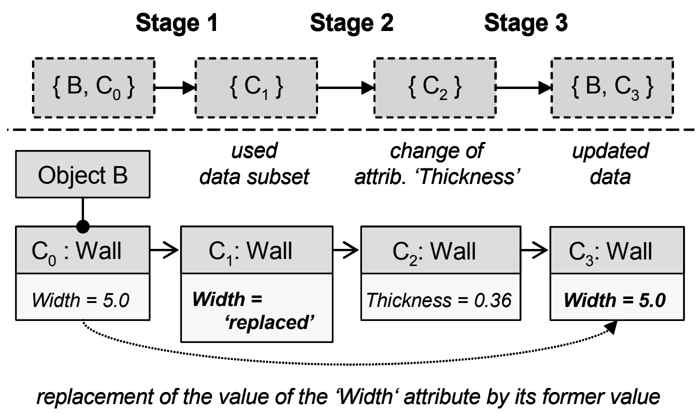

Figure 8. Re-creation of attributes by inverting their replacement.

The correct outcome of Stage 3 strongly depends on the correct identification of the changes done by the user. However, the suggested *undo* operation can warrant only the identification of low-level data conflicts caused by changes in the data structure,

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whereas data conflicts caused deliberately by the user or resulting from some external operation such as the mapping to/from an external model schema may or may not be correctly recognised. Therefore we subsume that Stage 3 will always be performed interactively. The user has to be aware of his responsibility to consistently update the shared product model instance. The developed delta approach supports the process but cannot perform it fully automatically.

4 EXAMPLE FROM IFC

By the time of this writing the suggested approach has been specifically tested for scenarios using the IFC Project Model (Wix & Liebich 2001). The goal of IFC is to integrate data of different domains and therefore it *has to* deal with model subsets. Such subsets are officially defined by the IAI to support different data exchange scenarios such as the coordination of building design, the transition from architectural to structural design etc (IAI-ISG 2003).

We have already tested several sub-cases of the mentioned scenarios with quite satisfactory results. To illustrate the developed approach, in this section we present a simple data roundtrip example for one building storey, downsized in accordance with the page limitations of the paper.

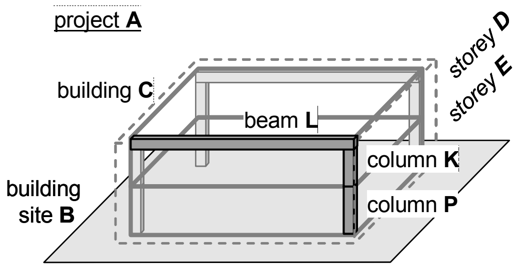

Figure 9. Example building structure.

Figure 9 presents the example building structure and Figure 10 shows a part of the data structures and the respective modifications in the three stages of the example design step. The depicted IFC elements are named and indicated by darker colour on Figure 9.

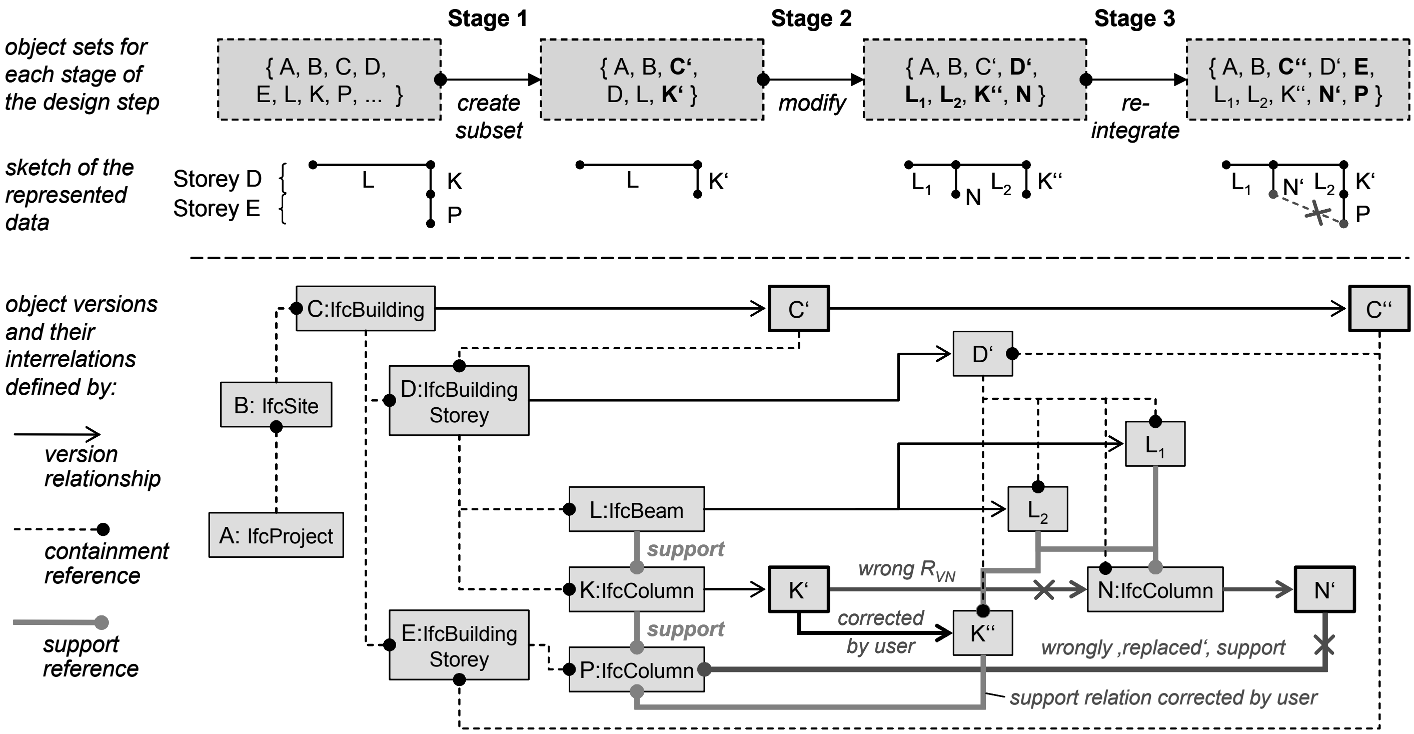

Figure 10. Schematic presentation of part of the IFC data structure, the changes in objects and relations and the respective delta-based object versions for the example from Figure 9.

Using a single storey of an IFC instance means to remove all other storeys from the existing project hierarchy, defined by spatial containers comprised of instances of the object types *IfcProject*, *IfcSite*, and *IfcBuilding*. Design coordination requires to handle various ‘contained’ element types such as floors, columns, walls, opening etc, whereas other elements like e.g. furniture or plumbing may not be needed. Therefore, in Stage 1 not all objects referenced from the *IfcBuildingStorey* instance D will be included in the partial model subset. To reflect these changes in the data structure, new delta versions for C and K are created, namely C’ and K’. However, in accordance with the suggested approach, no new versions for A, B, D and L are needed.

The next Stage 2 of the shown scenario comprises the modifications done by the designer, which includes the creation of a new column instance N and the ‘splitting’ of the beam instance L into two new instances L_1 and L_2, and the identification of these changes by the data management system. In this particular example, L_1 and L_2 will be correctly recog-

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nised by the comparison algorithm whereas N may be wrongly identified as a change to K', and K'' as the new column object. D' is correctly created to reflect the design change to beam L.

In Stage 3 the re-integration of the data into the shared model instance takes place. Here, due to the wrong assignment of column N as a change version of K', a wrong support connection for N to column P on storey E will be suggested by the *undo* operation. This has to be corrected by the designer, leading to replacement of the version relationship R_{vn}(K',N) by R_{vn}(K',K''), and the support reference *supp*(N,P) by *supp*(K'',P) respectively. The new version N' of column N will be automatically created by the *undo* operation to reflect the changed support reference. Of course, the technical adequacy of the changed load-bearing structure of the building must also be checked and approved by the structural engineer. This cannot be a task for the data management system.

This short example gives an impression of the large potential of the suggested approach for goal-oriented reduction of the data to what is really needed for a particular design task, at the same time ensuring consistency and coordination of the shared model data. For real projects where a shared model instance can easily grow to several gigabytes this is a clear benefit in terms of space, time and efficiency of the collaborative work.

5 CONCLUSIONS

The presented delta-based versioning approach provides a solid basis to manage the data changes created during design tasks that are performed as long transactions to a shared model database. Typical implementations of such databases are seen in Web-based model server environments (Eurostep 2003, Houbaux et al. 2005).

In order to tackle existing interoperability problems the design step is subdivided into *three stages*, namely (1) selection of needed design data, (2) modification of selected data and (3) re-integration of the changed design data to update the shared product model instance. Each of these stages is stored in terms of the generated changes in a *version model*, thereby allowing reviewing of each stage by the other designers. Capturing of interdependencies between design states is provided via a basic *change vocabulary*, which allows also to deal with design refinements, such as type change, splitting and unification of objects. This provides for higher flexibility to capture design steps compared to the ID-based concepts of more traditional object oriented approaches. The changes themselves are managed by a set of *deltas* which represent a data change and thereby reduce the amount of needed data for versioning significantly.

Based on the suggested approach, the management of design data allows to:

- get access to every design states created in the design process,
- be aware of data changes between different design states, and
- support the roundtrip of model subsets.

The approach enables active user involvement in the management of shared product data in a collaborative work environments. It can be realised on short-term to enhance current integration methods and eliminate much of the existing deficiencies.

6 ACKNOWLEDGEMENTS

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Multi-model Environment: Links between Objects in Different Building Models

A. Kiviniemi
VTT Building and Transport, Technical Research Centre of Finland, Espoo, Finland

M. Fischer
CIFE, Civil and Environmental Engineering, Stanford University, Palo Alto, USA

V. Bazjanac
Lawrence Berkeley National Laboratory, University of California, Berkeley, USA

ABSTRACT: The current IFC specifications include relations between objects and enable representation of complex structures in a building product model. However, several research projects have addressed the problem of one integrated model by pointing out the different content and structure of different design domains. The existing software products cannot support all features of the IFC specifications, and because of the structure of AEC industry there are no potential customers for applications which would cover all different information needs. We believe that there will be several instantiated models representing a building project, and these models share some parts of the information which must be linked between the models. However, IFC specifications do not enable links between objects in separate instantiated models. This paper will (1) discuss the reasons for the separation of instantiated models, (2) present the necessary extensions of the IFC specifications, (3) include examples of the links between the requirements model and architectural design model, and (4) discuss some possibilities how to implement this link in a model server environment.

1 INTRODUCTION

The problem of one integrated model in data exchange of a building project has been addressed in some earlier research projects. The "PM4D Final Report" (Kam & Fischer 2002) addressed it by pointing out the different content and structure of different design domains, although the report did not propose a solution for the problem. Also, John Haymaker recognized the need for several models in his Ph.D. research (Haymaker et al 2003). However, to our knowledge, a formal division of a project's data set into several models and solution for linkage between the objects in these sub-models has not been published prior the doctoral dissertation of the first author of this paper, which forms the basis of this paper (Kiviniemi 2005). The other two authors were advisers in the dissertation research.

2 SEPARATION OF THE INSTANTIATED MODELS

Our solution to address these problems was a concept that divides the instantiated model of a project, i.e., project's data set, into four separate main models: 1) Requirements Model, 2) Design Model(s), 3) Production Model(s), and 4) Maintenance Model. These linked sub-models form the integrated project information model, Figure 1.

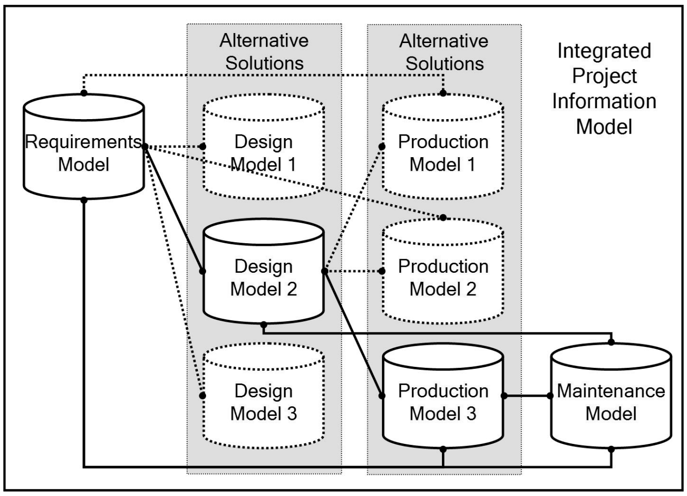

Figure 1: Integrated Project Information Model consisting of the four main models

This division of the project's data set does not mean that the information structure, model specification, would have to be separate models; it can be one specification. Our requirements model specification uses definitions from the current IFC specifications. Thus, the requirements model specification can be integrated with the IFC specifications. However, the instantiated model, i.e., project's data set, should be divided into several models. In fact, the information content in the different design and contractor domains is so different that there is a need for several design and production models, but this topic was not in the scope of our research.

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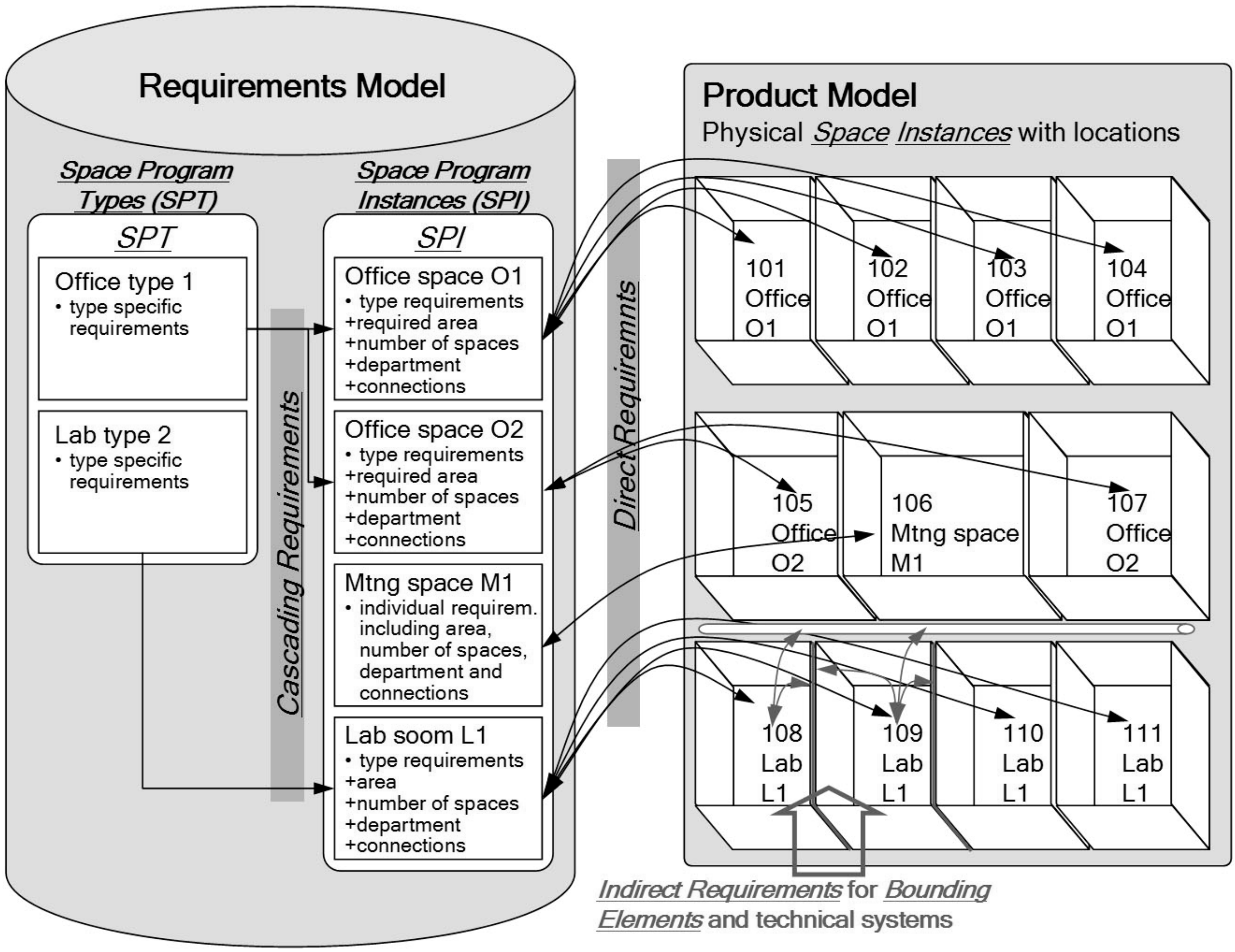

Figure 2: Concept used in the rapid prototyping to link requirements to a design model: Relations between Space Program Types (SPT), Space Program Instance (SPI), physical space instances and indirect requirements

There are several reasons for the separation of instantiated models. Our research focused on the requirements model and its connection to the architectural design model. Thus, most examples are from that area. However, most of the problems can be identified between different design models as well:

1. The data content and structure of the requirement and design models are different. For example, one requirements entity for spaces, a Space Program Instance (SPI, figure 2) can relate to a number of separate Instances with identical requirements in the design, production, and maintenance models. Similarly, for example, one slab or wall in the architectural design model can be several objects in the production model, or separate objects in the design and production models can be one object in the maintenance model.

2. Although the IFC specifications allow shared property sets, to our knowledge all IFC implementations are using instance-specific attribute sets, because the internal structures of design software do not support shared attributes. In practice it means that if the requirements are stored in the design model, the same requirements are multiplied in all instances, which can cause serious problems in the requirements management when the requirements evolve and must be updated (Kiviniemi 2005b).

3. Typically, the project team produces several alternative design proposals which all should meet the defined requirements. Thus, having one requirements model linked to the alternative design models is a logical structure instead of multiplying the same requirements to different design alternatives, which would easily lead to requirements management problems. Similarly, there can be several alternative production models and finally a separate maintenance model. All these models should be connected into one Integrated Project Information Model so that it is possible to access the content of the different models and compare the alternatives at any stage of the process (Figure 1).

4. The flexibility of the requirements model is greater if the models are separated and connected with a "thin" link, e.g., there is only one identifier in both models connecting the requirements and design objects (Kiviniemi 2005c). Adding or removing requirements in the requirements model specification does not change the design applications. In our prototype implementation, the only element needed for the link of space requirements was an ID in the

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space object, which is supported by almost any design software. For indirect requirements, the functional demand is to recognize the connection between bounding elements and spaces, which is supported by some commercially available building-product-model-based software.

5. Another reason for the separation is to make the distinction between requirements and properties clear; for example sound insulation is a requirement for a space in the requirements model and a property of the bounding elements in the design model.

6. Separation of requirements and design models allows access control of requirements; it is possible to show the information to designers but not allow them to modify requirements if such control is wanted, for example, for project management or quality system purposes.

7. Requirements are not attributes of design objects but independent entities, i.e., if the design changes so that a design object, such as a space, is removed, its requirements should remain unless the need for the space has changed too. Otherwise reliable comparison of the design solutions against the requirements is impossible.

8. A further important observation is that a Space Program Instance (SPI) in the requirements model has no geometrical locations, i.e., the requirements for bounding elements can relate to one space only. In the design, production, and maintenance models the bounding elements are always between two spaces; either between two rooms or as a part of the building envelope. This means that the requirements for the bounding elements must be aggregated from the requirements of the related spaces. They cannot be defined directly for the building elements in the same manner as the space requirements relate to the spaces (Figure 2).

3 NECESSARY IFC EXTENSIONS

3.1 *Link between objects in different models*

The information needed for the link between objects in different models is simple: The location and type of the model, and the IDs of the linked objects.

•The location of the model is the address where the linked model is stored. This can be a URL, address in the model server database, or some other address depending on the technical solution.

The type of the model is necessary because one object can be linked to several models, and the use of the link requires information of the purpose of the referenced model, for example, is it a requirements, design, or maintenance model. In our solution the list of models consists of six enumerations (requirements, design, production, maintenance, userdefined and notdefined), but the principle does not change if the list will be expanded with different domain models, such as structural, HVAC, electrical models.

The links between requirements and design models are from the design objects to the requirements objects. However, the links between the different design models must be two-directional, for example, a column instance in the architectural and structural model must be linked in both directions (Figure 3).

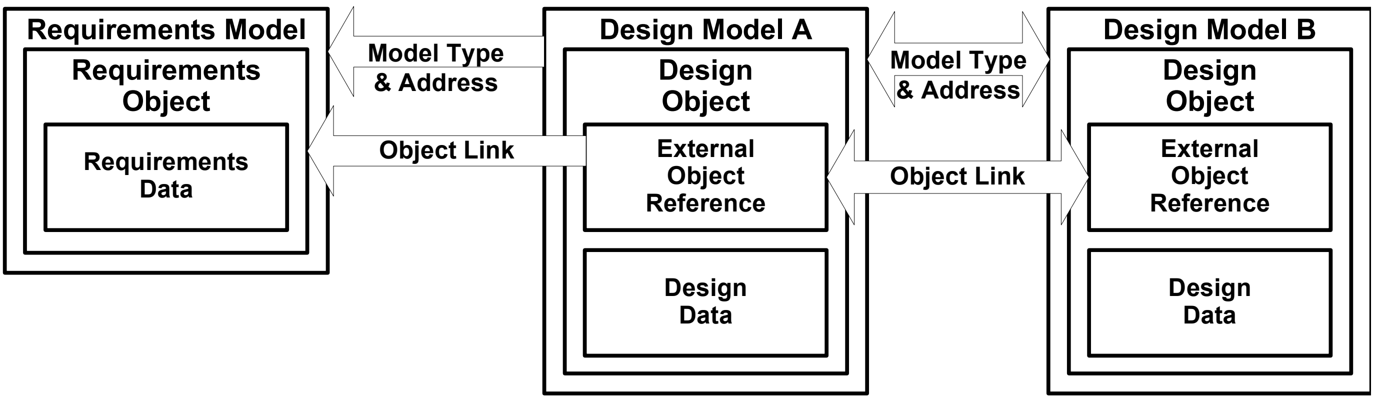

Figure 3: Links between objects in different models

3.2 *Existing IfcExternalReference*

The current IFC specifications include an element for external linkage, IfcExternalReference, but it does not include links between objects in different instantiated models; it only covers the links to library, classification and document, references. Thus, it was necessary to expand the current definition of the IfcExternalReference, which is now described by IAI in the following way (IFC 2005):

"An IfcExternalReference is the identification of information that is not explicitly represented in the current model or in the project database (as an implementation of the current model). Such information may be contained in classifications, documents or libraries.

Only the Location (e.g. as an URL) is given to describe the place where the information can be found. Also an optional ItemReference as a key to allow more specific references (as to sections or tables) is provided. The ItemReference defines a system interpretable method to identify the relevant part of information at the data source (given by Location).

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In addition a human interpretable Name can be assigned to identify the information subject (e.g. classification code).

IfcExternalReference is an abstract supertype of all external reference classes."

<u>*EXPRESS specification (IFC 2005):*</u>

```
ENTITY IfcExternalReference
  ABSTRACT SUPERTYPE OF  (ONE OF
  (IfcLibraryReference, IfcClassificationReference,
  IfcDocumentReference));
    Location : OPTIONAL IfcLabel;
    ItemReference : OPTIONAL IfcIdentifier;
    Name : OPTIONAL IfcLabel;
  WHERE
    WR1 : EXISTS(ItemReference) OR
    EXISTS(Location) OR EXISTS(Name);
END_ENTITY;
```

3.3 *Modified IfcExternalReference*

To address the limitations we modified the existing IfcExternalReference by adding one new subtype, NewExternalObjectReference:

<u>*EXPRESS specification:*</u>

```
ENTITY IfcExternalReference
  ABSTRACT SUPERTYPE OF (ONE OF
  (IfcLibraryReference, IfcClassificationReference,
  IfcDocumentReference,
  NewExternalObjectReference));
    Location  :  OPTIONAL IfcLabel;
    ItemReference  :  OPTIONAL IfcIdentifier;
    Name  :  OPTIONAL IfcLabel;
  WHERE
    WR1 :  EXISTS(ItemReference) OR
    EXISTS(Location) OR EXISTS(Name);
END_ENTITY;
```

This modification required some small modifications in the existing IfcRelAssociates entity, and addition of four new entities in the specification: NewExternalObjectReference, NewRelAssociates-ExternalObject, NewModelInformation, and New-ModelTypeEnum shown in Figure 4. The detailed EXPRESS specification is documented in the published dissertation (Kiviniemi 2005c).

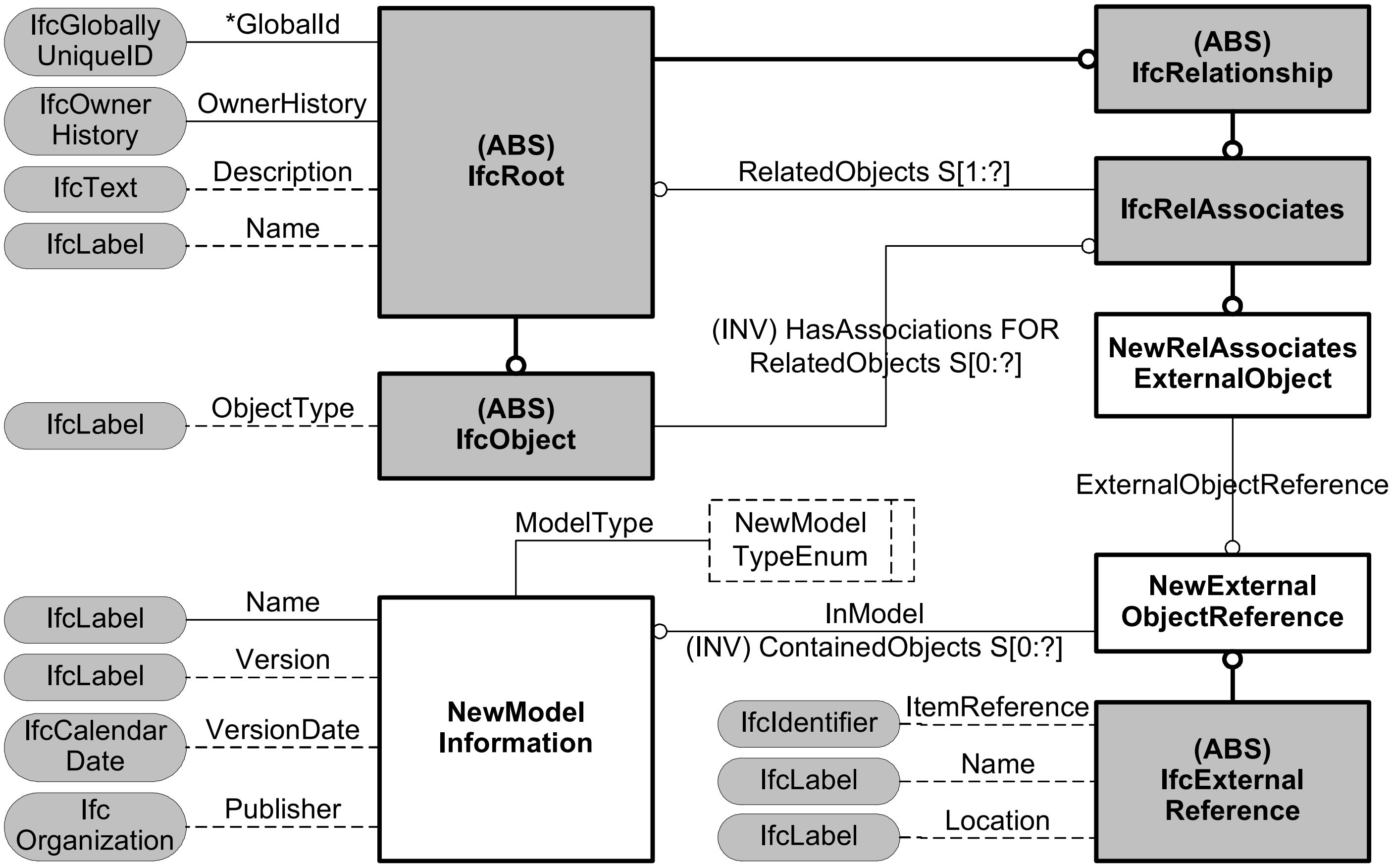

Figure4: Location and structure of the object link between models in the IFC specification. Grey background indicates the existing entities

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4 EXAMPLES OF LINKS BETWEEN REQUIREMENTS AND DESIGN MODEL

The requirements model linked to the design model was developed to enable the links between client requirements and design model, and its main purpose was to improve requirements management in the AEC process. The extension of IFC specifications documented in the previous chapter was necessary for this requirements model. The current IFC specifications include some requirements, but the IfcSpaceProgram is the only independent requirement object, and it includes only very few requirements, which are only related to spaces. All other requirements are property sets attached to the design objects, which causes problems described in chapter 2. In addition, the requirements in the current IFC specification are inconsistent and include many mistakes, such as duplication of the same requirements in several property sets in the specification (Kiviniemi 2005d). Thus it was necessary to develop a systematic way to define requirements and their relations to the design model.

The direct requirements in the system are requirements defined and maintained by some member of the project team. Direct requirements can cause indirect requirements to the building elements on lower level in the hierarchy or to the systems, including the technical systems, such as structural, electrical, HVAC and security systems, Figure 5.

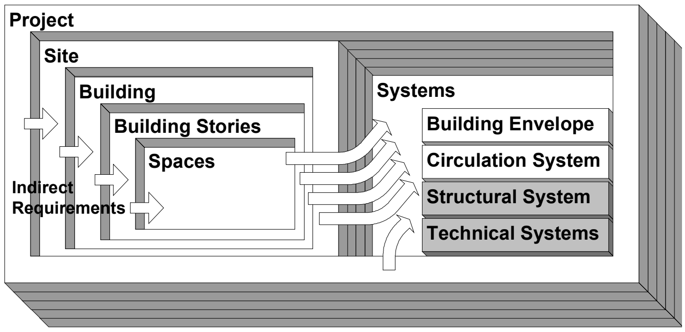

Figure 5: Levels of detail in the requirements model

A practical example of this is a space with requirements for area, sound insulation and temperature. Area is the only requirement directly affecting the physical space object. The sound insulation requirement causes indirect requirements for the bounding elements (walls, doors, windows), and the temperature requirement causes indirect requirements for the HVAC system and bounding elements.

The content of the requirements model developed in our research was limited to the architectural design of office and laboratory buildings, but most of the principles can be applied also to other building types and design domains. The basic idea to link the requirements and design models is based on the hierarchical composition of the IFC specification: the requirements are linked directly to five levels of detail in the model (project, site, building, story and spaces) or to the systems (building envelope and circulation system), Figure 6.

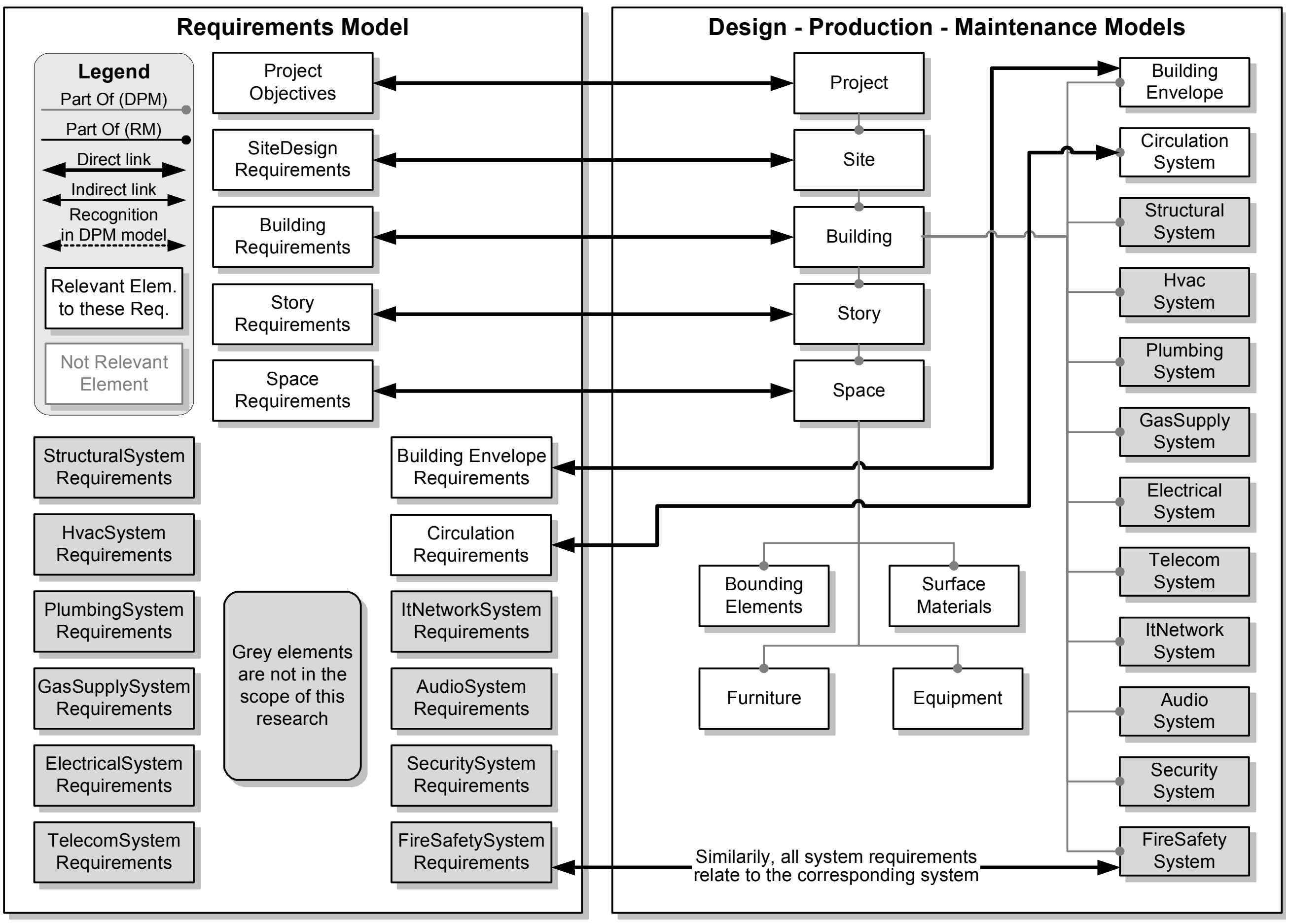

Figure 6: Basic relations between requirements and design-production-maintenance models

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In total our requirements model contains 300 requirements in 14 main and 35 sub-categories. These requirements are organized in the specification into 7 main-level and 30 sub-level requirements objects which have direct links to 5 levels of detail and 2 systems in the building product model plus indirect links to 4 levels of detail and 12 systems.

The lighting requirements for a space are an example to illustrate the detailed content of the requirements model. They are linked directly to the spaces in the design model. In addition they have indirect link to the electrical system and they need the recognition of some space-related elements in the design-production-maintenance models, e.g. the link to windows and colors of furniture, equipment and surface materials is a needed functionality, Figure 7.

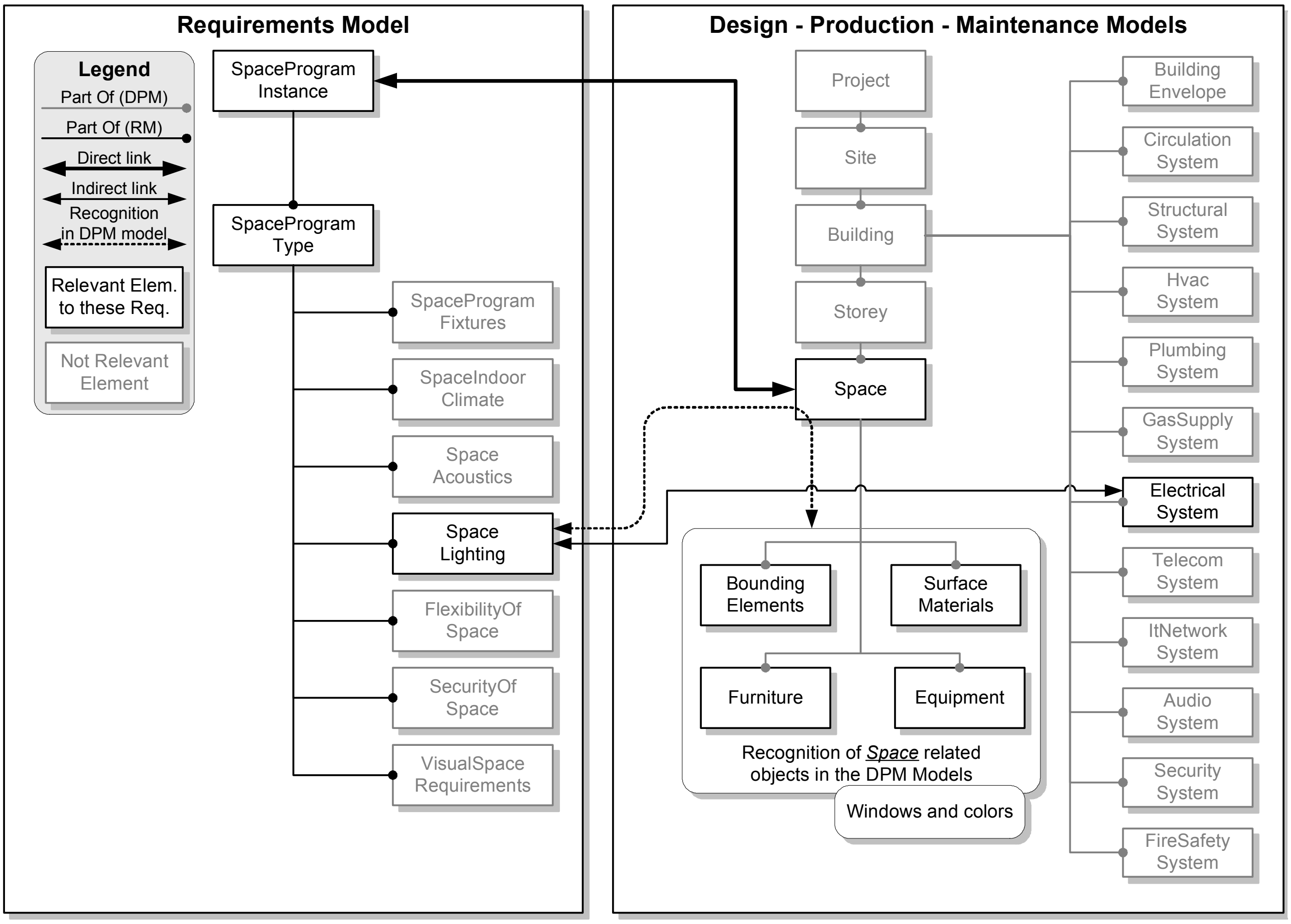

Figure 7: Space lighting requirements

5 THE USE OF MODEL SERVERS IN MULTI-MODEL ENVIRONMENT

The problem of file-based data exchange is the different internal data structures of the existing tools. A data set exported and imported between several software applications will almost certainly loose some data, because there is no place for all the data elements in all applications. It is hardly possible to believe that the software developers would solve this problem, because of the complexity of the data. In addition, the development of other software products would inevitably lead the constant need to change the data structures of all software products used in the AEC processes if the data should be maintained fully in the file-based exchange.

The only feasible solution seems to be an independent data platform; IFC compliant model server, which can store all information shared between the applications. In this case the interface between the application and model server handles only the data which is meaningful for the application and all other data in the model server will stay untouched.

However, this means quite complex data structures on the server, and control of the right to access and change information on the server. The AEC processes are iterative, and the design solutions affect each other. The changes must be approved by the owner of the data, which means that a proposed change by one player must not affect directly to the data of other players. A practical example of this is that if the HVAC engineer wants to move a duct which is going through a beam, the hole can not move before the structural engineer has approved its new position. This can be done only if the domain specific data sets are maintained independently; when the need of the hole for a duct in HVAC database is linked to the actual hole in the structural database, and the locations and sizes of these two objects can be checked and possible conflicts solved.

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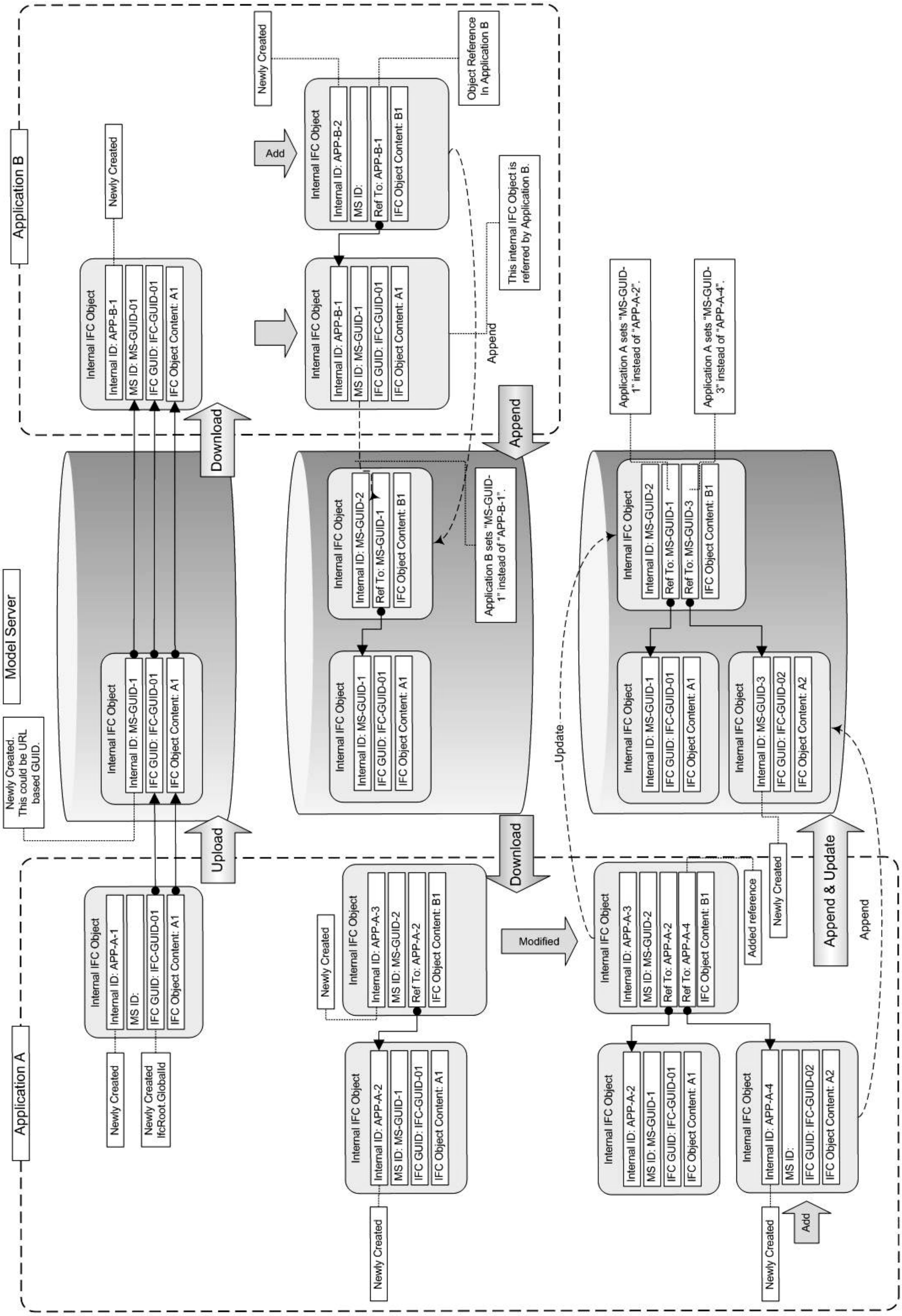

Figure 8: Model server object reference linkage (Adachi 2005)

Model server technology provides an excellent platform for this purpose. The IFC specifications have created a wide framework and defined objects, which can be stored and linked in the model server database as domain specific sub-models linked to each other, Figure 8.

6 CONCLUSIONS

Because of the numerous independent players in the AEC processes and tools supporting the individual tasks in these processes, the building information models must be able to handle different information content and compositions. Thus, an integrated instantiated project model is extremely difficult to implement into practical software tools and maintain in the design and construction process.

If the information sharing is based on file exchange, the integrity of the data is practically impossible to maintain because of the different data structures in different software products. The model server environment improves the situation significantly, because it can include all necessary data for different tools. However, because of access and control purposes it is necessary to divide the data into different subsets. This division can support also different compositions of data sets, which is often needed for different AEC tasks; what one domain sees as one object might be several objects for another domain.

Integrated product models can be utilized in the industry efficiently only if the different domain specific views are supported, but without links between the different domain-specific sub-models the situation will be almost the same as in the drafting-based processes; the data will be fragmented and changes in one model will be easily ignored in the other models, which will cause conflicts between different documents. Thus, links between the sub-models are necessary for information management.

Our research has pointed out a possible technical solution for the links between objects in different models, and also created a detailed documentation of the relation between requirements and design models in the architectural design. The next phase in our research will be the implementation of a set of software tools for integrated multi-model environment on the level which can be tested and validated in practical projects.

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Achieving ontology interoperability using formal concept analysis: an approach to inter-organizational collaboration

N. El-Gohary & T. El-Diraby
Department of Civil Engineering, University of Toronto, Toronto, On, Canada

ABSTRACT: Semantic systems that are based on ontologies are required to facilitate the collaboration between project teams and stakeholders in the infrastructure and construction domain. However, since no one ontology will be universally accepted, techniques are needed to achieve interoperability between different ontologies. This paper proposes an approach based on formal concept analysis (FCA) and relational concept analysis (RCA) for ontology merging that aims at enhancing inter-organizational collaboration among different organizations that use different ontologies / models.

1 INTRODUCTION

Advanced systems are needed to facilitate the collaboration between project teams and stakeholders in the infrastructure and construction domain. However, this requires more than the technical connectivity of entities or the sharing of online data. What is required is a semantic system that embeds human expertise and knowledge in a computer-understandable format, i.e. an ontology-based web system. However, since the development of a single ontology is not feasible given the multidisciplinary parties that are involved and the unique nature of each project; any semantic system has to provide for ontology interoperability. Thus, there is a need to develop a web-based system that depends on two components: 1) a core ontology for the infrastructure and construction domain, and 2) an ontology merging mechanism to allow for interoperability between different ontologies.

2 ONTOLOGY INTEROPERABILITY

Different definitions are provided in the literature for terms related to ontology interoperability including mapping, aligning, articulation, matching and merging (Klein 2001, Kalfoglou & Schorlemmer 2003). Mapping, aligning, and articulation are referred to in this paper as 'mapping', while 'matching' and 'mapping' are used interchangeably. In this paper, ontology mapping / matching is defined as the process of finding semantic correspondences between entities (i.e. concepts, relations, axioms etc.) of two or more ontologies. On the other hand, ontology merging is defined as the process of deriving a new (target) ontology from two or more existing (source) ontologies (McGuinness et al. 2000). Generally, combining two ontologies is composed of two main steps: 1) finding correspondences between both ontologies (i.e. mapping) and 2) merging both ontologies based on the established correspondences. Different methodologies and approaches for ontology mapping and merging are being developed and used, such as Chimaera PROMPT, ONION, GLUE, FCA-Merge, IFMap, KAON, Edamok, Matchmaker, and OBSERVER. The presentation and discussion of these different approaches are beyond the scope of this paper.

3 REQUIREMENTS FOR ONTOLOGY MERGING TOOLS

This paper classifies requirements for ontology merging tools as either practical or technical requirements. Practical requirements are those defined by ontology users and are mainly related to the type of input available, type of output they require, and level of user interaction that is needed. On the other hand, technical requirements are those defined by the developer in response to user requirements. Two of the major or challenging requirements that face developers of ontology merging tools are: 1) merging other relations besides taxonomic relations and 2) merging axioms. Most of the available ontology mapping and merging tools allow for the generation of taxonomic relations for the new ontology. However, ontologies usually have many other ontological relations that are fundamental to their semantics. For

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example in an infrastructure ontology, common relations would be performed_by, uses, and controlled_by. A process is performed by an actor, uses resources, and is controlled by constraints. Such relations need to be reflected in the new ontology based on source ontologies. Similarly, current ontology mapping and merging tools do not allow for the merging of functions and axioms. However, axioms are necessary to define the semantics of both concepts and relations. Therefore, tools for merging ontological relations and axioms are needed.

4 FORMAL CONCEPT ANALYSIS

4.1 *Formal Concept Analysis*

Formal Concept Analysis (FCA) is a mathematical theory that models the concept of ‘concept’ using lattice theory. A formal concept is modeled as a unit that has an extent and intent. A formal context is introduced to describe extensions and intensions mathematically. A formal context is defined as a triple (G,M,I), where G is a set whose elements are called objects, M is a set whose elements are called attributes, and I is a binary relation between G and M ($I \subseteq G \times M$). The relation I expresses which attributes describe each object or which objects are described by an attribute (Stumme 2003). A formal concept represents a group of objects. It is described by objects (the extent of the concept) and attributes (the intent of the concept). The extent represents all objects belonging to the concept, while the intent includes all attributes shared by these objects. A formal context is usually represented in a form of a table, where the left column represents the object set G, the upper row represents the attribute set M, and the cross cell values represent the relationship I. On the other hand, formal concepts are usually described using a *Hass Diagram*, forming a concept lattice. In the lattice, each node represents a formal concept. The ascending path of line segments represents the subconcept-superconcept relationship and vice versa (Ganter & Wille 1999).

Formal contexts discussed above deal with binary attributes only. However, in practical applications, attributes are usually represented by a value, such as ‘price’ of product. These multi-valued attributes are called ‘many-valued attributes’, in contrast to previously discussed ‘one-valued attributes’. As presented by Ganter & Wille (1999), these many-valued attributes form a many-valued context. A many-valued context is represented by (G, M, W, I), where G is a set whose elements are called objects, M is a set whose elements are called attributes, W is a set whose elements are called attribute values, and I is a ternary relation between G, M and W ($I \subseteq G \times M \times W$). Similar to one-valued contexts, a many-valued context is represented in a form of a table, where the left column represents the object set G, the first upper row represents the many-valued attribute set M, the second upper row represents the attribute value set W, and the cross cell values represent the relationship I (Ganter & Wille 1999).

In order to derive concepts from a many-valued context, the many-valued context is transformed into a one-valued context by means of conceptual scaling for attributes. Only then, the concepts of the derived one-valued context are interpreted as the concepts of the original many-valued context. Conceptual scaling is simply developing a ‘conceptual scale’ for each attribute. The scale is a context that is used to interpret the attributes, such that a scale for an attribute m of a many-valued context is a one-valued context given by: $Sm := (Gm, Mm, Im)$, where $m(G) \subseteq Gm$ and Mm is a set of new attributes and Im is the relation between attributes Gm and new attributes Mm. The choice of conceptual scales depends on the interpretation of the context and is not mathematically determined (Ganter & Wille 1999).

4.2 *Relational Concept Analysis*

Relational concept analysis (RCA) is an extension to formal concept analysis (FCA) proposed by Huchard et al. (2002). It allows for presenting relations between formal objects through the use of relational context family (RCF), so that formal concepts not only present shared attributes, but also reflect shared relations between objects.

A RCF is a set of formal multi-valued contexts and a set of relational attributes (extracted from relations between objects). In other words, a RCF R^S is a pair (K_R, M_R) where K_R is a set of s multi-valued contexts $K_i = (G_i, M_i, W_i, I_i)$ and M_R is a set of p relational attributes α_j such that for each j, $1 \leq j \leq p$ there exist r and q in $[1,s]$ with $\alpha_j : G_r \rightarrow 2^{Gq}$. The mappings domain and co-domain are $dom: M_R \rightarrow \{G_i\}$ and $cod: M_R \rightarrow \{G_i\}$; such that for all $\alpha : G_r \rightarrow 2^{Gq}$, $dom(\alpha_j) = G_r$ and $cod(\alpha_j) = G_q$. In addition, $rel: K_R \rightarrow 2^{M_R}$ with $rel(K_i) = \{ \alpha \mid dom(\alpha) = G_i \}$.

Rouane et al. (2004) propose the application of RCA to UML class hierarchies. Their proposed approach is composed of three steps: 1) encoding, 2) abstraction, 3) reverse encoding. For the encoding, classes and associations of the UML model are each presented in a separate context of the RCF. The class-association relation is reflected in both contexts as relational attributes, out-association vs. in-association for the class context and source-class vs. target-class for the association context. During the abstraction phase, a set of inter-related concept lattices are built. The initial lattice is constructed from classes and non-relational attributes. Based on this lattice, relational scaling is performed, resulting in relational attributes scaled along the lattice. Thus, the attribute name will have reference to both the association type and the formal context of the lattice.

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Table 1. Presentation of ontology 1.

Processes (Org A)	Processes	Products		Resources			Actors			Controls	
	Design Coordination Process	Architectural Drawings	Architectural Specifications	CAD Software	Constr. Lessons Learned	Hardware	Architect	Senior Architect	Drafter	Code Specifications	Available Construction Techniques
Architectural Design Process	supported_by	impacts	impacts				performed_by	managed_by	participates_in	controlled_by	
Constructability Analysis Process		could_modify	could_modify	aided_by	aided_by	utilizes	performed_by	managed_by	participates_in	controlled_by	controlled_by
Architectural Drawing Development Process		results_in		aided_by		utilizes	supervised_by		performed_by	controlled_by	
Specification Development Process			results_in			utilizes	performed_by			controlled_by	
Design Coordination Process							participates_in	performed_by	participates_in		

Table 2. Presentation of ontology 2.

Processes (Org B)	Products			Resources	Actors				Controls	
	Master Plan	Schedule	Budget	Scheduling Software	Planner	PM Engineer	PM Estimator	Project Manager	Budget	Design Documents
Planning Process	results_in				performed_by	participates_in	participates_in	managed_by		impacted_by
Scheduling Process		results_in		aided_by	performed_by	participates_in		managed_by		impacted_by
Budgeting Process			results_in			participates_in	performed_by	managed_by		impacted_by
Cost Control Process						performed_by	participates_in	managed_by	controlled_by	
Resource Management Process						performed_by		managed_by	controlled_by	
Project Coordination Process					participates_in	performed_by	participates_in	managed_by		

A process of mutual enrichment continues until isomorphism between two consecutive lattices is achieved.

RCA provides a relational connection between formal concepts of two formal contexts. So, the intent of a formal concept of a class context may include a relational attribute referring to a formal concept of the association context. This reference reflects the links between formal objects (classes) and association type.

5 DYNAMIC ONTOLOGY MERGING - PROPOSED APPROACH

5.1 *Introduction to the Proposed Approach*

Formal and relational concept analysis could be used as a key tool for merging two or more ontologies for information exchange. For example, if we need to exchange information between two ontologies, FCA algorithms would be used to link the two ontologies by producing a merged lattice that combines the two ontologies, thus allowing for a seamless exchange of information. In this case, each ontology will be represented in a form of context table. Consequently, the result will be a number of formal contexts that need to be merged in a dynamic environment. The methodology of the proposed approach consists of five main steps: 1) encoding, 2) axiomatic scaling, 3) mapping, 4) merging, and 5) reverse encoding.

5.2 *Encoding*

The aim of the encoding is to present each ontology in two main contexts. The first context, K_1, includes ontology concepts (including attributes of concepts). The second context, K_2, presents ontology relations (including attributes of relations). The concept-relation link is reflected in both contexts as relational attributes, out-relation vs. in-relation for the 'ontology concepts context' and source-class vs. target-class for the 'relation context'. For example, consider that Tables 1 and 2 present two different ontologies developed by two different organizations. Table 3 then shows a formal context presenting concepts (of ontology 1) as formal objects and both their non-relational attributes (such as process and product) and relational attributes (out-relations and in-relations) as formal attributes. On the other hand, Table 4 presents ontology relations as formal ob-

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jects, while their non-relational attributes (such as name) and their corresponding relational attributes (source-concepts and target-concepts) are reflected as formal attributes. In order to reduce the scale of the example, only few relations of ontology 1 are considered.

Table 3. Concepts of ontology 1 and their attributes.

Concept	process	product	out-Relation	in-Relation
Architectural Design Process	x		supported_by, impacts	
Constructability Analysis Process	x		could_modify	
Architectural Drawing Development Process	x		results_in	
Specification Development Process	x		results_in	
Design Coordination Process	x			supported_by
Architectural Drawings		x		impacts, could_modify, results_in
Architectural Specifications		x		impacts, could_modify, results_in

Table 4. Relations of ontology 1 and their attributes.

Relation	Name	Source	Target
Supported_by	supported_by	Architectural Design Process	Design Coordination Process
Impacts	impacts	Architectural Design Process	Architectural Drawings
Could_modify	could_modify	Constructability Analysis Process	Architectural Drawings
Results_in	results_in	Architectural Drawing Development Process	Architectural Drawings
Impacts	impacts	Architectural Design Process	Architectural Specifications
Could_modify	could_modify	Constructability Analysis Process	Architectural Specifications
Results_in	results_in	Specification Development Process	Architectural Specifications

5.3 *Axiomatic Scaling*

Axiomatic scaling aims at reflecting some of the axioms of the source ontologies in the formal context to achieve partial axiom merging. For example, if ontology 1 has an axiom stating that if an actor has a role it implies that he has a right too, then the formal context of Table 5 could be scaled according to this axiom, as shown in Table 6: $\forall(x)\ (actor(x) \wedge has\_role(x)) \supset has\_right(x)$. However, this approach does not yet propose a way for incorporating all axioms of the source ontologies.

Table 5. Partial formal context.

	actor	has_role
Architect	x	x
Senior Architect	x	x
Drafter	x	x

Table 6. Partial axiomatically scaled formal context.

	actor	has_role	has_right
Architect	x	x	x
Senior Architect	x	x	x
Drafter	x	x	x

5.4 *Mapping*

Mapping candidates will be suggested to the user or supply chain manager based on pre-defined algorithms. Four main types of heuristics will be used to suggest mappings: 1) name-similarity between concept names, 2) definition-similarity between concept definitions, 3) hierarchical-similarity based on similarity between taxonomical hierarchies and is-a relationships, and 4) relational-similarity matches based on similarity of other taxonomical and ontological relations between concepts. More discussion about the mapping methodology will be presented in future work.

5.5 *Merging: Multiple Lattice Construction*

A set of inter-related concept lattices are constructed at this stage (Rouane *et al* 2004). The initial lattice is constructed from concepts and non-relational attributes. For example, lattice $L^0_{concpet}$ (Fig. 1) is built from context $K^0_{concpet}$ (Table 7). This lattice constitutes the first iteration of the construction process.

The second iteration starts by relational scaling based on lattice $L^0_{concpet}$, resulting in relational attributes scaled along the lattice. Thus, the attribute name in the scaled context will have reference to both the relation type and the formal context of the preceding lattice. A process of mutual enrichment continues until isomorphism between two consecutive lattices is achieved. For example, Table 8 shows a scale context with: a) ontology concepts that are source concepts as objects, and b) relational attributes scaled along the existing lattice $L^0_{concpet}$ and thus corresponding to formal concepts of $L^0_{concpet}$ which have these ontology concepts in their extents.

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Table 7. Formal context $K^{0}_{concpet}$.

	process	product	resource	actor	control	design Document	software
Architectural Design Process	x						
Constructability Analysis Process	x						
Architectural Drawing Development Process	x						
Specification Development Process	x						
Design Coordination Process	x						
Planning Process	x						
Scheduling Process	x						
Budgeting Process	x						
Cost Control Process	x						
Resource Management Process	x						
Project Coordination Process	x						
Architectural Drawings		x				x	
Architectural Specifications		x				x	
CAD Software			x				x
Constr. Lessons Learned			x				
Hardware			x				
Architect				x			
Senior Architect				x			
Drafter				x			
Code Specifications					x		
Available Construction Techniques					x		
Master Plan		x					
Schedule		x					
Budget		x			x		
Scheduling Software			x				x
Planner				x			
PM Engineer				x			
PM Estimator				x			
Project Manager				x			
Design Documents					x	x	

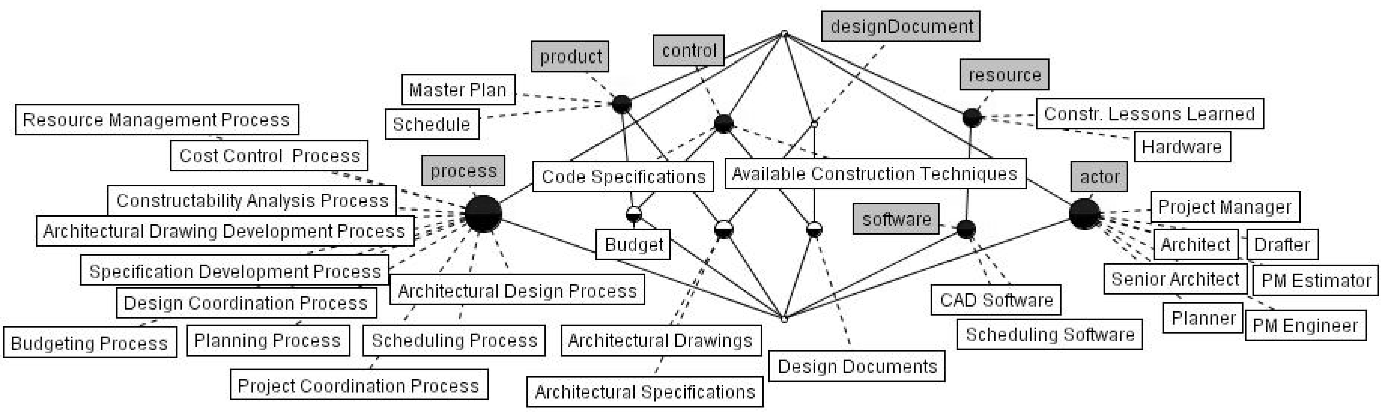

Figure 1. Lattice $L^{0}_{concpet}$.

Table 8. Scale context $K_{source\text{-}concept}$.

	sc-L10-Fc0	sc-L10-Fc5
Architectural Design Process	x	x
Constructability Analysis Process	x	x
Architectural Drawing Development Process	x	x
Specification Development Process	x	x

The relational attribute has the following notation r-L*ij*-FC*k*, where r refers to the relation type (being source concept in this case, abbreviated as sc), *Lij* is a reference to the existing lattice (*i* stands for the iterative step of the lattice construction and *j* is the context number), and *k* is the formal concept index in lattice *Lij*. A similar scale context is built for target concepts, as per Table 9. Table 10 shows the relational extension of context $K^{1}_{relation}$, which is de-

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rived by linking relations to concepts and thus having relations as objects and relational attributes corresponding to formal concepts of L^{0}_{concpet}. The relation context K^{1}_{relation} is then constructed by adding the non-relational attributes of relations to the relational extension of context K^{1}_{relation}, as per Table 11. Accordingly, the relational lattice L^{1}_{relation} (Fig. 2) is constructed from the context K^{1}_{relation}.

Table 9. Scale context K $_{\text{target-concept}}$.

	tc-L10-Fc0	tc-L10-Fc3	tc-L10-Fc5	tc-L10-Fc7
Design Coordination Process	x		x	
Architectural Drawings	x	x		x
Architectural Specifications	x	x		x

Table 10. Relational extension of K^{1}_{relation} through K $_{\text{source-concept}}$ and K $_{\text{target-concept}}$.

	sc-L10-Fc0	sc-L10-c5	tc-L10-Fc0	tc-L10-Fc3	tc-L10-Fc5	tc-L10-Fc7
Supported_by	x	x	x		x	
Impacts	x	x	x	x		x
Could_modify	x	x	x	x		x
Results_in	x	x	x	x		x

Table 11: Relation context K^{1}_{relation}.

	name	sc-L10-Fc0	sc-L10-c5	tc-L10-Fc0	tc-L10-Fc3	tc-L10-Fc5	tc-L10-Fc7
Supported_by	supported_by	x	x	x		x	
Impacts	impacts	x	x	x	x		x
Could_modify	could_modify	x	x	x	x		x
Results_in	results_in	x	x	x	x		x

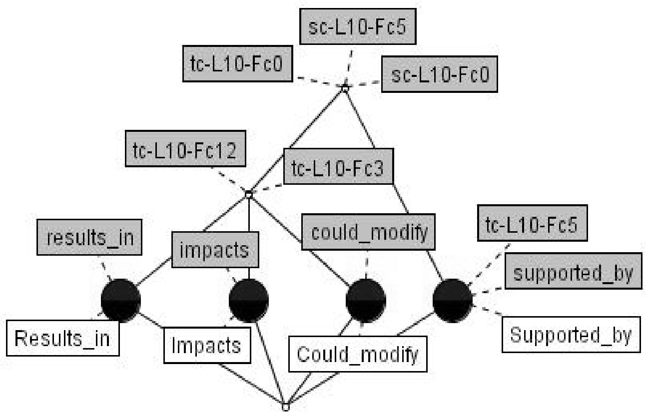

Figure 2. Relational lattice L^{1}_{relation}.

The second part of the second iteration deals with constructing the relational 'ontology concept lattice'. For example, Table 12 shows: a) a scale context with ontology relations that are out-relations as objects, and b) relational attributes scaled along the existing lattice L^{1}_{relation} and thus corresponding to formal concepts of L^{1}_{relation} which have these ontology relations in their extent. The similar scale context is built for in-relations, as per Table 13. Table 14 shows the relational extension of context K^{1}_{concept}, which is derived by linking concepts to relations and thus having concepts as objects and relational attributes corresponding to formal concepts of L^{1}_{relation}. The ontology concept context K^{1}_{concept} is then constructed by adding the non-relational attributes of concepts to the relational extension of context K^{1}_{concept}. Accordingly, the relational lattice L^{1}_{concept} (Fig. 3) is constructed from the context K^{1}_{concept}.

Accordingly, lattices L^{1}_{relation} and L^{1}_{concept} are both interpreted together. RCA provides a relational connection between formal concepts of the two formal contexts. So, the intent of a formal concept of an 'ontology concept lattice' may include a relational attribute referring to a formal concept of the 'ontology relation context'. This reference reflects the links between formal objects (ontology concepts) and ontology relations.

5.6 *Reverse Encoding*

The main objective of the reverse encoding step is to represent the merged combined lattice into a merged ontology (using the same format as the original source ontologies). Details of reverse encoding will be presented in future work.

6 CONCLUSION

Collaboration between semantic ontology-based systems is hindered by the lack of interoperability between different ontologies that are used by collaborating organizations. This paper proposed an approach based on FCA and RCA for developing a merged ontology for creating interoperability among more than one organization. Accordingly, organizations can use different process models and ontologies, but can still collaborate since interoperability is facilitated though dynamic ontology merging.

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Table 12. Scale context K $_{out\text{-}relation}$.

	out-L21-Fc0	out-L21-Fc1	out-L21-Fc2	out-L21-Fc3	out-L21-Fc4	out-L21-Fc5
Supported_by	x					x
Impacts	x	x		x		
Could_modify	x	x			x	
Results_in	x	x	x			

Table 13. Scale context K $_{in\text{-}relation}$.

	in-L21-Fc0	in-L21-Fc1	in-L21-Fc2	in-L21-Fc3	in-L21-Fc4	in-L21-Fc5
Supported_by	x					x
Impacts	x	x		x		
Could_modify	x	x			x	
Results_in	x	x	x			

Table 14. Relational extension of K$^{1}_{concept}$ through K $_{out\text{-}relation}$ and K $_{in\text{-}relation}$.

	out-L21-Fc0	out-L21-Fc1	out-L21-Fc2	out-L21-Fc4	in-L21-Fc0	in-L21-Fc1	in-L21-Fc5
Architectural Design Process	x						
Constructability Analysis Process	x	x		x			
Architectural Drawing Development Process	x	x	x				
Specification Development Process	x	x	x				
Design Coordination Process					x		x
Architectural Drawings					x	x	
Architectural Specifications					x	x	

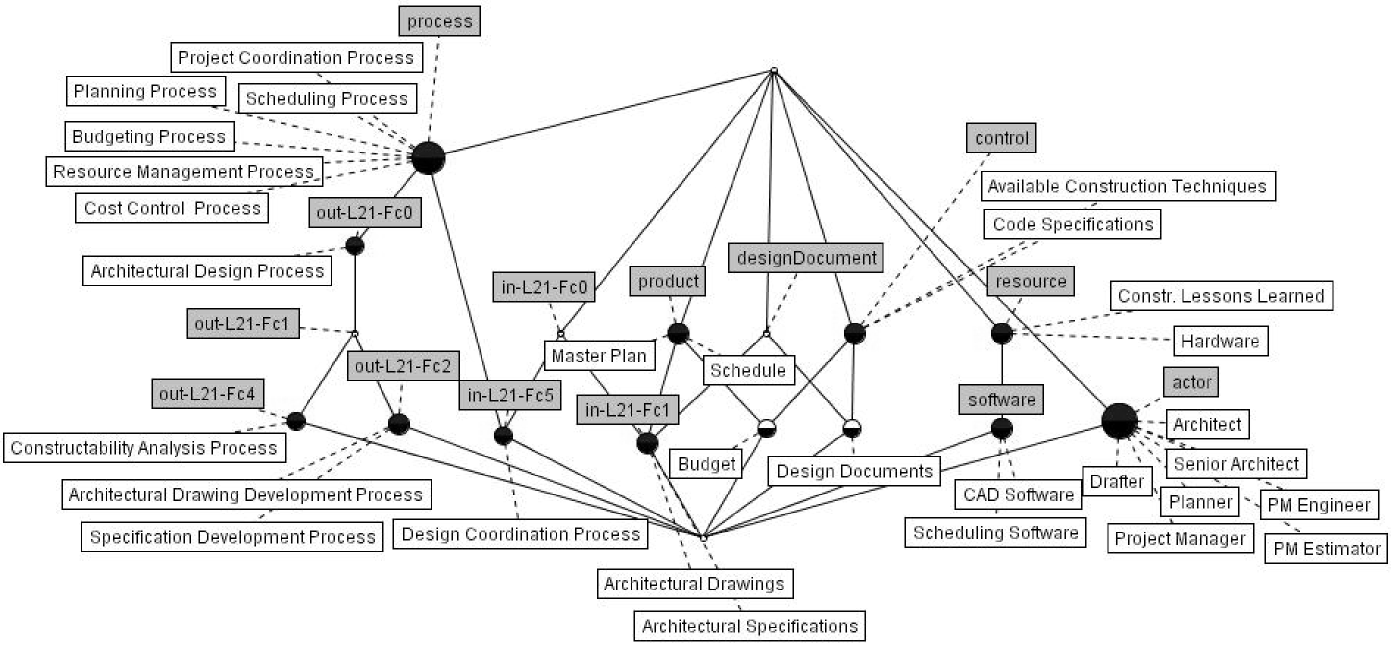

Figure 3. Lattice L$^{1}_{concpet}$

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Shifting the construction interoperability paradigm, in the advent of Service Oriented and Model Driven Architectures

A. Grilo
Instituto Superior de Engenharia de Lisboa, Neobiz Consulting,Portugal

R. Jardim-Gonçalves
Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, UNINOVA, Portugal

A. Steiger-Garcao
Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, UNINOVA, Portugal

ABSTRACT: A major difficulty construction companies are currently facing is the lack of interoperability of software applications to manage and progress in their business. Organizations are being pressured up by new business relationships, driven for instance by new contractual challenges, which the exchange of information and documents with new partners are often incapable of being executed automatically and in electronic format. This is principally due to problems of incompatibility with the information representation adopted by the software applications they are working with. This problem arises not only during the project phase but also across the whole life cycle that includes operation and maintenance stages. In order to create the enabling conditions for the deployment of the electronic collaborative and commerce platforms it is fundamental to understand the variables that may influence its development, and how they determine the configuration of the e-platform. This paper, after present technology driven standards for the construction industry data management, it proposes the adoption of the emerging Service Oriented and Model Driven Architectures to shift forward the interoperability paradigm in this industrial sector. The paper illustrates some scenarios where significant impact is expected when adopting the proposed methodology.

1 TECHNOLOGY DRIVEN STANDARDS

During the past decade the need for innovation and standardization has been recognized by several sectors. For instance, in the United Kingdom the government set up a Construction Best Practice Programme (CBPP) and an industry–led Movement for Innovation (M4I) [8]. The Japanese Ministry of Construction has established an action program (SCADEC) whose main objective is to develop a neutral CAD data exchange format based on STEP AP202 [23].

The major results from the projects previously presented pointed out that the adoption of normalized methodologies and platforms to achieve an adequate level of integration of applications and interoperable open environments would be indispensable. Primarily, the development and adoption of standard models for representation of the data structures was identified as the key to sustain the core of the integrated systems.

In an effort to provide an answer to these requirements, the TC184/SC4 (Industrial automation systems and integration - Product data representation and exchange: Industrial Data) of the International Organization for Standardization (ISO) launched, within its WG3 (Product Modeling), the T22: Building Construction Group. Under the umbrella of T22, for ISO10303-STEP, the part 225 titled: "Application Protocol (AP): Building Elements Using Explicit Shape Representation" was developed.

This part is now an International Standard (IS) and specifies the requirements for the exchange of building element shape, property, and spatial configuration information between application systems with explicit shape representations, specifically the physical parts of which a building is composed, such as structural elements, enclosing and separating elements, service elements, fixtures and equipment, and spaces.

In addition, other parts of STEP have been developed contributing to the release of standard models related to the building and construction industry, e.g., AP228 (ISO 10303-228) Building services: Heating, Ventilation and Air Conditioning (HVAC) and AP230 (ISO 10303-230) Building structural frames: Steelworks.

Also in Europe, the European Committee for Standardization (CEN) has been supporting the development of STEP in the WG2 of its TC310, which is working in line with ISO. CEN/TC310 is responsible for the development of the Standards required by industry for the integration in Advanced Manufacturing Technologies (AMT) systems, such as those required in the areas of Enterprise Modeling and System Architecture, Communication, Data, In-

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formation processing, Control equipment, Mechanical and System operational aspects. In other regions of the world, similar committees exist.

Moreover, in the mid 90s the Industrial Alliance for Interoperability (IAI) was created with the purpose of enabling software interoperability, providing a universal basis for process improvement and information sharing in the construction and facilities management industries (AEC/FM). Consequently, IAI developed the Industrial Foundation Classes (IAI/IFC) as an open standard model to allow software vendors to create interoperable applications via the IFC file format. The ISO EXPRESS language (STEP-11) was adopted by IFC to describe its models.

At the same time, the Part Library Usage and Supply - PLUS project - developed an exchange format for intelligent electronic catalogues, based on a common information model facilitating integration with third parties software. The results of this project contributed to the International Standard ISO13584: PLib (Parts Library). PLib intends to contribute to a solution for an electronic catalogue representation in proprietary formats, providing a tool for independent standard representation and supporting multi-representation and integration of different supplier catalogues. It uses a consistent exchange and product modeling format, in this case based on ISO10303 STEP.

2 INTEROPERABILITY IN THE CONSTRUCTION INDUSTRY

For as long as a decade, researchers and software industry are trying to push technology that would allow information interoperability and data integration across the whole construction life-cycle, mostly using standards-based solutions [4][5]. The approaches have essentially adopted a paradigm that is centered on product data [3][9]. Thus, for a seamless integration of information and data in a construction or engineering project, a repository of the product data must be physically or virtually built supported by Standard Data Access Interfaces (SDAIs) (Figure 1).

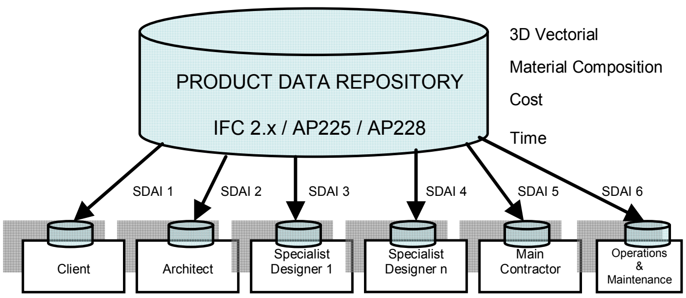

Figure 1 - Product-based repository, in a construction scenario

Despite all the research and practices efforts, the reality has proven that, although feasible, this technological approach is difficult to implement [2][6][11][24]. Indeed, people normally see their work and activities as part of processes, and the product-based integration paradigm requires a discipline of working around a product model, with processes changing to accommodate the need to fulfill the data repository.

Main conclusions from studies thus support the idea of the importance of governance structures in construction networks – mainly the role of the client – in enforcing new ways of working. This is hardly achieved in common, i.e. smaller and shorter term projects, or less knowledgeable construction players [13][14][15][16].

Regarding the wide dissemination of integration of digital data, some authors argue about what will be the “tipping point” for construction companies [7].

The argument made is that if most business factors are far from supporting or enabling the adoption of product-based e-platforms in construction projects, in order to reach the “tipping point”, researchers should seek technologies that are more aligned with the constraints of current construction companies’ infrastructures, relationships and networks.

3 MODEL DRIVEN ARCHITECTURE AND SERVICE ORIENTED ARCHITECTURE

The Model Driven Architecture approach is specified to allow an information model to also be able to work with various software platforms, meaning support to changes on the Operating System, programming language, data storage type or concept (e.g. data warehousing), data servers, data formats and types, networked-based systems implementations, communication levels standards and protocols, all the myriad of elements that form an interoperable application’s working software basis [1][20][21][22].

In the base step of defining an MDA we find the CIM (Computation-Independent Model), which is the most abstract model of the system, representing the system domain. It’s abstraction degree is such that it is often not specified on the definition of the MDA [18].

MDA allows design-time interoperability, in which the core idea – the system Model, also known as PIM (Platform Independent Model) – is defined as a conceptual model based on visual diagrams, use-case diagrams and metadata using the standards UML (Unified Modelling Language), OCL (Object Constraint Language), XMI (XML Metadata Interchange), MOF (Meta Object Facility) and CWM (Common Warehouse Metamodel) [12][21].

A Service Oriented Architecture (SOA) combines the capacity to invoke remote objects and services with tools for dynamic service discovery, placing emphasis on interoperability.

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The emergence of web services represents a step forward in the evolution on e-business. Its technical format ensures each of these self-contained business services is an application with a public standardized interface that will easily integrate with other services (from the same or different companies) to create a complete business process. This interoperability allows businesses to dynamically publish, discover and aggregate a range of web services through the Internet to more easily create innovative products, business processes and value chains.

Web services are based on the potential of the combination of XML (Extended Markup Language), a description of the network services as a set of endpoints operating on messages - WSDL (Web Services Description Language), registration of services in a registry – UDDI (Universal Description, Discovery and Integration) is normally used, and a communication protocol - SOAP (Simple Object Access Protocol). SOA needs a platform-independent model for services that address the service business requirements and represents the functionality of the services.

The service model can then be used to generate platform specific models, which are dependent of the platform. Web services are now widely used in B2B applications and MDA can employ web services as a target platform for implementing software systems.

MDA gives us the opportunity to bring web services to a higher level of abstraction, adding agility, flexibility, as well as a higher level of quality and robustness, due to the more formal and accurate specification of requirements and design. Having web services developers program directly to these technologies invites rapid obsolescence and is also far too labor-intensive [10].

One of MDA strengths lies in separating the business logic of the company from the technology infrastructure. MDA makes a clear distinction of implementation details and business functions. So, the technology change can be managed straightforward and when a requirement changes the business behavior, we are able to model this change in the abstract level and it will be directly mapped to our system.

By adopting this approach, companies can rapidly adapt to changing technology landscapes, without having to invest heavily in a great number of developers and operational personnel to support the new technology. Thus, because the business logic is encapsulated, it can be applied to different technology deployments like J2EE or .Net, resulting in a usable source code. This provides a strategic competitive advantage for a company that has to react quickly.

Adopting this paradigm, MDA and SOA can challenge construction and provide an adequate approach, overcoming the shortfalls of the traditional product-based approaches.

4 SHIFTING CONSTRUCTION INTEROPERABILITY PARADIGM

The introduction of MDA and SOA on information systems solutions for the construction sector means that it will be possible to shift from a product-based data model paradigm to a process-based, services oriented object data model paradigm.

Thus, construction players like clients, architects, specialist designers, contractors and suppliers will not need to change the way they work in order to electronically exchange information and data of the project. Rather than building a product data repository for each project, the players will need to access a repository of e.g. web services that support their common interaction processes (Figure 2) [25].

Moreover, most of the research work carried out so far, namely on STEP and IFC driven projects may be reused in the emerging technological context of MDA and SOA, supporting the creation of PIMs in the construction sector business situations.

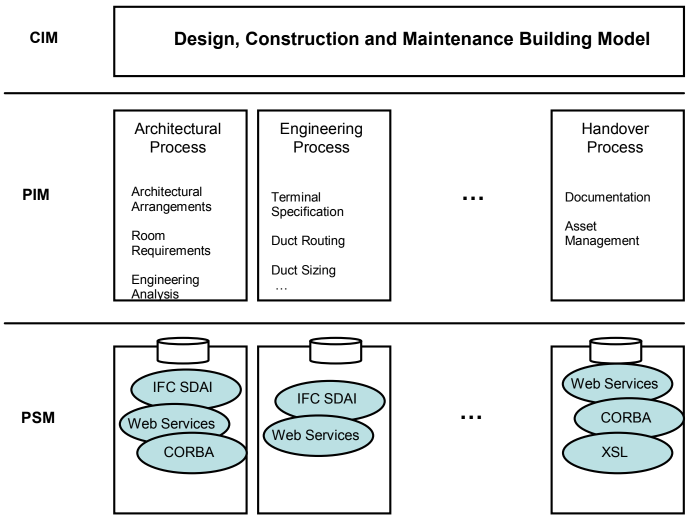

Figure 2 - Services-based Repositories

A HVAC specialist consultant and an Architect Company exist at different locations and are using different business models. At a certain point in their lifetime a Client contracts both companies to build a large office building. This means that they will need to interoperate, building a strong business cooperation model, supported by integrated electronic exchange of information.

Their collaboration is bound to the use of Service Oriented Architectures, but the service implementation is based on different underlying system architectures. Each one has its own services available and with well defined entry-points.

The specialist consultant is using web-services and the architect is using CORBA (figure 3). Regarding the type of information, the first needs the layout and properties of the rooms in the building – called here Service Y - in order to be able to produce the engineering analysis regarding air flows – Ser-

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vice X. Thus, there is a need for a Service Broker in order to produce the composition of services.

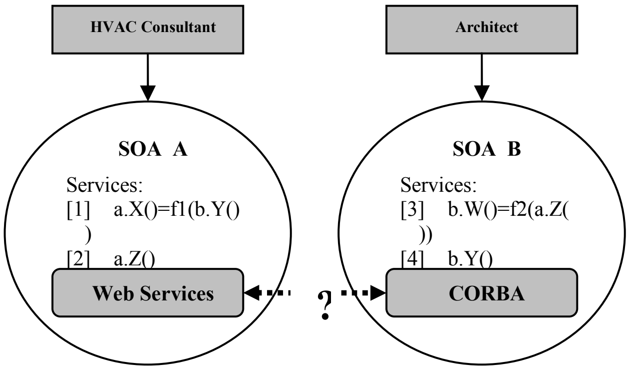

Figure 3 – Interoperability problem at services level

Should the services be implemented in the same system architecture and there would be no problem. But in this case we have services built in two different system architectures. Each company uses its own platform, and different proprietary applications, though allowing external communication of data. Here is the point were MDA adds its great value to make a seamless integration of services.

Traditional approaches would mean that the applications of each company could exchange data through a specifically developed interface. As stressed before, the SOA approach can be a solution for interoperability, but it requires a platform independent model.

Thus, in this example, the brokerage service of the SOA through the MDA approach can be determined by a CIM – e.g. the Process Protocol (see e.g. [19]) - a PIM that determines the various processes and activities involved in the Architect – HVAC Specialist Consultant interaction [17], and a repository of PSMs, with CORBA, Web Services, SDAI, etc. related services (Figure 4), that support application specific interoperability.

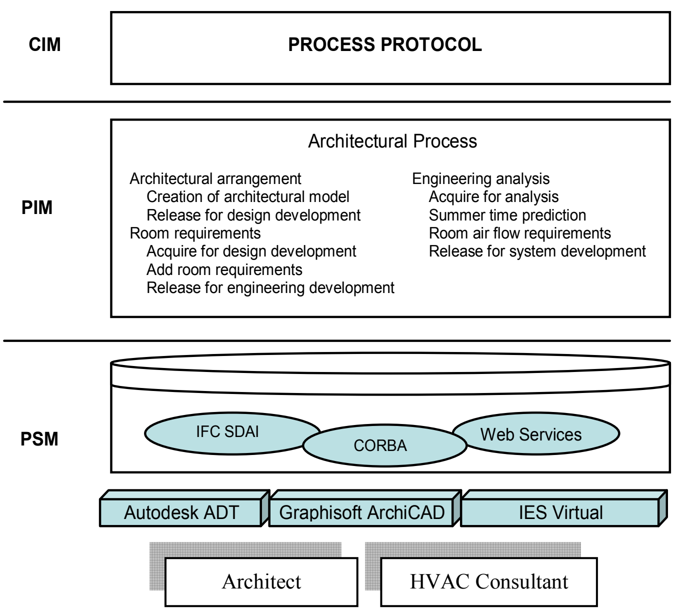

Figure 4 – An MDA and SOA Application

The service definition does not need to be unique for this business relationship. Indeed, this type of process and exchanged information is very common in any project and thus the CIM and PIM could be generically used by both parties in other business transactions.

Transforming the high-level models to a concrete entire IT Infrastructure, it can be created services and SOAs that are decoupled from the lower level platforms, infrastructures and implementations, opening the way to seamless interoperability.

This would mean that functional applications would have access to a pool of normalized and interoperable services and SOAs that translate common information transaction needs between construction parties and through service brokerage, and obtain the seamless integration.

4.1 Validation of the integrated environment

Conformance and interoperability testing are procedures that should be performed to validate and assure the quality of the global integrated system, as a monitoring procedure or when a new application is plugged in. This issue is even more sensitive when different standards (e.g., Application Protocols) are concerned, and semantics and harmonization of concepts and structures have to be realized. In advent of the Model Driven and Services Oriented Architecture, where it is expected many of the interoperability issues to be solved, this would be a major challenge to face.

Validation procedures should be performed after developing the interfaces to the services to assure conformity of the application with the adopted standard. Also, to assure a complete interoperability with all other parties integrated in the global system, verification and validation should be performed between one application and all parties in order to assure a reliable exchange of information conforming to the standard, syntactically as well as semantically.

After one application develops an interface, validation procedures should be executed to assess conformity with the adopted standard. Also, to validate interoperability between one application and the others in the integrated global system, syntax and semantic validation procedures should be performed among all parties, to guarantee a reliable exchange of information conforming to the standard. In this way, conformance testing (CT) and interoperability checking (IC) are mechanisms that should be performed to validate and assure the quality of the global integrated system, as a monitoring procedure or when a new party is plugged in. This issue is even more sensitive when different standards (e.g., Application Protocols) are concerned, and semantics and harmonization of concepts and structures exist or have to be realized.

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Validation is directly related with the fact that erroneous assumptions in the early phase of development (e.g., data modeling) can cause correction work in later stages. To guarantee the syntactical correctness of a data model with a standard is not the main problem because it comprehends the complete formal description of its methods and grammar, and parsers are usually available. However, the main difficulty is typically related when dealing with semantics. The more semantics are included, the more complex the conceptual data model becomes, and so more difficult the correct interpretation of the model by all applications willing to adopt it.

4.2 Methodology for the development of an ATS

Considering a System Under Test (SUT) adopting an AP, e.g., a CAD system, the developed processors implementing the interface with the standard model, i.e., the Implementation Under Test (IUT), should be verified through a set of Abstract Test Suits (ATS). In case of success, this IUT can be certified as compliant with the standard AP. Systematizing the contents in parts 30s of standard ISO10303, an ATS should be developed and released, tied with an AP to support the validation procedures of a standard AP implementation.

In general terms, an ATS describes the procedures, and respective verdict for verification and validation of an application that implemented a translator to adopt an AP. This ATS is defined by a set of Abstract Test Cases (ATC) describing in a conceptual format, e.g., in free text, what kind of tests should be executed, how to proceed, and what the inputs to apply should be and what the correspondent expected outputs are, i.e., the Input Data Specification (IDS) and its associated verdict.

To execute the physical test to validate the system, the ATS needs to be instantiated creating the Executable Test Cases (ETC), which are the data and commands to be used to execute the test described in computer format.

With the ATS defined for one AP, the Conformance Testing procedures can be executed on the IUT. This test is executed twofold: one to validate the implemented pre-processor, and another to validate the post-processor. The pre-processor validation starts introducing in the internal data structure of the application the case as described in the ATS to be validated, e.g., piece of furniture. This input should be performed using the available application's commands, and usually done manually. Next, the pre-processor is activated to generate the correspondent data in standard format. Its result is analyzed in terms of syntax, structure and semantics, and the resultant file directly compared with the pre-defined expected result stored in the ETC database.

To validate the post-processor, one of the examples stored in the ETC database is used as input to the IUT. After the SUT import the ETC example, a set of queries to the SUT is executed in order to analyze the respective response, and check its correctness in terms of semantics. A typical example is to set the system importing one product representation, and later to analyze it according to several presuppositions to validate the semantics.

This methodology and architecture for CT of APs may also be adopted when developing multilevel application protocols. Indeed, considering that each module is already tested and certificated, this approach hopes to reduce the effort when validating the integrated multilayer AP, compared with the necessity to validate the complete integrated AP from scratch.

4.3 Internet-enabled conformance testing environment

When one application is adopting a standard and developing its translators, it is important to have access to tools that can validate the implementation and check if it is compliant with the standard. Such validation tools are of some complexity, and sometimes it is not practical to have them installed in all platforms and operating systems where the translators are in development.

To give support to any implementation adopting standard APs, we propose an internet-enabled conformance testing environment, adopting a Service Oriented Architecture, as well. This environment would be established in a web-server and use internet-based services for its access which could be done anywhere through the net.

In the core of this platform there is a compiler offering most of the mechanisms needed to perform model validation through the standard and model's rules and constraints. On top of it, extensions were developed to make them available through web-services to the implementers. Major services are data check and services raporteur.

When the implementer would like to validate a translator (the IUT) in development, he/she can submit the respective standard data file to the server, receiving by return the respective validation report. Because the validation procedure can take a long time, and to avoid having the user waiting on the net at submission time, when the job is done and the report completed, the server sends back an email message notifying him that the report is ready and available for download.

5 CONCLUSIONS

The construction industry, due to its structure, dynamics and characteristics of its companies and business relationships has been laggard as far as interoperability is concerned.

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The emerging MDA (Model Driven Architecture) paradigm has been evolving and becoming the standard way of handling middleware and infrastructure development for enterprise systems groups. The developments towards greater interoperability has also been supported by the Service Oriented Architecture (SOA), that combines the capacity to invoke remote objects and functions/services with tools for dynamic service discovery.

The paper stresses that construction business systems integration through interoperability are likely to be better attained with the benefits of enhancement of SOA with MDA. This combination provides flexibility and rapid deployment, but maintaining current business processes, and thus enabling a faster adopting of e-platforms by constructions companies.

Conformance and interoperability testing are procedures that should be performed to validate and assure the quality of the global integrated system, as a monitoring procedure or when a new application is plugged in. In advent of the Model Driven and Services Oriented Architecture this would be a major challenge to face.

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Towards Semantic Interoperability in Virtual Organisations

A. Gehre
Institute for Construction Informatics, Technical University of Dresden, Germany

P. Katranuschkov
Institute for Construction Informatics, Technical University of Dresden, Germany

V. Stankovski
Faculty of Civil and Geodetic Engineering, University of Ljubljana, Slovenia

R.J. Scherer
Institute for Construction Informatics, Technical University of Dresden, Germany

ABSTRACT: Virtual organisations (VOs) are amongst the most advanced forms of doing business to date. Their emergence and growing capacities are closely related to the networking and collaboration capabilities provided by a supporting ICT infrastructure. However, whilst considerable progress in the development of such infrastructures has been achieved over the years, interoperability still remains a major challenge.
In this paper we analyse the nature of the semantic interoperability problem, review the state of the art, and derive a set of requirements. On that basis, we propose a novel semantic interoperability framework for VOs, utilising current semantic Web technologies, and suggest possible design and implementation methods for its achievement. Reported is in-house work of the authors as well as on-going research in the frames of the EU project InteliGrid (IST-2004-004664).

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1 THE VO INTEROPERABILITY PROBLEM

Virtual organizations have emerged in the last years as an answer to the changing socio-economic challenges brought about by the globalization process. Today they are quickly becoming a preferred organizational form for one-of-a-kind businesses delivering one-of-a-kind products, such as AEC/FM.

According to (Camarinha-Matos & Afsarmanesh 1999), a virtual organization (VO) is "*a temporary alliance of enterprises that come together to share skills or core competences and resources in order to better respond to business opportunism, and whose co-operation is supported by computer networks*". The Globemen project defines a VO as a *"customer solutions delivery system created by a temporary and reconfigurable ICT enabled aggregation of core competencies"* (Karvonen et al. 2003).

These and other definitions, as e.g. from (Camarinha-Matos et al. 2005), emphasize the importance of ICT for the effective functioning of a VO. Whilst there are many other aspects that distinguish VOs from traditional organisations, such as differences in teamwork, management style, resource utilisation etc., the efficiency of the installed ICT infrastructure is a widely recognised prerequisite for the operability of a VO. In that respect there are two major issues to be considered: (1) appropriate communication networks, and (2) interoperability.

Indeed, interoperability is amongst the most critical issues for the successful development and further growth of the VO paradigm. Connecting computers by fast communication channels is only a preliminary first step. Interoperability targeting efficient information sharing requires to go a step further. According to the *ICH Glossary* interoperability is defined as:

> *"the ability of information systems to operate in conjunction with each other encompassing hardware, communication protocols, applications, and data compatibility layers" (ICH 2004).*

Of these, data compatibility is of greatest importance for the interoperability in VO collaborative networks. It is a prerequisite for establishing a common shared language for interactions between the heterogeneous partners and services in the VO.

The *Dublin Core Metadata Glossary* (Dublin Core 2004) elaborates in more detail the data compatibility layer by defining three sub-layers, namely *syntactical, structural* and *semantic* interoperability:

> "Syntactic *interoperability is achieved by marking up our data in a similar fashion so we can share the data and so that our machines can understand and take the data apart in sensible ways; for example, XML, EAD and MARC.*

Structural *interoperability is achieved through data models for specifying semantic schemas in a way that they can be shared; for example, RDF.*

Semantic *interoperability is achieved through agreements about* content description standards*; for example, Dublin Core, Anglo-American Cataloguing Rules." (Dublin Core 2004)*

However, such content description standards can ensure semantic interoperability only if a domain ontology that suffices a set of basic features is established, in accordance with the following definition based on (Gruber 1993):

"An ontology is a formal, explicit specification of a shared conceptualization."

In this extended form of Gruber's initial definition *formal* means that the ontology should be machine readable (and interpretable), e*xplicit* means that it contains clear, unambiguous, assertive definitions of concept types and constraints modelling the targeted domain of discourse, and *shared* means that it is used to define a common standard in that domain. The term *conceptualization* refers to the objects, concepts and other entities that are presumed to exist in the domain of interest and the relationships that hold them (Genesereth & Nilsson 1987).

While the concept of interoperability is not new for VOs, how it needs to be applied, interpreted and implemented at practical level is subject to continuous controversial discussions, especially because achievement of efficient interoperability is generally seen as a major factor for a number of vital VO features (cf. Barbini 2001):

1 *VOs are subject to market-driven cooperation*. Not the available interoperability channels, but business opportunities determine the dynamic collaborative structure of VOs, i.e. heterogeneity of the consortium is inherent and underpins the requirement of using flexible structures and methods of interoperability, capable of integrating several parallel and oppositional business domains and branches.

2 *VOs are subject to complementarity*. Each VO partner excels in particular subprocesses and/or has critical knowledge about the market. Interoperability has to ensure that technical/technological fertilisation and concertation takes place, i.e. the knowledge and services of each involved partner should be available for effective exploitation.

3 The *dynamic participation of VO partners* requires that organisations can connect into the VO network and disconnect from it in a dynamic way. Therefore, just-in-time information about available services, actors, resources etc. is necessary and that information must be updated regularly.

4 *Process and resource sharing* is a major challenge for VO interoperability. By blurring single enterprise's boundaries, partners can be enabled to work together, integrating business processes and sharing data, information and knowledge resources.

5 There is *no single organisational structure* for all virtual enterprises; rather, the organisational structure and information flows depend on the business to be exploited and on the partner characteristics. This *organisational polymorphism* is another major challenge for the provision of interoperable methods that are generally applicable.

This set of issues advises that methods, services and structural definitions composing the interoperability framework of a VO must be designed as flexible, robust and fault tolerant entities, with special emphasis on maintainability. Current state-of-the-art solutions only tackle the problem from the technology side. Support methods and tools are available that allow to unify the process of accessing interfaces, facilitate finding of services and describe input/output parameters in an automated, machine interpretable way. However, such technical interoperability support ensures only access compatibility and at the most provides for syntactic interoperability. For more flexible management of information and "*meaning*", adequate semantic interoperability has to be established that enables communication on the basis of an elaborated common semantic vocabulary of concepts, i.e. on *ontological level*.

By this:

– Interfaces are freed from the burden of defining specialised functions with fixed input/output parameters that are only applicable for a specific task, i.e. connecting two VO partners or services would be no longer a matter of establishing hardwired communication channels, but becomes a challenge of sharing the meaning of the content;
– The interpretation of communicated content is separated from the communicative act itself, ensuring a maximum of flexibility and robustness for extracting interpretable and necessary information;
– Flexible business process integration becomes possible by establishing an expressive and sound semantic business process model that can then be supported by a coherent business process integration methodology and services.

Figure 1 below illustrates how a common ontology can facilitate integration between semantically heterogeneous tools. Indeed, on the high level, the relationship between terms, models and reality can be represented by the so called *Ogden triangle* (Ogden & Richards 1994). In IT the terms used are symbols that *designate* concepts, e.g. the term "building" designates the concept "building" which *stands for* a real world artefact. The problem is that different tools would typically use different models *related to* that real world artefact, depending on their specific objectives and domains of interest (structural analy-

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sis, HVAC, cost estimation etc.), i.e. for each tool its own Ogden triangle can be drawn. However, by *committing* to a shared set of concepts (the ontology of the VO), they would be capable to 'understand' each other and to communicate about a mutual domain of discourse. It is not necessary that each tool interprets the ontology concepts in the same way, it is only needed that its observable actions are consistent with the definitions in the ontology.

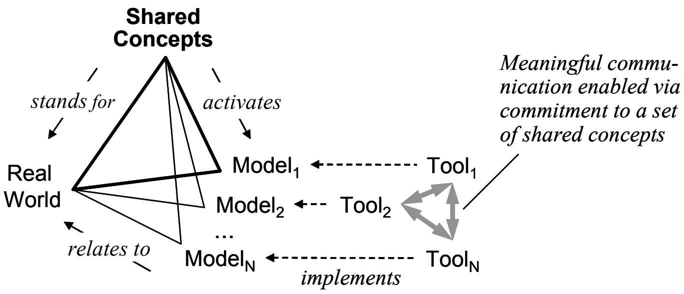

Figure 1. Ogden's triangle revisited. Interoperability between heterogeneous tools is enabled by a common ontology layer.

The price that has to be paid for the benefits of a common ontology layer is the increased development effort regarding complex algorithms for interpreting and formulating the content of interactions. Sustainable development of metadata ontologies and achieving agreement to these is the other challenge to face.

This brief outline of pros and cons shows why a properly elaborated framework for semantic VO interoperability is so important to meet the key requirements arising from the five major VO features mentioned above. Moreover, it provides valuable hints for establishing an appropriate development methodology.

2 STATE OF THE ART IN WEB-BASED SEMANTIC INTEROPERABILITY

The benefits of web-based semantic interoperability and the purpose of ontologies for its achievement are explained in a number of recent publications (cf. e.g. Berners-Lee et al. 2001, Miller 2003, Herman 2004). The hierarchical position of ontology specifications and their inter-realtionship to other specifications related to the World Wide Web is best illustrated by the so called Semantic Web Stack.

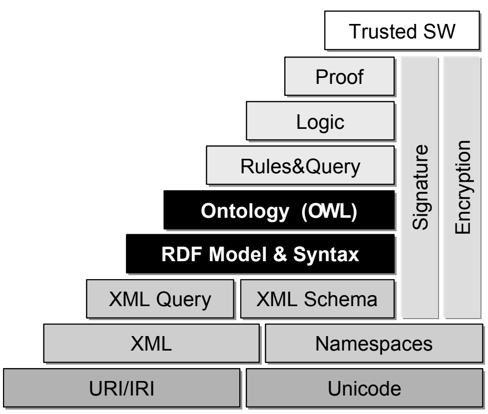

Figure 2. The Semantic Web Stack (after Herman 2004). Ontological layers are highlighted.

Languages

An important prerequisite for achieving semantic interoperability is the ability to make use of rich computer languages, such as the Web Ontology Language OWL (W3C 2004d) allowing to describe the various entities in the computing environment. OWL has been developed recently on top of the existing XML and RDF standards (cf. W3C 2004a, c) which did not appear adequate for achieving efficient semantic interoperability. Thus, although XML DTDs and XML Schemas seem sufficient for exchanging data between parties who have previously agreed to some set of shared definitions, their lack of constructs to describe the deeper meaning of these definitions prevents machines from reliably performing this task. For example, when a new XML vocabulary is introduced, the same term may be used with (sometimes subtle) different meaning in different contexts, and different terms may be used for items that have the same meaning. RDF and RDF Schema (RDFS) address this problem by allowing simple semantics to be associated with identifiers. With RDFS (W3C 2004c), one can define classes that may have multiple subclasses and superclasses, and can define properties, which may have subproperties, domains, and ranges. In this sense, RDFS can be seen as a simple ontology language. However, in order to achieve interoperation between numerous, autonomously developed and managed schemas, richer semantics are needed. For example, RDFS cannot specify that the classes *Person* and *House* are disjoint, or that a construction company has exactly four sub-contractors. In summary, OWL adds more vocabulary for describing properties and classes: among others, relations between classes (e.g. disjointness), cardinality (e.g. "exactly one"), equality, richer typing of properties, characteristics of properties (e.g. symmetry), and enumerated classes. OWL provides three increasingly expressive sublanguages (Lite, DL, Full) designed for use by specific communities of implementers and users.

Web Services

Recent developments in IT have introduced the concept of *Web services*, which are self-contained, self-describing, modular applications that can be published, located, and invoked across the web. Web services perform functions that can be anything from simple requests to complicated business processes. Once a Web service is deployed, other applications (and other Web services) can discover and invoke the deployed service (cf. Vasudevan 2001). There seems to be a consensus that the future of e-business collaboration will be through Web services; so, obviously this is an aspect of interoperability that has to be considered when analysing the needs of future IT infrastructures utilising semantic interoperability.

Although generic in nature, OWL has been designed with the clear intention to support Web

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service discovery – a functionality by which Web services can be described, advertised, and discovered by others. Indeed, with OWL it is especially convenient to describe the characteristics and the functionalities of Web services. An important initiative of W3C in this respect is the Web Ontology Language for Web Services OWL-S, which evolved from its precursor DAML-S (cf. DAML 2004, W3C 2004b). OWL-S is an OWL-based Web service ontology, which gives Web service providers a core set of markup language constructs for describing the properties and capabilities of their Web services in unambiguous, computer-interpretable form. The OWL-S markup of web services aims to facilitate the automation of web service tasks including automated service discovery, execution, interoperation, composition and execution monitoring.

Support Tools and Frameworks

Work on tools and systems using and processing ontologies to achieve semantic interoperability brought about a number of promising developments.

For modelling ontologies with visualization support mainly the *Protégé* ontology editor and knowledge acquisition system is used today (Protégé 2005). It allows users to construct domain ontologies, customize data entry forms, and enter data. It is also a platform which can easily be extended to include graphical components such as graphs and tables, media such as sound, images, video, and various storage formats such as OWL, RDF, XML, and HTML. The Protégé API makes it possible for other applications to use, access, and display knowledge bases created with Protégé.

A full fledged ontology management infrastructure is provided by KAON which is an open-source system targeting business applications (cf. Gabel et al. 2004). It includes a comprehensive tool suite allowing easy ontology creation and management, and provides a framework for building ontology based applications. An important focus of KAON is the scalable and efficient reasoning with ontologies. The KAON system is the public continuation of the semantic web research and development effort that has lead to the commercial tools of the *Ontoprise* company (cf. Ontoprise 2005).

Finally, a number of ontology and metadata frameworks and servers exist, supporting RDF and OWL ontology languages. Very promising are the *Jena* framework (Jena 2005) and the *Kowari Metastore* (Kowari 2004). Jena is specifically suited to develop Java based Semantic Web applications. Among other features, it provides a programmatic environment for RDF, RDFS and OWL, including a rule-based inference engine. Kowari Metastore is an Open Source database for the storage and retrieval of metadata that is held in the form of short *subject-predicate-object* statements.

However, in practice and practice-oriented research there are yet little known efforts fostering ontologies and semantic interoperability. The focus is still mainly on tools and frameworks for general technological ontology support, rather than on practical business-relevant issues. One of the few exceptions in the construction domain is the e-COGNOS project (Lima et al. 2003). It specified and developed an open model-based infrastructure and a set of tools that promote consistent knowledge management within collaborative construction environments. Another valuable contribution has been made by the ISTforCE project which developed tools and applications that use an engineering ontology specification to facilitate end user interfaces and product data model translations (Katranuschkov et al. 2003). Continuing and extending that work, Gehre et al. (2004) suggested an agent-enabled peer-to-peer infrastructure for cross-company teamwork in building construction that uses metadata ontologies for managing distributed resources and teams. However, in spite of such efforts, all achievements are rather fragmentary and of limited practical value. Coherent comprehensive frameworks for VO interoperability are still an open issue.

3 REQUIREMENTS TO A SEMANTIC INTEROPERABILITY FRAMEWORK FOR VO

Support of VO interoperability by a semantic framework encompassing semantic services and ontologies offers good prospects, but it is also subject to a series of non-functional requirements that have to be carefully considered when realising it in practice.

Reactivity / Response times

Interoperability and interactions in general that involve ontology-based semantics tend to be highly resource and time consuming. Therefore, a major non-functional requirement is to ensure reasonable system response times. Whilst longer response times (10 seconds or longer) are acceptable for sophisticated ontology-based directory services, background services (e.g. responsible for translating ontology-based interactions into direct actions) ought to be much faster (less than 1 second) to achieve end-user acceptance.

Usability

Usability is a major requirement for end-user interface facilities that are upgraded by ontological features. It pertains to the level of training required to achieve a goal with the application, to which extend its use is intuitive, and the balance between efforts and benefits of usage.

Maintainability

For larger and longer lasting VO projects, the initially developed project specific ontology definitions will typically not be final in every respect. Therefore, the framework for ontology-based VO inter-

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operability must enable flexible tackling of changes and extensions by means of adequate ontology management tools.

Compatibility with industry standards

As interoperability is one of the main success factors for VOs, support by ontological semantics has to follow available standards to the greatest possible extend. End users need reliability in API definitions, relying on standards fosters end-user acceptance.

Installability / Executability

VOs typically use heterogeneous IT infrastructures. Therefore, installability and executability are major concerns with regard to middleware technology. All tools and services that are needed to provide semantic interoperability with local applications have to be installable and executable at each VO partner.

Scalability

Ontology frameworks tend to have problems with larger ontology definitions and higher inherent complexity. Therefore, robustness of an ontology based VO interoperability framework is very important with regard to larger amounts of data. Consequently, the requirement for scalability introduces the need for less complex ontology definitions, which is contradictory to the needs for comprehensiveness and completeness.

Upgradeability

This requirement is specifically related to the need to upgrade/update ontology definitions at runtime. Automated schema generators translating ontology definitions to programming language classes can greatly help in meeting this requirement.

4 SERVICES FOR ACHIEVING SEMANTIC INTEROPERABILITY

Efficient semantic interoperability in a VO environment targets several operational objectives:

– By using semantic interactions between heterogeneous software of VO actors the established message based communication must create a desirable *loosely coupled system*;
– Semantic interoperability must provide advanced metadata support services enabling *management of decentralised heterogeneous information*;
– Coherent support for business process integration, a key enabler for modern IT supported VO businesses, should be provided by *dedicated ontology services*; such services can help in ad-hoc modelling, handling and processing of business processes thereby *fostering B2B integration*.

Especially for achieving the third of the above goals, the five principle life cycle phases of a business process must be taken into account (cf. Foss 1998):

1 Identification of a process prototype or, if necessary, ad-hoc definition of a new one;
2 Identification and procurement of information and services needed to perform the process, including e-payment;
3 Integration of all process input into a suitable processing workflow to perform the business process;
4 Performing the business process;
5 Disassembling of process components when the process is finally completed.

Except for the step of performing the process itself (step 4), each of these lifecycle phases can significantly benefit from the support of advanced ontology services. Whilst many useful ontology services can be envisaged directly from that life cycle, we identify four particular types as essential for achieving business process integration support. Three of these are dedicated to general VO business tasks, whereas the fourth stands for a (potentially unlimited) set of domain specific ontology services.

4.1 *General VO Ontology Services*

Harmonised management and integration of information and services is needed to establish support for business process integration. This includes the management of information directly related to the structure of and information logistics within the VO. Three essential General VO Ontology Services can be identified for that target.

VO Logistics Service

This ontology service has to provide information about general VO entities, such as actors, roles, persons, organizations, organizational structures and principal legal constraints of the VO. Even though VOs can be subject to organisational changes during their lifetime, information provided by this service is more static. It is defined at the initialization stage of the VO and only updated if something changes in the VO structure. This support service provides necessary input for the other services listed below.

Resource Sharing Service

Distributed resources in a VO network, i.e. services and information contained in databases and files, are typically heterogeneous with regard to type, structure, syntax, access directives, specifics of the owning local network and available metadata support. In order to exploit all available resources in a VO network coherently, a common resource sharing service that unifies the resource access and resource metadata services is needed. Essential prerequisite for the achievement of such a service is the commitment to (1) a formal explicit ontology defining resource metadata concepts, and (2) a superordinate ontology describing basic structural VO concepts. Using these ontologies the Resource Sharing Service can provide

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the necessary functionality to achieve resource integration in business processes. Thus, it directly supports the business process life cycle phase 2.

Resource Integration Service

Performing business processes that are based on distributed resources requires an integration approach. This can be fulfilled by a formal Resource Integration Service that provides information about what kinds of resources are put together and how in order to compose the business process. Using the Resource Sharing Service outlined above, the Resource Integration Service describes the information flows that establish the business process, i.e. what information resources are input for which service resource, and how these services are composed in order to establish the business process. Thus, it supports the business process life cycle phases 1, 2, and in particular 3.

4.2 *Domain Specific Ontology Services*

Along with the general VO services it is important to provide a spectrum of dedicated Domain Specific Ontology Services. Tightly associated with the specific business domain(s) of the VO, such services target VO support through domain specific functionality. This may include model extraction, translation and mapping, as well as specialised domain specific methods.

An especially important semantic service that is domain specific by nature but at the same time generic within its business domain, is the service for *information retrieval*. Its purpose is to extract information from structured documents, databases and product models through proprietary interfaces and then provide the extracted information through a shareable "condensed" ontological model. This service plays a core role for the achievement of efficient semantic interoperability. It may be augmented by services for automated model mappings to facilitate VO interoperability on model level. As a whole, these services provide domain specific support to the business process life cycle phases 2 and 3.

As an example in the construction domain, such services can be used to extract information from server-based IFC Product Models (IAI 2005), with subsequent mapping to a condensed ontological representation. This representation can then serve as a metadata repository, as well as a data pool for applications and users that are only interested in specific model aspects. The objective is to capture and describe an activity in a process on general "business object" level, using terms like "storey", "room", "wall" and messages like "calculate thermal resistance" or "show all rooms with office usage", rather than technical low-level model objects like *IfcSpace*, *IfcWall*, *IfcLocalPlacement*, *IfcCartesianPoint* etc. The concepts of this higher level ontological representation should act as logical containers for the data and the respective operations needed to carry out the required activity. Responsibility how exactly this activity is performed is at the respective domain tools and/or the user. More information to that is provided in the InteliGrid report D13.1 (Turk et al. 2004).

5 CONSENSUAL ONTOLOGIES

A consensual ontology is an ontology that is developed for the purpose of information and knowledge sharing in a certain domain and to which all players (and tools) in the VO acting in that domain have agreed to commit. Consensual ontologies are a prerequisite for semantic interoperability as they establish the common shared language that is the foundation of all ontology services interactions. Accordingly, commitment to existing ontology standards is an important issue. This applies to commitment to ontology language standards (e.g. OWL), as well as to existing consensual ontologies, e.g. the web services ontology defined as OWL-S.

A major design consideration in ontology development is that a structured system of interconnected specialised ontologies utilising Semantic Web technology is much more effective with regard to defining, maintaining, interweaving and processing them, than deploying a huge and complex single ontology. The semantic web ontology language OWL provides advanced mechanisms for referencing and integrating ontology entities of separate definitions. It thereby offers the needed flexibility for constructing powerful systems of hierarchical interrelated ontologies.

The two types of ontology services defined in the preceding chapter prompt for a hierarchical ontology structure comprising two systems of ontology definitions. The first describes generally applicable VO business constructs, and the second focuses on domain specific business processes. However, seamless support for business process integration can only be ensured if both these systems are coherently defined and elaborated to a granularity that allows to specify business processes in uniform, ad-hoc manner. For real practice scenarios this is a highly challenging design requirement.

VO Business and Environment Ontology

This generic part of the ontology definitions for semantic interoperability in VOs consists of an extensible core set of concepts targeting specific VO interoperability tasks. It establishes the underlying common language for the VO Logistics, Resource Sharing and Resource Integration Services. It captures information about general VO entities, ranging from actors and other VO structural concepts to administrative information and service resources within the VO. Service aggregation mechanisms, e.g. based on the established OWL-S standard, provide concepts for ontology supported automated integration of complex business processes.

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Specialised Ontologies for the VO domain

Specialised ontologies for dedicated business processes of the VO are the basis for all Domain Specific Ontology Services. They integrate and build on the generic part of the ontology definitions. As currently relevant targets are seen in first place model mapping and extraction, as key enablers for achieving B2B integration.

Regarding the building construction domain, an OWL-IFC ontology can provide for model interoperability based on a subset of the IFC standard (IAI 2005), extended by ontology specific concepts and rules. Such OWL-IFC information can be created directly by qualified ontology-enabled applications, or extracted from IFC product model servers by a dedicated Construction Domain Ontology Service. It can greatly facilitate upgrading the IFC Project Model to a true Semantic Web ontology resource of real practical relevance.

6 SUGGESTED REFERENCE ARCHITECTURE FOR ONTOLOGY SERVICES

A generalised *Ontology Service System* comprises a set of self-sustained semantic services that can be structured into a layered architecture as suggested in Figure 3 below. Information flow with business services/applications and middleware services that provide dedicated resource access is only roughly represented on this figure, in order to focus on the structure of the ontology services itself.

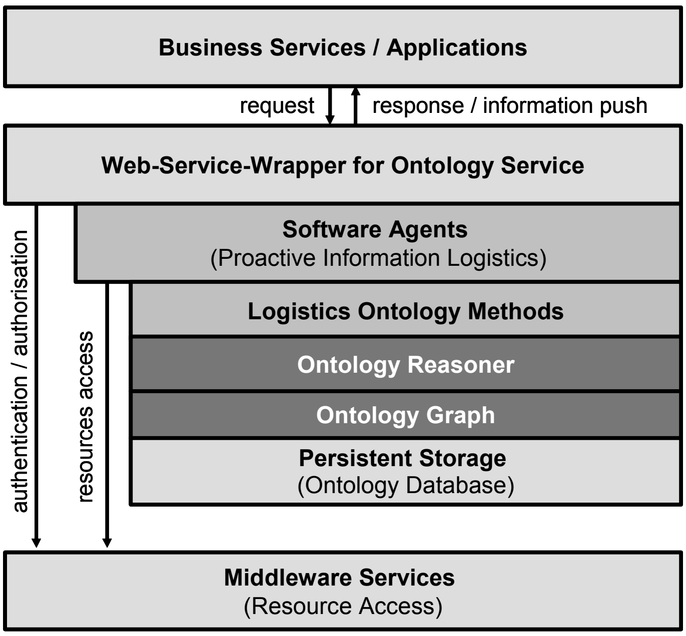

Figure 3. Suggested Architecture for a Web-Enabled Ontology Services System.

Following the modern philosophy of a Service Oriented Architecture (SoA), common access to the Ontology Service System is provided through a *Web Service Interface*, so that the ontology service is pervasive and platform neutral. In accordance to that, a *Web-Service-Wrapper* has to map HTTP-based SOAP interactions to the internal service infrastructure. Such interactions include: (1) client authorisation requests to external central authentication authorities, (2) resource access to middleware services, (3) response to requests from business services and applications, and (4) possible proactive information push to web entities that have registered to the recurrently provided service.

As essential central component of the Ontology Service System we suggest to use *software agent technology* for coordination and cooperation processes. This has several advantages (cf. Reitbauer 2005):

– use of components that are more closer to reality and provide improved level of abstraction;
– flexibility in modelling coordination behaviour, i.e. modelling ontology-based management processes as encapsulated agent behaviours, thereby ensuring extensibility of the service (especially with regard to domain specific services);
– enabling more efficient runtime reactivity with regard to dynamic events with the help of rules for ad-hoc composition of agent behaviours;
– utilisation of cyclic behaviours to automatically maintain the information pool of the Ontology Service System;
– capability to proactively initiate an *information push* to registered entities in the VO environment; such an information push can be initiated e.g. by cyclic agent behaviours (time intervals), by triggers fired by rules specified in the ontology, or as a result of some planning activities.

Underlying the software agents layer, an *ontology graph and related reasoning facilities* provide object-oriented access to the ontology. This allows for structured ontology management on model and entity level. Access on entity level is provided by the ontology graph via specialised access methods. Based on the ontology graph, a *reasoner engine* enables the derivation of additional assertions entailed from the model, together with any optional ontology information and the axioms and rules associated with the reasoner. The primary use of this mechanism is to support the inference process of deriving additional facts from instance data and class descriptions. A reference implementation for such an ontology framework is the *Jena* framework for building Semantic Web applications (Jena 2005).

Finally, the Ontology Service System must also incorporate persistent storage for ontology data and models by using a back-end database engine integrated through the ontology layer. Jena provides for that purpose an abstract Java interface for ontology database model management.

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7 CONCLUSIONS AND FURTHER WORK

The presented ontology-based approach for tackling VO interoperability generalises early high-level conceptual development work done by the authors in the frames of the EU project InteliGrid. This work builds upon experience gathered from related in-house implementations and studies, as well as on findings from the earlier EU projects ISTforCE and e-COGNOS.

At this stage, several opportunities of the suggested approach can already be drawn up:

1. It enables management of various types of distributed information resources in uniform manner;
2. It promotes integration on the basis of a common language that describes VO concepts and inherent dependencies in a flexible way;
3. It can help to extend product data technology use beyond its current scope of application (mainly CAD);
4. Last but not least, much of the outlined concepts and services are generic and therefore applicable in various domains.

The approach is extensible regarding further intelligent ontology services, due to the coherent integration of software agents and ontological reasoning. Potential candidates for extensions are triggers based on VO events, automated business object processing, and advanced automated notification services. More detailed capabilities and options are expected to emerge in the progress of the work.

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Automated classification of A/E/C web content

R. Amor & K. Xu
Department of Computer Science, University of Auckland, Auckland, New Zealand

ABSTRACT: The amount of useful information available on the web for A/E/C professionals increases inexorably. Numerous search engines allow users to identify potentially useful information in this vast resource, though the majority of these systems work purely on the search terms entered by the user. This means that the web pages which are found are often not as relevant to the user's needs as would be expected. What is returned is certainly far from the promise of the semantic web where the properties of the content can be readily ascertained. To help address this issue the authors adapt the Latent Semantic Indexing algorithm to enable web pages and sites to be automatically matched to codes in a classification system. This paper discusses the issues involved in developing such a system for A/E/C as well as measuring the results in comparison to the general search engines currently available to professionals.

1 INTRODUCTION

In this paper the adaptation of a standard information retrieval technique, namely latent semantic indexing, is examined for a domain specific search engine. The premise behind this approach is that it is possible to accurately identify classification codes related to the content of the web page or web site. If content can be accurately classified then a user searching for content in a particular area (e.g. by specifying a classification code) will be presented only with highly relevant web information.

The reason that we attempt to classify to a standard classification code is that these are used and understood by the vast majority of professionals within the A/E/C industries. Because a classification code has a well described scope it is likely to be understood similarly by professionals from many disciplines. Therefore, a system that can accurately retrieve information associated with a classification code is one which can be tied to many processes within the A/E/C profession where information is associated with these codes.

This paper describes the ongoing development of the LSI-based search engine. It concentrates particularly on the testing of the resultant search engine in terms of the precision of the classification of construction industry web pages to a construction industry classification system (by comparison with an expert's determination of correct classifications). It also provides an analysis of the developed search engine's search result accuracy by comparison with the results returned by other major search engines in current use (e.g. Google and Yahoo) on the same query formulation.

1.1 Previous work

The field of information retrieval has grown rapidly since the 1940's (Chu 2003), though the majority of the useful approaches to retrieval were developed in the early years of the field. With the birth of the Internet information retrieval has gained further prominence and the major search engines (e.g. Google and Yahoo) are used by a large percentage of people in the western world. Though there are large search engines which are used frequently by those in business they are usually based on fairly simple retrieval algorithms (to achieve their speed requirements) and by serving all domains for all people will often throw up irrelevant results to any specific query.

Domain specific search engines are being investigated and in the A/E/C industry there have been previous approaches to establishing such search systems. In the EU-funded CONNET project the Signposts system was developed (Signposts 2000, Turk & Amor 2000) based on Boolean search of keywords, though utilizing web page structure to help rank results. Further developments of this system utilized the HITS algorithm and mappings from pre-classified web page repositories (Chen & Amor 2002) to help improve the precision of returned web pages. However, none of these systems were signifi-

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cantly better than the commercial search engines of that time.

Research has also been undertaken to classify research papers within the A/E/C field through automated means (Turk & Cerovšek 2003), though again the authors report discrepancies in the results returned by the automated process.

1.2 Latent Semantic Indexing

To allow web content to be classified more accurately the LSI (Latent Semantic Indexing) algorithm (Deerwester et al. 1990) has been examined. This algorithm looks at all the words in a document which are relevant to the domain, and uses counts of these relevant words to help determine similarity to another item (which may be a search term, or another document).

The basic idea behind the algorithm is that a set of keywords (and their synonyms) is selected to cover all the required concepts in a domain. The words and phrases in each web page, or web site, are then indexed against every one of the previously selected keywords. If a matrix column, representing a web page or site, is then compared against a similar matrix which has been computed for all of the terms in a classification system then it is possible to identify classification codes which are most closely related to a particular web page or site (by calculating the cosine of the angle between the two vectors that comprise these matrix columns).

Therefore, as web pages are gathered from the Internet they are compared to the matrix representing a particular classification system and for each classification code a similarity measure is assigned. When a user of the search engine requests information, by specifying a classification code, the system can then return a ranked list of web pages and sites which are determined to be the most close to that code. If a user searches by specifying keywords and phrases the LSI algorithm can be applied to their search term to identify the most relevant classification codes, and then identify the most relevant web pages or web sites.

2 SEARCH ENGINE APPROACH

To test the applicability of LSI for classification of web content for A/E/C it was necessary to establish domain specific terms and vocabularies to drive the LSI algorithm. This section describes where this information was derived from and how it was applied for our search engine.

2.1 A/E/C terms

A success factor for the LSI algorithm is the choice of suitable domain specific terms which cover all concepts in the area in which information is to be retrieved. For the A/E/C domain there are very few digital resources which profess to cover the vocabulary of the professions. However, the LexiCon (Woestenenk 2002) has been developed over many years to try and capture terms used in construction, and the relationships between them, based on the wide variety of construction specific classification systems in use across the world.

The LexiCon database was used as the seed for the set of terms required for the LSI algorithm. Mining the LexiCon database provided over 15,000 terms covering the whole A/E/C domain. However, not all terms were unique, as some represented synonyms of other terms in the system. To enable similar concepts to be captured as a single term in the LSI algorithm each of the LexiCon terms was expanded with known synonyms and each of these sets of terms were treated as a single concept. As part of this thesaurus expansion the terms were stemmed to reduce the susceptibility of the system to problems of singular, plural, and other forms that terms commonly take in natural language text.

2.2 A/E/C classification system

This search engine has been developed to allow the use of the developers preferred classification system. However, as each web page is classified against all terms in the classification system there is quite a cost to introducing a new classification system into the search engine. As this search engine is developed to serve an audience of New Zealand's A/E/C professionals the standard classification system for the country was utilized.

The CBI (1999, Coordinated Building Information) has over 1000 classification codes in a four level decimal classification structure. The CBI classification system provides a textual description for each of the codes and it is this piece of text, along with the title of each code, which is used to populate the term matrix derived from LexiCon.

While the descriptive text associated with each code is not extensive (usually about a paragraph) it does provide the system with a much larger set of words than a plain code title with which to populate the term matrix as required in LSI.

2.3 Populating the page repository

To provide a source set of web pages to examine the system's performance, just over 14,000 web pages were gathered drawn from an existing database of web sites know to be relevant to A/E/C in New Zealand (Chen & Amor 2002). In this search engine a conscious decision was made to distinguish between web sites and web pages. A web site comprises all web pages found below a particular URL. For example where http://www.sopers.co.nz/ is identified

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as the entry point for a web site, all web pages identified by links from this page, but still part of the Sopers domain, are tagged as part of this web site.

With this distinction in place a user can retrieve web information either at the specific web page level for detailed and closely matching information related to their search, or at the web site level, which is closer to a view of the company associated with information on the particular search area.

2.4 *A user interface*

A user of the search engine is provided with two methods of searching the repository, either through the classification system, or by keyword search.

2.4.1 *Classification-based search*

A user can search by providing a known CBI code (e.g. 38-3 for Timber floors, stairs and covers) or by navigating the tree representing the CBI classification system to identify a code they wish to utilize.

Once a code is specified the web page and web site indexes are utilized to identify pages and sites most closely associated with that code. Results of the search are presented to the user in a ranked order as shown in Figure 1.

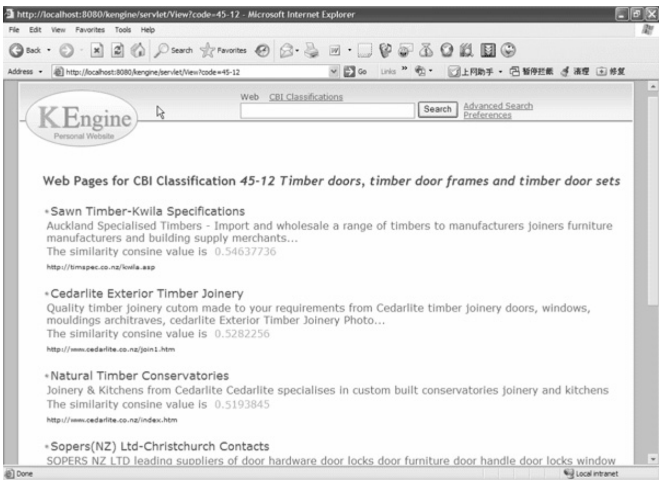

Figure 1. Result screen from classification code search.

2.4.2 *Keyword-based search*

A user can also search by providing a set of keywords. In this mode the search process has two steps. In the first step the user's keywords are matched to the CBI classification system. This is achieved by using the LSI algorithm to determine from the set of CBI codes which is closest to the entered keywords. The resultant list of ranked CBI codes is proffered to the user for them to select their desired code, or to navigate the CBI classification hierarchy from one of those codes to identify their preferred code. Once the code is identified the search proceeds as for the classification-based search.

3 RELEVANCE OF RESULTS

Determining the accuracy of this new search engine proves difficult. In the information retrieval domain there are measures to be used for this task (Chu 2003), however, many of these measures (e.g. recall) require knowledge of the set of relevant information items which were not retrieved. As can be imagined, with any collection of useful size, this figure is almost impossible to ascertain (it would require every web page to be hand classified).

3.1 *A measure of precision*

For the analysis of this system we have chosen to use precision as out main measure of accuracy. Precision is a measure of the ratio of relevant documents retrieved versus the total number of retrieved documents. For our testing we have further restricted this by analyzing the relevance of the first twenty documents which are retrieved by search engines.

3.2 *The testing framework*

Our test suite comprises a set of twenty CBI classification codes. Ten of these codes represent more general topics in the CBI system (i.e. those at level two in the classification system) and the other ten represent more specific topics in the CBI system (i.e. those at level three in the classification system).

Testing against a search engine proceeded by examining the top twenty results returned by the search engine. Each of these results was hand classified as 'relevant' or 'not relevant' to the particular classification code. To perform our calculation of the precision we also recorded the total number of pages returned (as this can be less than twenty).

Searches were carried out against the new LSI-based search engine as well as through Google and Yahoo, both of which can be restricted to New Zealand sites.

3.3 *Test results for the new search engine*

For the new search engine this test was run both for web pages and web sites to determine what affect the larger set of information (i.e. web site) had on the accuracy of the returned results. Results from web sites and pages are shown in Figure 2.

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Query topics	KEngine Web sites			KEngine Web pages		
	Related/20	Total	Relevance	Related/20	Total	Relevance
Demolition (21)	2	7	0.29	9	10	0.90
Masonry (33)	3	4	0.75	5	9	0.56
Timber (38)	15	58	0.75	19	1287	0.95
Doors, windows and roof lights (45)	14	71	0.70	17	401	0.85
Glazing (46)	15	32	0.75	16	75	0.80
Ceilings (53)	8	9	0.89	10	73	0.50
Carpeting (65)	9	21	0.45	11	208	0.55
Pools (84)	7	12	0.58	13	101	0.65
Concrete (31)	6	6	1.00	14	64	0.70
Ventilation and air-conditioning (76)	17	45	0.85	18	156	0.90
Natural energy (75-2)	6	7	0.86	11	201	0.55
Fencing and walling (83-3)	7	13	0.54	12	124	0.60
Space heating steam and hot water (75-4)	5	11	0.45	7	101	0.35
Aluminium doors, windows, and roof lights (45-2)	3	14	0.21	7	34	0.35
Thermal insulation (47-1)	2	3	0.67	18	23	0.90
Trowelledand sprayed coatings (61-1)	1	5	0.20	6	14	0.43
Timber floors, stairs and covers (38-3)	7	13	0.54	18	42	0.90
Exhaust systems (76-1)	1	3	0.33	4	10	0.40
Monitoring systems (78-5)	1	2	0.50	2	4	0.50
Pools, spas, saunas, and showers (84-1)	4	5	0.80	19	47	0.95
		Average relevance	0.61			0.66
		Average relevance (general topics)	0.70			0.74
		Average relevance (specific topics)	0.51			0.59

Figure 2. Precision of results for web sites and pages

As will be noted from these results there is a significant level of variability in the precision of the searches. Of great interest is the fact that the precision is higher for general classification codes than it is for specific classification codes. This result was unexpected as the fact that a more specific vocabulary is used for specific classifications had suggested that this would lead to a better match than over more general terms. There is also a slight difference (0.61 versus 0.66) between the precision of retrieval of web sites versus web pages. This is less surprising as many web sites (i.e. companies) deal with many products and services and hence have a wider spread of terms to represent their complete site.

3.4 *Test results for Google and Yahoo*

To perform the same test in Google (2005) and Yahoo (2005) we accessed the country specific versions of these search engines (i.e. restricting the search to New Zealand web pages). Formulating equivalent queries for each classification code is of course not possible as the three search engines use very different search algorithms. The approach undertaken for this project was to use the classification code titles as the search term for both Google and Yahoo (e.g. Timber floors stairs and covers). In both cases there was no enforced grouping or sequencing of the words in the terms, though in some cases this would improve the results (e.g. 'air conditioning' as a sequence of words rather than 'air' and 'conditioning' as separate search terms). Results for Google and Yahoo are shown in Figure 3.

These results show the same trends as in the LSI-based search engine. Google appears to offer slightly higher precision than Yahoo, especially in the specific topics. In relation to the LSI-based search engine these results are remarkably similar, practically equivalent within the margins of error.

4 CONCLUSIONS AND FUTURE WORK

In this project a new search engine was developed specifically for the A/E/C profession within New Zealand. The aim of this system was to allow searches based on the standard classification system (CBI) utilized in New Zealand. To this extent the project is successful, allowing a user to search for web sites and web pages directly from a CBI classification code.

However, to be useful to the A/E/C profession in New Zealand the search engine should perform more accurately than the alternatives that people commonly use. The LSI-based search engine has been tested against two of the most popular general search engines (Google and Yahoo) and disappointingly it is found that the precision of the results returned by the new system is no different from that of other more generic search engines. Though these generic search engines do not allow searches purely on classification code (however the mapping to a search term is trivial).

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Query topics	Google			Yahoo		
	Web pages			Web pages		
	Related/20	Total	Relevance	Related/20	Total	Relevance
Demolition (21)	15	4020	0.75	13	2820	0.65
Masonry (33)	18	2760	0.90	15	4950	0.75
Timber (38)	18	22100	0.90	17	16100	0.85
Doors, windows and roof lights (45)	11	108000	0.55	14	117000	0.70
Glazing (46)	14	2180	0.70	16	2840	0.80
Ceilings (53)	19	2640	0.95	15	2950	0.75
Carpeting (65)	10	423	0.50	11	654	0.55
Pools (84)	6	18200	0.30	8	23200	0.40
Concrete (31)	15	21000	0.75	14	21800	0.70
Ventilation and air-conditioning (76)	18	15100	0.90	18	13600	0.90
Natural energy (75-2)	12	169	0.60	10	115	0.50
Fencing and walling (83-3)	7	8250	0.35	8	7640	0.40
Space heating steam and hot water (75-4)	17	342	0.85	12	561	0.60
Aluminium doors, windows, and roof lights (45-2)	19	3010	0.95	18	2990	0.90
Thermal insulation (47-1)	19	643	0.95	16	678	0.80
Trowelledand sprayed coatings (61-1)	3	3	1.00	5	11	0.45
Timber floors, stairs and covers (38-3)	16	3050	0.80	11	654	0.55
Exhaust systems (76-1)	3	367	0.15	2	423	0.10
Monitoring systems (78-5)	6	1390	0.30	8	1250	0.40
Pools, spas, saunas, and showers (84-1)	7	25700	0.35	12	17865	0.60
		Average relevance	0.68			0.62
		Average relevance (general topics)	0.72			0.71
		Average relevance (specific topics)	0.63			0.53

Figure 3. Precision measures for Google and Yahoo

All may not be lost however, the work presented to date is based on a very simple analysis of results and a more detailed analysis should be undertaken. Specifically a three or five point scale should be employed to mark the relevance of retrieved web pages, which is likely to paint a very different picture of the precision of each system.

It is also likely that amalgamating other retrieval techniques with LSI results (e.g. Boolean search terms based on a user query) will provide a more precise set of results for the user to work with.

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Woestenenk, K. 2002. The LexiCon: structuring semantics, *Proceedings of CIB W78 conference on Distributing Knowledge in Building, Aarhus, Denmark, 12-14 June*, 2, 241-247.

Yahoo 2005. http://au.yahoo.com/, last accessed April 2005.

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Context Aware Information Delivery for On-Site Construction Operations

Z. Aziz, C.J. Anumba, D. Ruikar, P.M. Carrillo & N.M. Bouchlaghem
Centre for Innovative & Collaborative Engineering, Department of Civil and Building Engineering, Loughborough University, Leics, UK

ABSTRACT: The information intensive nature of construction projects requires the site personnel to have an on-demand access to project information. Current information delivery methods are primarily static and do not take into account the site personnel's changing context. Delivering information to site staff, based on their context (such as location, time and profile) has the tremendous potential to improve construction productivity. In this paper a prototype application for context-aware information delivery is discussed. The implementation is based on a Pocket-PC platform and makes use of wireless local area networking (WLAN) to capture context parameters. A semantics-based Resource Description Framework Schema (RDFS) is used for both context interpretation and to define construction documents and project task structure. Conclusions are drawn about the possible future impact of context-aware applications for the construction industry.

1 INTRODUCTION

The construction industry is experiencing unprecedented change and dynamic conditions resulting from clients demanding better value-for-money, higher quality, shorter cycle times and access to the latest information, produced at any point in the project life cycle and supply chain. This demand reflects the increasingly competitive pressure to deliver faster and cheaper solutions. Current thinking within the industry is that major benefits can be obtained through improved collaboration and enhanced enterprise efficiency. A fundamental underpinning to achieve these goals is construction field force enablement, by ensuring optimal support for onsite staff.

The information-intensive nature of construction projects requires the site staff to have on-demand access to construction project plans, drawings, schedules, budgets, etc. The unstructured and dynamic nature of the construction site, and the hazards and difficulties presented by the on-site work, also necessitate the use of intelligent ways to support on-site construction staff.

In recent years, the emergence of powerful wireless web technologies coupled with the availability of improved bandwidth, has enabled mobile workers to access in real time different corporate back-end systems and multiple inter-enterprise data resources to enhance construction collaboration. Context-aware information delivery adds an additional layer on top of such real time wireless connectivity, by providing the ability to intelligently interpret the user context, and delivering data and services to the mobile worker based on the user's context. This way, it is possible to eliminate distractions for mobile workers, related to the volume and level of information. Also, user interaction with the system can be reduced by using context as a filtering mechanism to deliver only context-relevant information to users. This has the potential to increase usability, by decreasing the level of interaction required between the mobile devices and the end-users. The emergence of complementary technologies such as user profiling, ubiquitous computing and sensor networking enables the capture of many other context parameters.

This paper presents a scalable architecture and a prototype implementation for a context-based information delivery system for supporting construction site staff. The paper is organised as follows. The next section reviews the concept of context-aware computing and related work. Section 3 discusses the system architecture for context-aware data delivery, and is followed by presentation of the prototype system. Section 5 presents the future outlook and summary.

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2 CONTEXT-AWARE COMPUTING

Context-aware computing is defined by Burrell et al (2001) as the use of environmental characteristics such as the user's location, time, identity, profile and activity to inform the computing device so that it may provide information to the user that is relevant to the current context. Context-aware computing enables a mobile application to leverage knowledge about various context parameters such as who the user is, what the user is doing, where the user is and what terminal the user is using. The application adapts services to the interpreted context, thereby ensuring that the busy user gets highly specific data and services (Schilit et al., 1994). Pashtan (2005) described four key partitions of context parameters, including user static context, user dynamic context, network connectivity and environmental context (Figure 1).

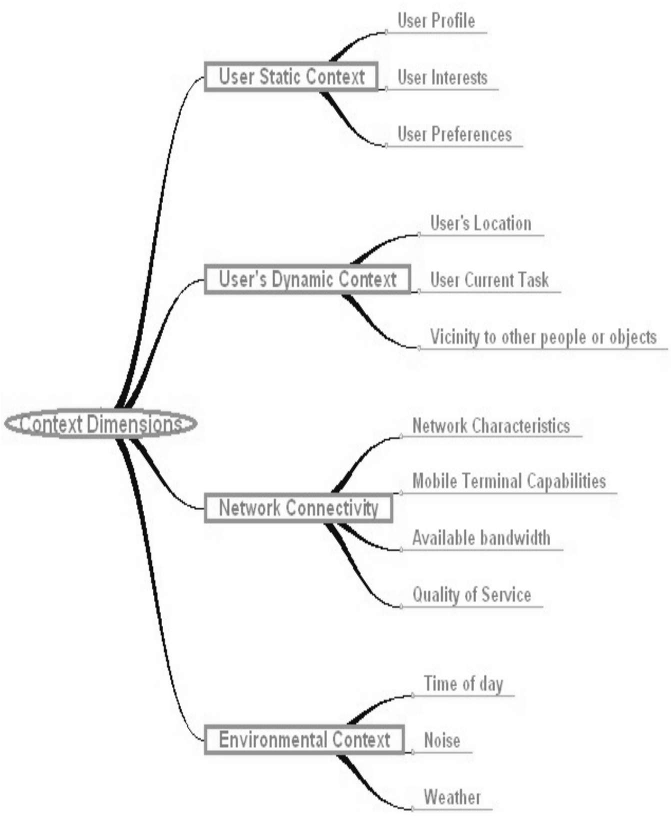

Figure 1. Context Dimensions

2.1 *Related Work*

The application of context-awareness for mobile users has been demonstrated in a large number of applications, including fieldwork (Kortuem et al., 1999; Pascoe et al., 1998), museums (Fleck et al., 02; Lassila et al., 2003), route planning (Marmasse et al., 2002), libraries (Aittola et al., 03) and tourism (Long et al., 1996; Laukkanen et al., 2002). Other projects that have specifically focused on location-based data delivery include the GUIDE project (Davies et al., 99) and the Mobile Shadow Project (MSP) (Fischmeister et al. 2002). The MSP approach is based on the use of agents, to map the physical context to the virtual context. Ambience project (Ambience, 2004) has adopted a different approach by focusing on creating a digital environment that is aware of persons' presence, context, and sensitivity and responds accordingly. Context-aware applications are also being investigated by other fields of research in computer science, including mobile computing, wearable computing, augmented reality, ubiquitous computing and human-computer interaction.

There is also a great deal of interest in the application of Semantic Web technologies in context aware applications. The Semantic Web technologies provide a framework for shared definition of context, resources and their relationships. It also provides an application and platform independent way to interpret context, thereby enabling both humans and software agents to infer new context knowledge and consequently take intelligent actions. In the Konti Project, an ontology is developed for expressing the properties required for constructing contextual profiles (Toivonen et al., 2003). Chen et al (2003) also applied the Semantic Web technologies for modeling context and for supporting context reasoning.

3 CONTEXT AWARE SERVICE DELIVERY ARCHITECTURE

The concept of "context-aware information delivery" as discussed in this paper centres on the need to provide mobile construction workers highly specific information and services on an as-needed basis. This concept goes beyond merely capturing user context. It encompasses the creation of a pervasive, user centred mobile work environment, which has the ability to deliver relevant information to the workers by intelligent interpretation of their context so that they can take more informed decisions. Figure 2 presents a system architecture for context aware information delivery. It is based on multiple tiers which are explained below:

3.1 *The Client Tier*

The Client tier provides users with access to the system. It also facilitates context capture. It includes WLAN-enabled devices and WLAN tags, which contain information about the objects they are attached to.

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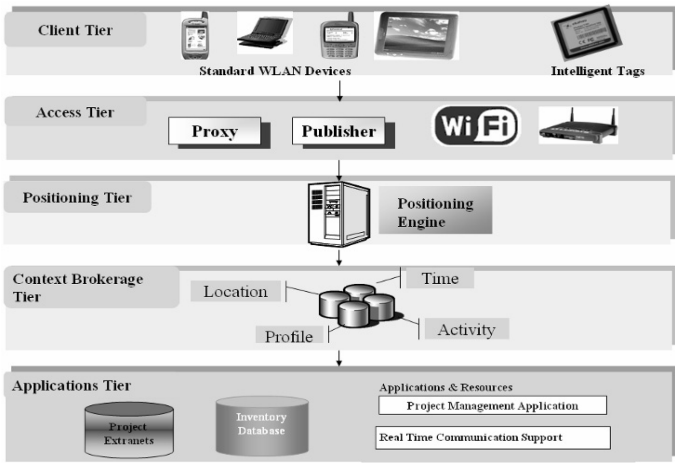

Figure 2. Context Aware Services Delivery Architecture

3.2 *The Access Tier*

This provides the vital communication link between the wired back-end and the wireless front-end, using a WLAN-based infrastructure. The proposed architecture relies entirely on standard Internet technologies (e.g. IP addressing, HTTP). This ensures that any IP-based wireless technology can possibly be used. Key components in the access tier include a proxy and a publisher. The proxy server keeps a cache of active user sessions and the most accessed services. This eliminates unnecessary traffic over the wireless network. The publisher handles device detection and content update based on the changing user context. The access tier supports both push and pull modes of interaction (i.e. information can be pushed to the user while the user can also proactively access the relevant information.

3.3 *The Positioning Tier*

The positioning tier tracks all mobile devices and tags in a wireless domain and determines their current location, by displaying coordinates corresponding to device/tag current location on a map. Tags contain important information about the object they are attached to.

3.4 *The Context Broker*

The context broker acquires context information, applies semantics-based reasoning to the captured contextual information and determines information relevant to users based on their existing context.

3.5 *The Application Tier*

It contains construction applications and services, to support mobile workers. As logic and data processing resides on the wired network, the mobile client is charged with minimal memory and processor-consuming tasks.

4 CONTEXT BROKERAGE AND MAPPING

Five context dimensions are addressed in this research, including Location, Time, User Device, User Profile and User Activity (Figure 3).

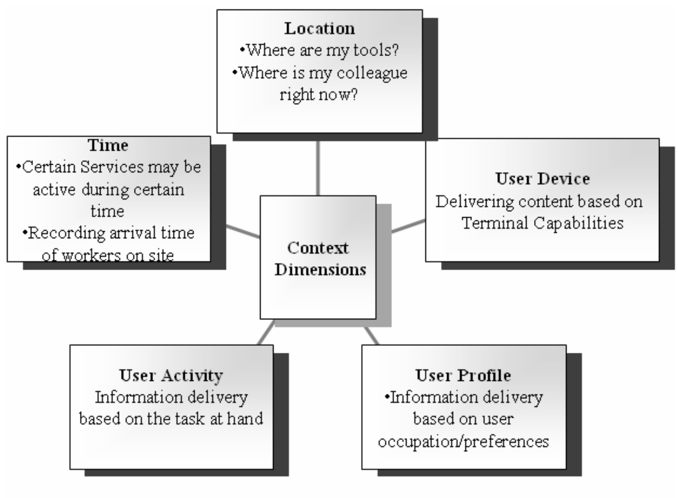

Figure 3. Context Dimensions

Context is drawn from the following sources:

– Current location, via a wireless local area network-based positioning system. A client application running on a user's mobile device or a WLAN tag sends constant position updates to the position engine over a wireless link. This allows real time position determination of users and equipment;
– User Device, through a Microsoft.NET framework application;
– User profile, associated with mobile device's unique IP address;
– User's Activity via integration with MS Pocket Outlook;
– Time via computer clock.

Changes in the context prompt the context broker to trigger the pre-programmed events. Events may include delivery of push-based messages to the users (e.g. H&S warnings) or an exchange of information with other applications, to make them aware of the events on the site. As the user context changes (e.g. change of location, tasks), the context broker recalculates the available services to users in real time. In the prototype implementation, RDF schema (RDF, 2004) was used to provide vocabulary and structure to express the gathered contextual information. Previously, many researchers have also used RDF schema for representing and delivering the context information (Ferscha et al., 2002; Chen et al., 2004; Toivonen et al., 2003). Being XML-based, RDF also ensures provision of context information in an application and platform-independent way.

Using RDF schema, the context broker maps captured contextual information to available data and services.

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Mapping includes:

- *User Profile to Project Data:* Mapping of information, based on the role of user on site;
- *Location to Project Data:* Mapping user location to project data (e.g. if electrician is on floor 3, he probably requires floor 3 drawings and services);
- *User Task to Project Data:* Mapping information delivery to the task at hand.

This mapping is then *used* as a filtering mechanism to find relevant documents for a given context. Figure 4 shows a higher level ontology used in the mapping process, describing the link between user profiles and associated resources.

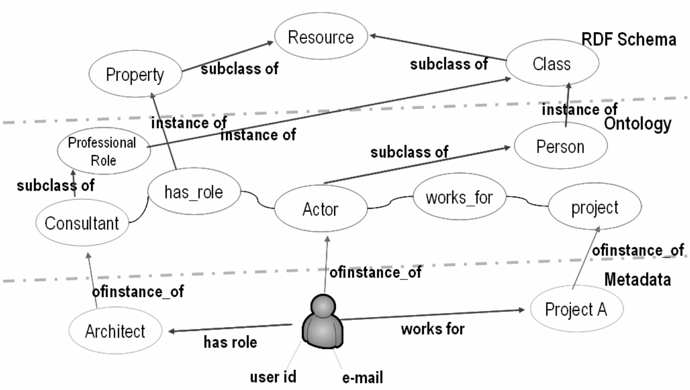

Figure 4.Team Profile Ontology

The Resource Description Framework Schema (RDFS) was selected as the ontology language of the system. With regard to ontologies, RDFS provides two important contributions: a standardized syntax for writing ontologies and a standard set of modelling primitives such as 'instance-of' and 'sub-class-of' relationships (W3C, 2004). Ontology is developed using a modular approach with high flexibility so that it can be extended to accommodate an unlimited amount of new ontologies in the future.

RDF was also used as a meta-language for annotating construction project resources, drawing, images etc. with machine readable information. For instance, the RDF description of a CAD drawing of the main entrance slab with unique identification FF-A23 is illustrated in Listing 1.

Such a semantic description provides a deeper understanding of the semantics of construction documents and an ability to flexibly discover required resources. The RDF schema can also become more detailed by adding related documents and tasks. A semantic view of construction project resources logically interconnects project resources, resulting in the better application of context information. At the same time, semantic description enables users to have different views of data, based on different criteria such as location and profile (e.g. all the electric drawings for floor 3). This allows mapping of the captured context (e.g. Joe is an electrician working on floor 3) to available data (e.g. drawings of floor 3).

```
<rdf:description
about="http://www.lboroCivilExtension.co.uk/dra
wings/Floor1/MainEnteranceSlab.CAD"
ref:ID="FF-A23">
      <res:creator>
      <rdf:Description>
         <architect:name> Joe Blog     </architect:name>
         <architect:email> joe.blog@lboro.com
</architect:email>
      </rdf:Description>
      </res:creator>
   <res:description> Drawing OF Main Enternance Slab for
Floor 1 </res:description>
   <res:title> Floor 1 Main Enterance Slab Drawing
</res:title>
   <res:date> Feb 10, 2005 </res:date>
   <res:type> CAD Drawing </res:type>
</rdf:description>
```

Listing 1. RDF description

5 PROTOTYPE IMPLEMENTATION:

5.1 *Overview*

The prototype implementation involves a proof-of-concept demonstrator and provides an initial working model of a large, more complex entity. It demonstrates some of the concepts presented in this research in realistic construction scenarios. The implementation is based on a Pocket-PC platform. It makes use of a wireless local area network (WLAN)-based positioning engine to map a user's physical location to a virtual environment. Figure 6 shows the implementation architecture.

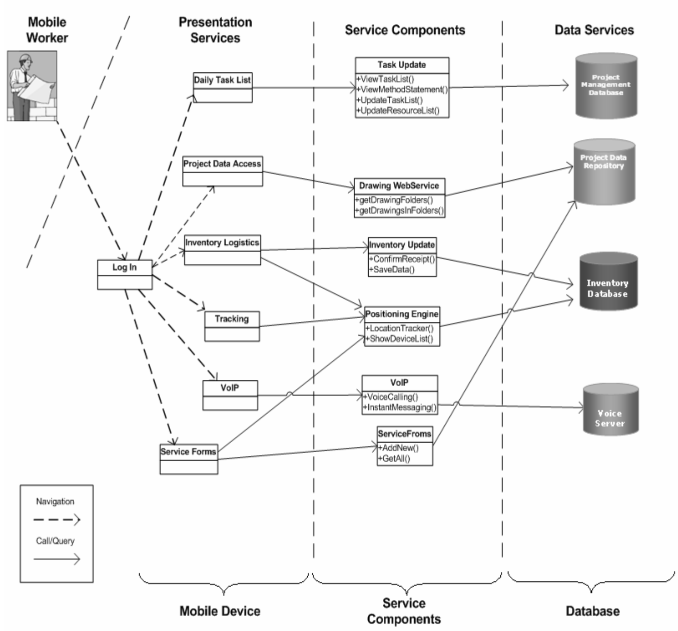

Figure 6. The application architecture

After a successful Log-In, the site worker can see a set of services. These services could be accessed on

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an as-needed basis. Three of these services are discussed in more detail below:

5.2 *Profile Based Task Allocation*

This implementation describes the process by which tasks are allocated to site workers based on their profile. Task list specifies the activities a site-worker must perform and it also includes the associated method statement, describing how tasks need to be performed. As the site worker arrives for work, the site server detects the unique IP address of their mobile device and prompts the worker to log-in. On a successful log-in, the worker can see his/her task list and associated method statement (Figure 7).

Using an administration application, the site manager assigns tasks and method statements to site worker. The client application running on the site worker mobile device detects that data on the server has been changed. The changed files are then synchronized using WLAN-based synchronization. Synchronization is a two ways process (i.e. synchronizing files between the mobile device and the server application). This way, the completion of tasks can be monitored in real-time and an audit trail maintained. A Similar concept can be used to update changes in project management plans.

5.3 *Inventory Logistics Support*

WLAN tags were used to store important information about a bulk delivery item. XML schema was used to describe the tag information structure. As the delivery arrives at the construction site, an on-site wireless network scans the tag attached to the bulk delivery and sends an instant message to site manager's mobile device, prompting him/her to confirm the delivery receipt.

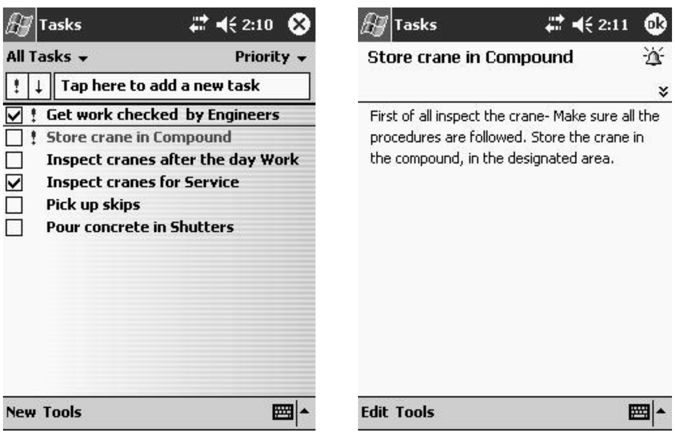

Figure7. Profile based task allocation

The site-supervisor browses through the delivery contents and records any discrepancies. Once the delivery receipt is confirmed (Figure 8), data is stored locally on the site manager's mobile device. Local information stored on the mobile device is subsequently synchronized with the site server, resulting in an update of the inventory database.

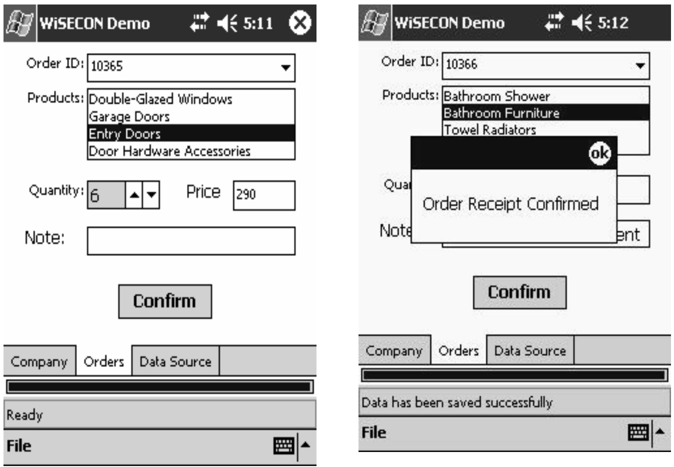

Figure 8: Inventory Logistics Support

5.4 *Real Time Tracking Support*

For real time tracking support, a WLAN-based positioning engine from Ekahau (Ekahau, 2004) was used. The Positioning Engine tracks the real time position of a WLAN-enabled mobile device/tag. It discovers all the WLAN-enabled devices using their IP addresses, and makes use of the signal strength measurements as detected by the access points to determine the actual position. A key advantage of using a WLAN-based positioning engine is that it has considerably less infrastructure requirements, compared to other location determination techniques such as Global Positioning System (GPS) and other real time location tracking systems. This makes it affordable for deployment in a site environment. Also, it is appropriate for use within the indoor environment.

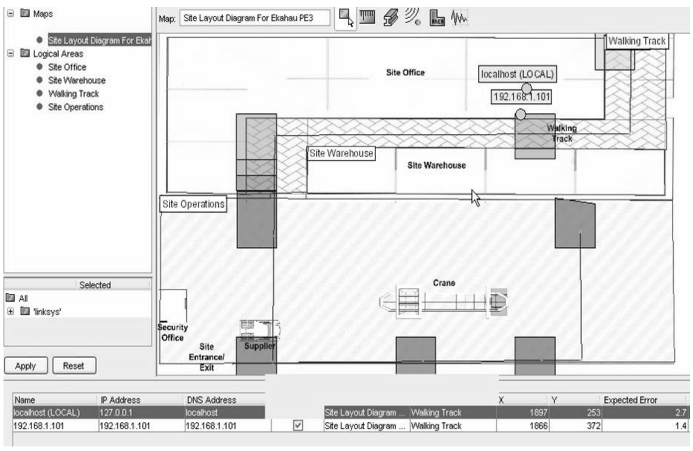

Figure 9: Tracking a notebook device and a W-LAN tag

As the user moves across the construction site, his location details are updated on the corresponding site map using a positioning engine. Real time positioning of site workers can be recorded for Health and Safety objectives. Four logical areas were defined within a simulated construction site, including a site office, site warehouse, a walking track and site

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operations area (Figure 9). As a site worker enters a restricted area, appropriate warning messages are generated.

Similarly, tracking information was used to assist site-operatives to query the system using various search strings (e.g. Device type and area, etc). Using a positioning engine, a mobile worker can obtain a map-based navigation from his/her current location to the target object. Also, knowledge of the user's location was used to deliver data relevant to the location context (Figure 10). To implement this functionality, an XML Web Service was written to query the semantically annotated data on the server, using the location context as a filtering mechanism.

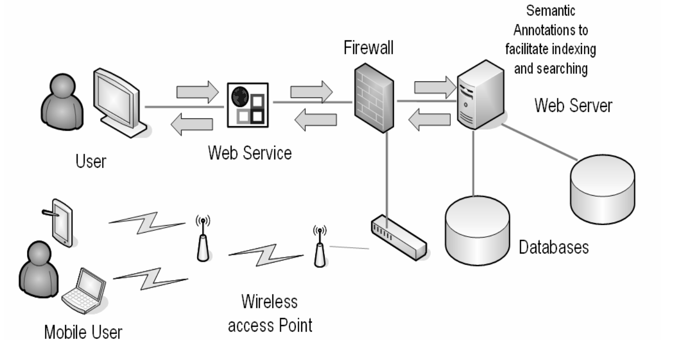

Figure 10. Location-based data delivery

6 SUMMARY AND OUTLOOK:

In this paper, the architecture and implementation of a context-aware information delivery system for mobile construction workers was discussed. The application of Semantic Web technologies, both in context interpretation and at the application and services layer allows for better understanding of contextual meaning and relationship. Better context-awareness has the potential to cause a paradigm shift in construction management practices, by allowing mobile workers access to context-specific information and services on an as-needed basis. The proposed architecture can be adapted to different implementations. For instance, integration with a project management application will allow a project manager to monitor:

- What tasks have been assigned to worker A?
- How much time has it taken for worker A to complete the tasks?
- Which task is worker X involved in right now?
- What is the on the task queue (tasks which can be allocated to workers in real time)? Based on worker location and real time progress, how can this task queue be allocated to workers?

The knowledge of such contextual information allows for better monitoring of the current status of the project (the tasks completed) and the velocity with which the project is moving ahead (against the project plan). In future, using different enabling technologies such as wireless communications, smart materials, sensors and actuators, it is possible to capture a wide range of context variables. This enables the design of better user-interfaces, by shifting the focus from explicit to implicit human-computer interaction (Schmidt et al., 1999). It also prevents users from information overload, thereby allowing the site workers to do their tasks efficiently and safely. Also, new application scenarios are becoming viable by the ongoing miniaturisation, developments in sensor networking, the increase in computational power and the fact that broadband is becoming technically and financially feasible. However, realisation of the real potential of context-aware services for mobile computing in the construction industry needs to satisfy the constraints introduced by technological complexity, cost, user needs and interoperability. At the same time, at the level of an individual construction firm, it often takes more than technology to determine whether or not returns on innovation investments are always positive. Also there is a need for successful industrial case studies. The next step in this research is to undertake field trials to test the prototype system in a real life construction project.

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Multilevel information management in geotechnical engineering

F. Schley & K.-P. Holz
Lehrstuhl Bauinformatik, Brandenburg University of Technology at Cottbus, Cottbus, Germany

ABSTRACT: A generalized approach is described aiming at the integrated management of heterogeneous information in geotechnical engineering. The generalized architecture of a possible hybrid management system joins two approaches operating on different levels of information integration. This paper analyzes both kinds of systems. In particular notice will be given to the components of a strictly integrated management system for geotechnical engineering, following the demands of time-critical information management. Elements supporting presentation of all kinds of information as well as tools supporting net-based cooperation will be considered. The aspect of demands and potential for ICT support in construction engineering is briefly touched.

1 INTRODUCTION

Geotechnical engineering like other engineering disciplines can be seen as an information driven discipline. The need of information recurs throughout all stages of construction, ranging from design, planning and execution to the use of the building. However, throughout its lifecycle different demands on the management of information and different levels of integration can be identified.

Information in construction engineering is in general very heterogeneous. Typical types of information are: CAD drawings and plans, sketches, rough calculations from the early design phases, detailed calculations from blueprint and implementation planning, dimensioning of construction members, contracts, construction logs, cost estimations and accounting, schedules for planning and execution, and so on. Traditionally working small and medium construction companies have a working environment which consists of a heterogeneous collection of engineering software applications and 'standard software' including office software for processing this information. However, ICT support is not yet as sophisticated as in other engineering industries (Jung et al. 2004); quite some information processing is still handled 'manually' (handwritten). The application of ICT becomes profitable with a certain complexity of tasks. Big companies only apply heavyweight integrated software solutions which support the information processing throughout all phases of a construction project including project communication, workflow functionality, documentation and financial issues (like AEC/community, baulogis, BuildOnline and others).

To support particularly small and medium construction companies the following approach of a multilevel information management is proposed. The information management system combines two approaches operating on different levels of information integration.

The first approach is to manage information resources in a distributed project environment applying web-based technologies. Each single document as a container of heterogeneous information is managed by a semantically describing database. The information resources themselves remain physically at their point of origin in the responsibility of their authors. By application of web-based technologies the documents can be shared among the partners; they are available any place any time. The organization of the documents, however, goes beyond the scope of file system structures. No special software is needed on the client side.

However, for a comprehensive information management a simple document management does not appear to be sufficient. Therefore the second approach is to integrate information that is contained in the aforementioned information resources into a system that supports the finding of information and raises the transparency. Moreover, frequently accessed information shall be provided to the engineer in a suitable manner without the obligation to access and open the documents containing it. This demands for the abstraction of typical engineering information. Engineering processes and flow of information have been analyzed to identify 'key information' as

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an abstraction of detailed information. An information model for geotechnical engineering has been developed on this level and complemented with an appropriate user interface.

The combination of the resource management system operating on the level of documents and data files with the model-based information management system operating on the level of key information results in a multilevel information management applicable in geotechnical engineering. The generalized design of the information model allows for the adaptation for other engineering disciplines.

2 RESOURCE-BASED INFORMATION MANAGEMENT

One part of the multilevel information management system is provided by a web-based resource management system (Hildebrandt 2004, Holz et al. 2003). It was developed to support the sharing of heterogeneous information resources in distributed project environments by a common information base on a semantic level. This approach is closely related to the traditional working processes which base on the exchange of information, mostly contained in documents. However, the major drawback of information exchange is the lack of topicality due to different copies and versions of circulating information. This is overcome by the information sharing mechanisms supported by the web-based resource management system.

Typical information resources in engineering are all kinds of (traditional) engineering documents (plans, drawings, calculations, schedules, contracts, construction logs, codes), data files (monitoring data), charts, pictures and video files (observation and documentation). The management of these information resources demands for the explication of its implicit and hidden information. To overcome the problem of semantic heterogeneity a single domain ontology is the base for the semantic markup of the information resources with descriptors (Fig. 1). The ontology is flexibly adaptable for each project depending on special glossaries of the respective discipline and companies and the demands of involved partners.

The format of an information resource is indicated by its MIME type.

The management of the resources is handled by resource entries stored in a meta-database. They contain the semantic markup, the format information and information about the physical location of the resource (URL). Only the resource entries are stored in a meta-database. The resources themselves remain physically at their origin on any server worldwide in the responsibility of their authors. The resource management system is implemented as a web application (Java Servlets) running the database and handling the requests of the users.

The system is accessed from the client side by the web browser. No special software is needed. Any equipment such as PC, PDA or even mobile phone (limited) can be used. As these instruments are mobile, access to the system exists at any time from any place. Basic functionalities include search mechanisms (according to the semantic markup), resource browsing (by tree structure), resource editing, integrated resource visualization (provided by special customizable applets, e.g. visualization of time series from data files), personal workspaces for registered authors and bulletin board communication.

This architecture has the advantage that the responsibility towards content and topicality remains with the provider of the resource. Furthermore it has the advantage that the presentation of the resource on the client side follows the MIME type supporting tools and thus is always familiar to the engineer. The users have an always up-to-date common information base.

3 MODEL-BASED INFORMATION MANAGEMENT

Building is contracted to consortia operating as closed systems not open to the public. Between the partners, however, information about the contracted

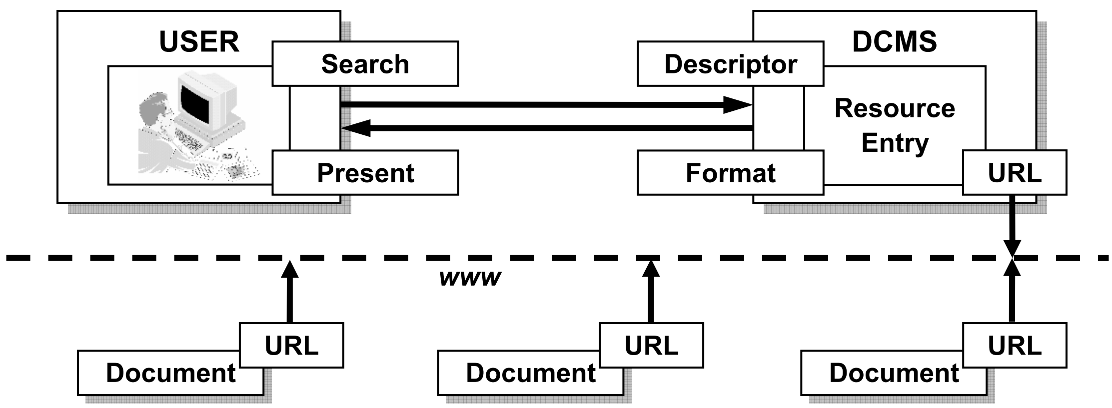

Figure 1. Web-based resource management system.

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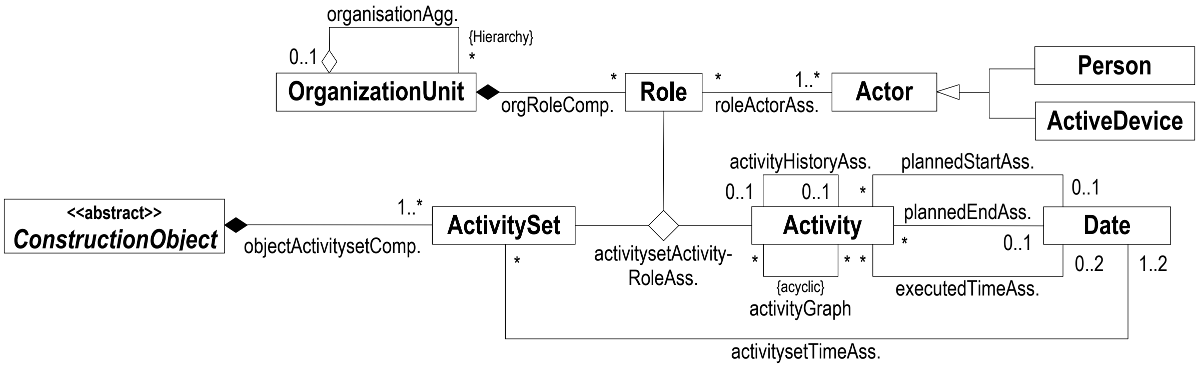

Figure 2. Excerpt from the construction site information model.

construction and operation of the building site is commonly shared. Providing just this information within a password protected resource management system as described might well be used in this environment.

However, when contracts with consortia are established, they contain precise information of partners, objectives, tasks, finances, responsibilities, time-frame and organizational structure. This information permits the design of information models on a densely integrating level for rapid construction follow-up and fast reaction in emergency situations. An information model for geotechnical engineering has been developed integrating construction elements, building processes, monitoring, actors and organizational structure (Schley et al. 2004). The main objective for this information model lies in the support of handling emergency situations in geotechnical engineering. It is designed to contain key information only, since only few technical details about construction members and their states are needed for emergency handling. However, it has shown that this information model is applicable for the information management throughout the entire construction process.

The information model and its corresponding model editors are not intended to replace existing software packages and tools the engineers are using at their regular work. It is rather intended to be a supplementary instrument that fits into the engineer's working environment and provides a central point of reference concerning information management. A corresponding mechanism for interfacing with other sources of information is presented.

3.1 *Construction site information model*

The information model (Fig. 2) follows an object oriented approach and is described by the unified modeling language (UML). The abstract generalized model consists of three components. They represent the construction objects of the building, the construction process and the organizational structure.

Construction objects are structure components (members), measuring devices, construction equipment, site facilities and machines of the construction project as well as objects interfering directly or indirectly with the project like neighboring buildings or soil and groundwater bodies. An extendable class hierarchy has been created to model typical geotechnical engineering construction objects like excavation, sealing slab, slotted wall, anchor, gauge and pump. The construction object's properties are modeled separately with specialized property classes. They contain the actual key information. The integrity of the model is ensured by the definition of mandatory properties for certain construction object types. Other properties are optional and can be combined freely.

Construction processes are mapped with activities and relations between them. An activity graph maps the work schedule with its planned and actual times of execution as well as completion. It allows for a complete control and survey of the construction process. Changes of the work schedule are documented in the information model for later evaluation and assessment of critical emergency situations. Property objects provide information about the planning, execution and finish state of construction objects. Predefined construction sequences can be integrated.

The organizational structure model component is rather independent from the other ones. It is capable of mapping the prevalent organizational and responsibility structures of building sites. The hierarchic structures, as determined by contracts, are represented with organization units. They can be real (company, division, department …) as well as virtual units (joint venture …). For one building project there can be mapped several organization hierarchies (subcontractors).

3.2 *Interfacing with external models*

Major problems in model-based information systems are the integrity and the consistency of the information model. Many software products are available for all the different engineering tasks covering the whole construction and building process providing their own underlying models. For persistent storage and exchange of information proprietary formats are established. However, integrated solutions are feasi-

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ble with the development of common product models, like IFC (IAI 2004) for civil and building engineering. But the implementation and support of common product models in commercial products is not yet as satisfactory as necessary.

The described information model for geotechnical engineering was designed for quick access to key information only. The key information considered is usually contained in other resources available to the engineers, sometimes ‘hidden’ or implicit. However, tough competition does not permit to spend extra effort, costs and manpower on condensation and integration into the information model. Besides this the problem of undesired redundancies arises from the concurrent provision of information from both the information model and the original information sources (e.g. proprietary storage within the information generating software products).

The following approach of a collection based core model has been developed to overcome both problems (Brüggemann & Liang 2004). It defines selected proprietary formats as persistent core together with providing a collection based generalized interfacing methodology. The described information model is integrated part of the persistent core. Interfacing is done with reader and writer components implemented specifically for the proprietary formats. The readers and writers are interconnected with trasformer components. Readers, writers and transformers operate with basic set operations on a transient collection based model consisting of objects, collections and relations only. The collection based model is a very high level of abstraction of the information to be interfaced. No further semantics is contained.

As a side effect the inevitable redundancy is managed by the collection core approach. Information is marked as original and dependant information, thus allowing for consistency checks if parts of the (whole, distributed) model change.

4 MULTILEVEL INFORMATION MANAGEMENT

The proposed multilevel information management system combines both aforementioned approaches. The resource-based approach provides the management of all kinds of traditional documents usually shared during construction processes. Moreover it can handle heterogeneous information resources that change dynamically during their life time like all kinds of data files providing for instance measured data. The web-based resource management system also allocates communication and collaboration tools and makes it part of a web-based cooperation platform. The model-based approach provides the access to and the management of distinctive information, topological correlations and dependent information which cannot be recognized out of documents. However, the underlying information model cannot give and is not designed to provide whole coverage of all information for construction management. Only key information is provided. The link between both approaches is managed by the information model. Special properties of construction objects, activities or organization objects contain links to resources, pre-formulated queries or dynamically formulated queries for the search mechanisms of the resource management system.

Navigation through information to access key information is crucial for decision making processes and crisis management. To support these needs a graphical navigator has been set up (Fig. 3). It serves as central information editor for the entire information model presenting the construction project with its construction objects in a schematic generalized form by appropriate tools and editors. This allows for quick information retrieval and the recognition of spatial and temporal bearings to the engineer. The temporal context, provided by the process compo-

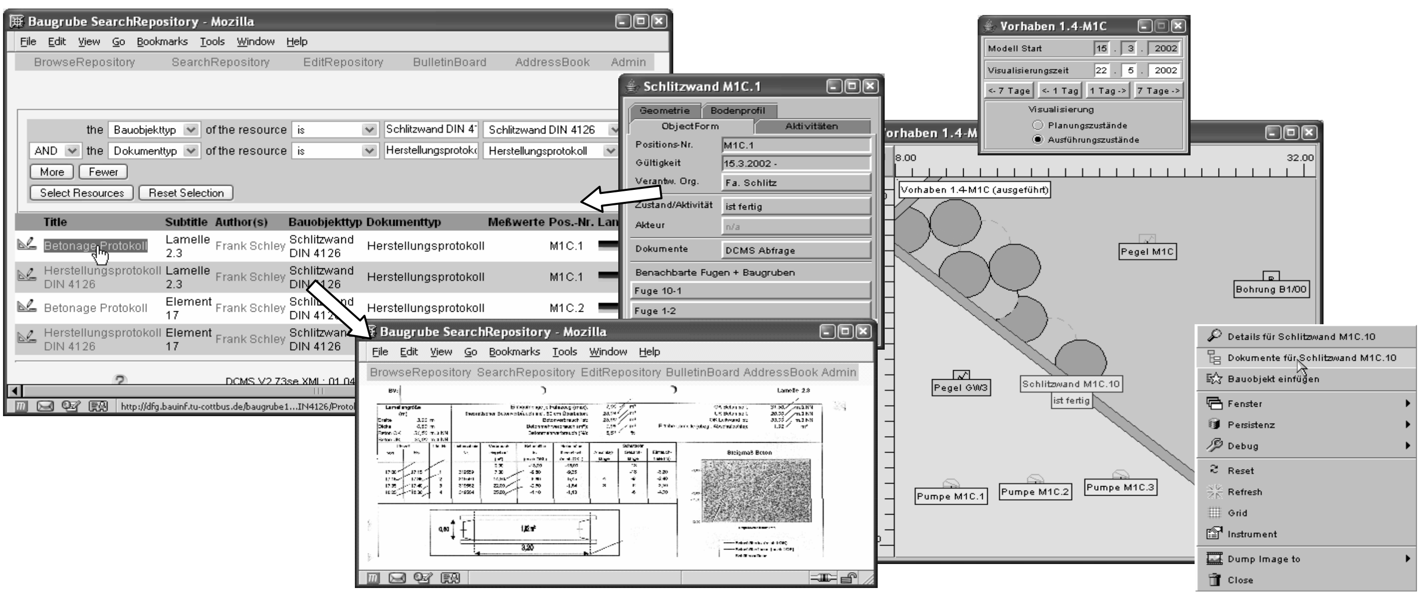

Figure 3. Graphical information navigator and some model editors.

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nent of the model, displays the status of the building process at any time level of construction work. It also allows for comparisons of both the as-built and the as-planned states. Accessibility to information about the project status at current and any previous time supports decision makers to understand possible interactions between building, soil, water and activities as well as the development of failures and their reasons.

The graphical navigator provides the following groups of tools and information editors:

- Tools and editors for construction object information. They handle the type specific properties of construction objects and their topologic dependencies. These tools provide continuous comparison of target and actual values on construction object base. A modular structure of these tools allows for an easy combination of desired tools and implementation for other type specific properties.
- Tools and editors for process information. This group of tools is designed for tracing, control and editing of construction process information.
- Tools and editors for organization information. They visualize organization hierarchies and make them editable easily. The definition and assignment of roles to their organization units as well as roles to actors and activities is provided. Contact information assigned to organization units, roles and actors (persons) can be edited and instantly applied for the establishment of communication channels (e-mail, SMS, net-based telephony). Links to construction object and process information are navigable.

Furthermore the graphical navigator is interlinked with tools that according to type of critical development propose engineers immediate prevention measures according to predefined scenarios and collaboration schemes. This supports remembering and considering alternatives which might be difficult during alert times.

All of the abovementioned tools contain links to the resource management system for further information not provided by the corresponding part of the information model.

An alternative approach for an efficient information access in less time critical situations through a navigational model is given by Reinhardt et al. (2004).

5 CONCLUSION

The approach to manage heterogeneous information in geotechnical engineering with a multilevel management system has been outlined. Wide use of web technology has been made. The first level is used for loosely integrated information in document and data file based information resources. This level follows closely the traditional document based working processes taking advantage of ICT for information sharing instead of information exchange. The second level is the level of key information mapped in an information model. Both the information model and the resource management system are integrated in a web-based cooperation platform.

The general approach taken supports 'virtual' collaboration 'any time – any place'. Furthermore the model driven approach extends this working paradigm towards the information retrieval paradigm 'right time – right place'. It seems that this dimension is not yet familiar to practice in this environment and will need some more preparedness.

6 ACKNOWLEDGEMENT

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Structuring Technical Guidelines in Fire Protection Engineering with Topic Maps

U. Rüppel, M. Lange & A. Wagenknecht
Institute for Numerical Methods and Informatics in Civil Engineering, Technical University of Darmstadt, Darmstadt, Germany

ABSTRACT: Due to the federal structure of Germany and the continuous adaptation of engineering standards in the field of fire protection, there is a multiplicity of complex and heavily interrelated laws, technical guidelines, rules and regulations. This poses a challenge for all actors in the building planning process because for every trade structural fire protection aspects have to be considered.
In this paper, an approach based on the Topic Maps Standard to facilitate the planning-task related retrieval of fire protection regulations is described. As a result of this approach, the planner can query a term network with a text search or navigate through it in order to find the relevant information for his specific task. Considering fire protection as an example this contribution points out the aims, the requirements and an implementation approach for structuring and presenting of technical knowledge by use of semantic technologies.

1 INTRODUCTION

In the building planning process in Germany the structural fire protection is of great importance. For every trade of the building technical fire protection regulations have to be taken in account by the various involved planners.

Because of the federal structure of Germany, the fire protection regulations can differ in every federal state and even a local authority can enact special regulations. Furthermore, various private institutions and associations publish additional fire protection regulations which have to be observed by the building planners.

As a result, they are confronted with a multitude of laws, technical guidelines and rules concerning structural fire protection. To find the right regulations for a certain planning task, e.g. using printed media or full-text-search in electronic texts, is time-consuming and less effective.

In order to facilitate the retrieval of relevant passages in fire protection regulations, a network of terms describing the contents of the regulations and a link to them would be of great help. Firstly, the planer would get a quick overview of the used vocabulary and adjacent topics. Secondly, complementary fire protection rules which can be found in different regulations are bundled and linked to the same network terms.

In this paper an approach is presented using the ISO-Standard Topic Maps to structure the contents of fire protection regulations with a term network in order to facilitate the searching process in these documents for planners and engineers.

2 TECHNICAL GUIDELINES IN FIRE PROTECTION ENGINEERING IN GERMANY

This section will demonstrate the importance of structural fire protection in the building planning process and its influence on the characteristics of technical guidelines in the fire protection domain.

2.1 *Significance of fire protection in the planning process*

Fire protection planning in building design is a dominant aspect for the prevention of fire and for the protection of life and property in the case of fire. Therefore structural fire protection plays a major role in the building planning process and all trades of a building have to comply strictly with fire protection requirements. This fact implies that every planner, specialist in the field of a certain trade, also has to consider fire protection aspects, although not being an expert in this domain.

Furthermore, research in the field of fire protection engineering is leading to the development of progressive methods and to a frequent change of the state of the art in this domain.

Considering material damage, fire is one of the largest risks the insurance companies have to account for. Therefore, the association of property-

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insurers publishes additional fire protection regulations which are - in general - stricter than the national and federal regulations. Furthermore, in addition to the different regulations of the federal states, other private institutions like the German Fire Protection Association (vfdb) also enact rules in structural fire protection.

All these aspects lead to characteristics concerning the structure of technical fire protection guidelines, rules and regulations. These characteristics will be pointed out in the following subsection.

2.2 *Characteristics of technical fire protection guidelines*

As mentioned above, a lot of different public and private institutions publish additional fire protection guidelines and regulations. As a result, there is a variety of different rules and regulations and their contents overlap, complete or replace each other. Furthermore, most fire protection rules do not only have an impact on a special trade but affect many trades of the building planning process. Thus, fire protection rules are generally not categorized by trades.

Nevertheless, all actors in the building planning process have to work with the complex fire protection guidelines and regulations which is time and cost consuming. Fire protection handbooks, best practice manuals, electronic full-text-search and indexing may support the planner in considering the important fire protection aspects, but for a particular planning task they are not sufficient to find the relevant regulations and rules. In order to augment the retrieval of fire protection regulations their complex contents can be structured by adding meta-information to them and by organizing the meta-information in a term network. This approach will be discussed in general and in detail in the next section.

3 TERM NETWORKS TO STRUCTURE THE CONTENTS OF TECHNICAL FIRE PROTECTION GUIDELINES

In the previous section the particularities of fire protection regulations and guidelines were pointed out. Due to their characteristics it is difficult and time-consuming for the planner to consult the regulations in order to comply with them. To make the search process in regulation documents more effective it is suggested to implement a network of fire protection terms based on meta-information of the contents of fire protection regulations. The requirements on the structure of such a term network will be analyzed in the next subsection. In order to implement the term network a metadata framework is needed. Therefore, Topic Maps (ISO 1999) and RDF (W3C 2004a) in combination with RDFS (W3C 2004b) could be – among others – deployed and will be compared to each other on the basis of the term network requirements. Finally, a brief description of the XTM Topic Maps Standard (TopicMaps.Org 2001) will be given. This metadata framework has been chosen to build the term network for technical fire protection guidelines with.

3.1 *Requirements on the term network for technical fire protection guidelines*

The term network could contain nodes which represent terms of the elements of structural fire protection and terms of elements of the building model (e.g., firewall, storey, fire area or emergency stairway). These terms could be assigned to paragraphs of the regulation documents which contain fire protection rules about the elements the terms stand for. An example could be the term “firewall” being assigned to a paragraph in which the fire resistance class of a firewall is defined. In the majority of cases the description of a paragraph by a single term is too general to get precise search results. Consequently, it should also be possible to assign two or even more terms to a particular paragraph. According to a paragraph in the fire protection regulations, a firewall of a central heating room located in the basement has to conform to a higher fire resistance class. The term-bundle “firewall” “central heating room” and “basement” could be assigned to this paragraph. As well as simple nexuses between terms, semantic connections - in form of verbs - should be possible to augment the expressiveness of the term network. One example of a semantic connection could be the expression “has a” between the term “emergency stairway” and the term “window”.

As planners of different disciplines have to consult fire protection regulations, they often use their own terminology and have their own discipline-specific perception in mind. In order to take this aspect into account synonyms should be represented in the term network.

The suggested term network can be implemented with different metadata frameworks. In the next subsection two of them will be compared taking into consideration the requirements pointed out in this section.

3.2 *Comparison of Topic Maps with RDF/RDFS*

In the wider context of semantic search, the metadata framework RDF in combination with ontologies, formulated in RDFS or OWL (W3C 2004c) is mainly applied in current research. The Resource Description Framework (RDF), standardized from W3C, is a very generic and minimalistic framework to describe metadata for the World Wide Web, yet very flexible at the same time. The framework focuses on the description of metadata which is machine-processable and which consists of only three

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components: *resources*, *properties* and *statements*. The RDF-statement is structured in form of an English sentence with a subject (the *resource*), a verb (the *property*) and an object (the *value*). Different *resources* can also be linked by *properties*. As with RDF neither properties nor relationships between *properties* and other *resources* can be described, the schema language RDFS was developed. RDFS allows this description by providing classes and properties.

Referring to the requirements of the suggested term network, RDF/RDFS can be used to implement the network, because of its flexible generic nature. However, relationships between more than two terms can only be expressed with workarounds. Furthermore, an intuitive mechanism to assign elements of the network to particular passages in electronic regulation documents does not exist.

In addition to the metadata framework RDF/RDFS, the Topic Maps Standard, originally developed to merge back-of-the-book indexes, is also applied in the area of knowledge management. This ISO-Standard offers an intuitive description of knowledge structure and the possibility to assign information to this structure. A Topic Map can be described as a link network of metadata which is stored separately from the information resources but the elements of the network can be connected to the resources (Rath 2003) (Fig. 1).

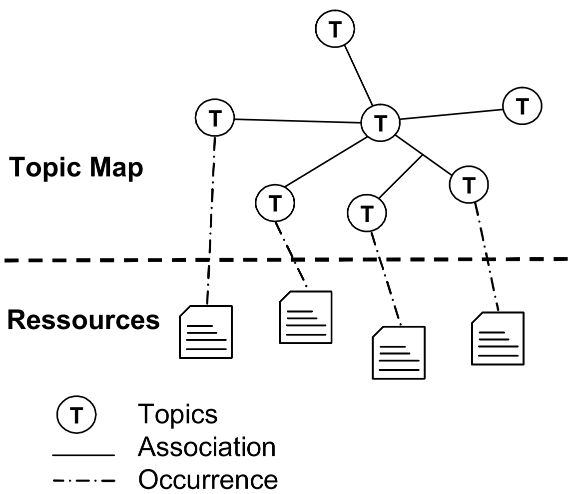

Figure 1. Elements of Topic Maps

Topic Maps mainly consist of *topics*, *associations* and *occurrences*. The *topics* represent objects from the real world in the broadest sense, e.g. building components. The *associations* can interlink two or more *topics*. The information (e.g., a book, a hyperlink, a document) to the *topic* is assigned by *occurrences*. Additionally, the element *scope* makes it possible to express the view of different planners in the same Topic Map, so that synonyms or different terminologies in the fire-protection domain can be represented. Consequently, the Topic Maps Standard focuses on representing knowledge for the perspective of humans (Pepper 2002) and includes an intuitive, rich but also flexible data model. Therefore, the term network will be modeled using the XTM Topic Maps Standard whose elements and structure will be briefly presented in the next subsection.

3.3 *Elements and structure of XTM Topic Maps*

In this section, a short introduction to XTM Topic Maps based on Pepper (2000) will be given. The core elements will be mainly explained. They will be used later in the fire protection term network. A comprehensive description of all elements of the data model is out of the scope of this paper.

The following remarks refer to the XML Topic Maps language which differs from an older standard called HyTM which is rarely used in nowadays.

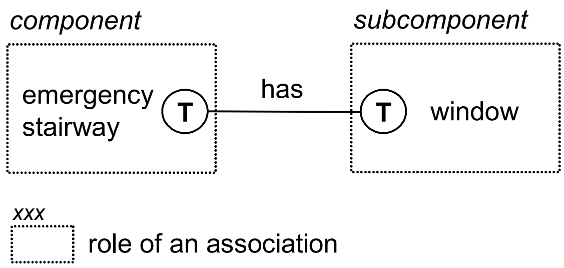

Figure 2. Associations in Topic Maps

The most important element of the subject-centric standard is the *topic* itself. It has a name and can be a representation of any physical or non-physical subject. In case of the developed term network it is used to model the fire protection terms. *Topics* can also have one or more *topic types* which allow modeling hierarchical relations like a “firewall” being “building component”. The *topics* can be interlinked by *associations*. An *association* does not have an implicit direction but can be determined by either the human reader or by the role that the two *topics* have in the *association*. In Figure 2, the direction of the *association* is fixed because it is obvious for the human reader that a component can have a subcomponent but not vice versa. Among *associations* between two *topics*, n-array *associations* can also be modeled with Topic Maps.

Using the described elements, a network of metadata can be built expressing coherences between the different contents of fire protection regulations. The connection of the network to the electronic resources is realized by *occurrences*. *Occurrences* are available to assign *associations* and *topics* to the underlying information resources (electronic documents). Another important element in Topic Maps is the *scope*. *Topics*, *associations* and *occurrences* can have two or more *scopes* allowing for multiple contexts. Existing synonyms in the different regulations and technical guidelines treating fire protection issues can be represented by *scopes* for the names of the *topics* in the term network.

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It is also possible to assign the characteristics (names, *associations* and *occurrences*) of a *topic* to *associations* and *occurrences* using the technique of reification. This means, creating a *topic* which does not represents a subject of the real world but rather an element in the Topic Map itself. As a result, the characteristics of this *topic* also belong to the Topic Map element (*association* or *occurrence*) it reifies.

In the presented approach, this technique is mainly used to name *associations* and to assign not only *topics* to paragraphs of electronic documents but is also used to assign *associations* to the electronic resources.

The next section shows how a term network structuring fire protection regulations can be built on the basis of Topic Maps and with use of an implemented editing tool.

4 BUILDING THE TERM NETWORK WITH TOPIC MAPS

In the last section, possible metadata frameworks to implement the term network for fire protection regulations were discussed and the Topic Maps Standard was chosen because of his flexible and intuitive design and its focus to offer a human-oriented knowledge representation. In the next subsection the structure and the creation of the term network and the implemented editing tool, which supports the creation, will be described. Furthermore, the creation process of the term network will be illustrated.

4.1 *Structure and creation of the term network*

The structure of the suggested term network is simple and adapted to the contents of the regulation texts for which it should serve as a metadata layer. The network contains only few elements which are:
- *topics* with names (for fire protection terms)
- typed *associations* between two *topics* (to link two terms with a verb)
- untyped *associations* between more than two *topics* (to bundle multiple fire protection terms)

Each of these elements can be assigned to one or more particular paragraphs in fire protection regulation texts which should be available in html-format (Fig. 3). The connection of network elements with the underlying electronic documents is realized by *occurrences* which contain the URLs of the specific part of the document (e.g., one paragraph).
As in Germany fire protection regulations often differ for each federal state, *scopes* are used to specify the *occurrence* which connects a network element to the electronic resource (Fig. 5).

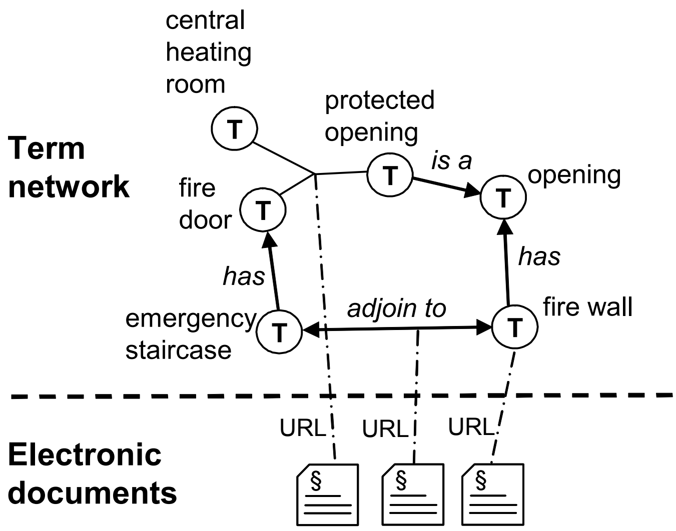

Figure 3. Structure of the term network

Additionally, the *scope* for an *occurrence* is used to attach further characteristics to the referenced regulation paragraph e.g., for which building type (e.g., fire proof doors in hospitals) the paragraph is valid.

A single term which is connected to a particular regulation passage only allows a very general metadata description of what the specific paragraph is about. Connecting two terms with one verb and assigning this “phrase” to a paragraph gives a more differentiated description of its content. One example could be a paragraph containing requirements of windows in safe staircases which will be assigned to the *association* “has” which connects the *topics* “safe staircase” and “window”. In addition, through the connection of more than two *topics* by an untyped *association* it is possible to describe complex assertions of paragraphs. To cite an example, a particular paragraph in one regulation contains special fire protection requirements for partition walls in assembly rooms which are located on the ground floor. This paragraph could be assigned to the bundle of *topics* (inter-linked with untyped *associations*) “partition wall”, “assembly room” and “ground floor”. Furthermore, it is possible that in two regulations - treating the same fire protection aspect - different terms are used, like “fire protection wall” and “fire wall”. This means that each *topic* can have a list of synonyms expressed with the Topic Maps element *scope*.

The last examples show that the application of fire protection rules depends on many aspects like building type, occupancy, location etc. Due to this complexity the term network has to reflect these technical correlations as accurately as possible to assure that the planner finds the right fire regulations for his specific planning task. This is the reason for creating the term network manually by a fire protection expert.

As this expert generally does not have skills in abstract knowledge representation standards an editing tool with a graphical user interface was imple-

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mented which encapsulates the used Topic Maps Standard and is geared to the linguistical needs of the field of structural fire protection.

The next subsection demonstrates how to create term network elements and how to assign them to the electronic information source.

4.2 *Annotation of an exemplary fire protection regulation paragraph*

In this subsection it is shown, based on a concrete paragraph, how fire protection regulations in the form of electronic documents can be structured with the term network by using the Topic Maps Standard. A regulation for staircases in residential buildings with more than five storeys contains the following passage:

The staircase which is located inside the building may only be accessible by a separate anteroom.

This fire protection rule should prevent that - in case of fire - smoke can easily reach the inside of the staircase which serves as fire rescue path. This rule only exists for the federal state Hessen.

The expert, who creates and maintains the term network will add the *topics* "emergency staircase" and "anteroom" to it (in case they do not exist yet) and will connect the two *topics* with the *association* "adjoins to". Then he will assign this *association* to the cited paragraph with an *occurrence* which contains the hyperlink to the html-document of the paragraph text. Furthermore, he will add the *scope* "Hessian" and the *scope* "residential building with more than five storeys" to this *occurrence*.

Up to this point, the term network is created and linked to the different electronic documents which contain the fire protection regulation texts. In order to utilize the term network to facilitate the retrieval of specific regulation paragraphs it has to be put to the disposal of the building planner. The user interface of the term network will be discussed in the next section. Furthermore, an implemented search tool using the term network will be presented.

5 THE TERM NETWORK AS A SEARCH INSTRUMENT FOR FIRE PROTECTION REGULATIONS

In the previous sections, it was described how the content of the different complex fire protection regulations and technical guidelines in Germany can be structured by a term network expressed in the Topic Maps Standard. In the following subsection the requirements for a representation of the term network to the user, bearing in mind the application domain, will be discussed. Finally, an implemented search tool using the term network will be presented.

5.1 *Requirements for the user interface of the term network*

Due to the complexity of fire protection rules and because of the fact that building planners in general do not have expert knowledge in the fire protection domain, they are not well acquainted in fire protection terminology and the complex structure of regulation documents. That is why the network of fire protection terms should be graphically presented to them. A graphical user interface – for which Topic Maps are predestinated – allows the planner to navigate in the term network if he does not know the exact technical terms for the subject he is searching for. Even if he knows the exact term the network representation shows adjacent subject areas which can also be of interest to him. However, there should be a mechanism to present only the specific area of interest of the term network to the planner. Otherwise he could not find the *topics* he is searching for because of an overloaded representation.

The mentioned aspects have been considered for the implementation of the search tool "Fire Protection Navigator". This software tool will be introduced in the following subsection, referring to the regulation paragraph of subsection 4.2.

5.2 *Application examples*

The search tool "Fire Protection Navigator" is presented using the following scenario to demonstrate the advantages of a search in regulation documents with Topic Maps:

An architect who has to plan a residential building with six storeys in Hesse wants to integrate emergency staircases which are located inside the building. He does not know which fire protection rules he has to comply with for these staircases.

In order to find relevant regulations, he uses the "Fire Protection Navigator" which offers him a graphical network of fire protection terms which are associated to the regulation documents.

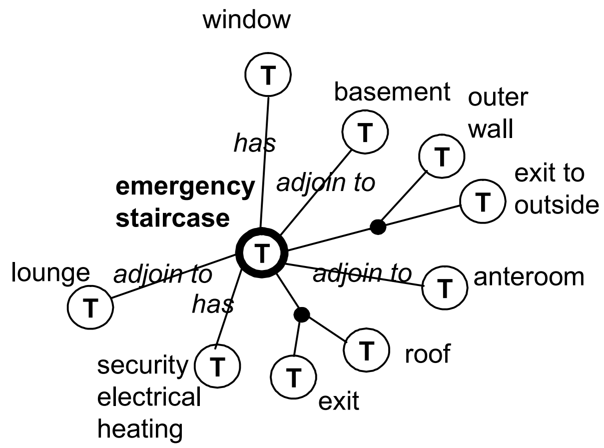

Figure 4. Graphical representation of the term network

In order to choose the relevant section of the network for his question, he may use a free-text search

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field. He enters the word "emergency staircase" in the field. As a result, the specific section of the network is displayed (Fig. 4).

The architect could now choose the *topic* "emergency staircase" and would get a long list of regulation paragraphs which are linked to this term. As this list also contains paragraphs of other federal states he could filter these paragraphs by constraining the search to documents which are only valid to "Hesse" and to the type "residential building" as it is demonstrated in Figure 5.

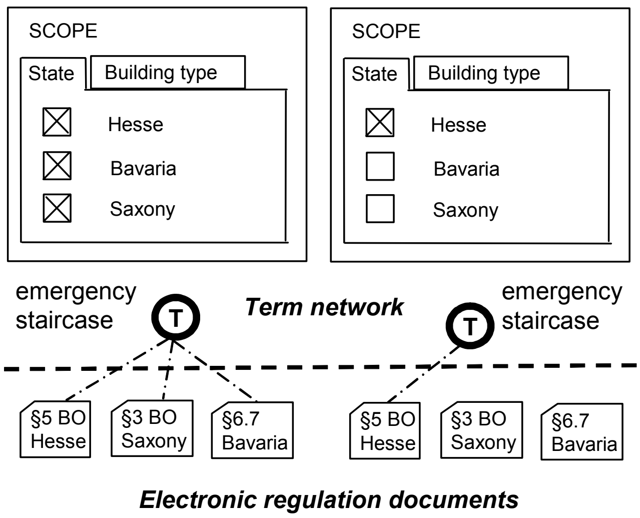

Figure 5. The effect of scopes for occurrences

As a result he would find most of the relevant paragraphs but not the one of subsection 4.2, because in this paragraph the word "staircase" and not "emergency staircase" is used although the fire protection rule is actually also related to emergency staircases which are located inside the building. But due to the network representation of the fire protection terms the architect recognizes that there are staircases which have anterooms. Thus, he clicks on the *association* "adjoin to" which connects the *topics* "emergency staircase" and "anteroom". As a result he gets the link to the important Hessian paragraph stating that in this case the emergency staircases must obligatorily have an anteroom.

The fire protection navigator is implemented in Java using the Topic Maps library TM4J (Ahmed 2003) and the graphics library TOUCHGRAPH (Shapiro 2005).

6 RELATED WORKS

In the domain of knowledge management in civil engineering, two big research projects on the level of the European Union have principally to be mentioned. Within the scope of the e-Cognos project (Bourdeau et al. 2001) an extensive multilingual ontology for the construction domain was developed in the DAML+OIL (Horrocks et al. 2001) ontology language. This ontology can serve together with implemented services to create, to capture, to index and to retrieve disseminated knowledge in the construction sector.

One of the aims of the European FUNSIEC-project (Lima et al. 2004) is the development of an Open Semantic Infrastructure for the European Construction Sector (OSIEC). In order to realize this aim FUNSIEC reverts to existing norms and ontologies like IFC and e-Cognos. These projects focus on the integration of information resources of the whole construction domain and follow a generic approach including European wide standardizations while the approach of this paper is to cover the needs of a specific field in the construction domain. In order to structure fire protection regulations in (Rueppel 2002) and (Meissner et al. 2004), first approaches of a rule based expert system have been introduced. This system allows for validation of fire protection concepts. Admittedly, only hard fire protection rules can be analyzed by the system.

7 CONCLUSIONS

In this paper, the complexity of regulations and technical guidelines of fire protection is pointed out. The fire protection rules in Germany are disseminated over different regulations, they are not categorized by building trades and they are often interwoven. As a result, it is difficult and time consuming for the planners of a building to find all relevant fire protection rules for a particular planning task.

In order to offer a semantic search in regulation documents to the planner a network of fire protection terms was introduced which serves as a metadata layer whose elements are connected to the underlying electronic resources. The term network is based on the ISO-Standard Topic Maps whose advantages to RDF/RDFS for this special use case were pointed out. The creation of the term network has to be done manually by fire protection experts to guarantee exact search results. They are supported in this task by an implemented editing tool which encapsulates the abstract data model of Topic Maps.

Furthermore, it was decided to support the planner in his search with a graphical user interface. The visualization allows the planner to navigate in the network and finally to display the electronic documents which are assigned to the network elements. As a result, the planner may realize connections between different fire protection rules easier. Furthermore, the network offers extra information about adjacent subjects of interest to him which was demonstrated within a previous example.

In order to structure the contents of different electronic resource types (databases, documents etc.) and in order to structure larger knowledge bases, an ontology-driven approach should be preferred because of its higher expressiveness and better valida-

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tion mechanisms. But to realize a quick gain for the retrieval of documents in a limited knowledge base of a special construction domain Topic Maps can be a possible practice-oriented alternative to highly formal ontology approaches.

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Constructing Building Information Networks from Proprietary Documents and Product Model Data

R.J. Scherer & S.-E. Schapke
Institute for Construction Informatics, TU Dresden, Germany

ABSTRACT: The paper presents a novel *Building Information Mining Framework* (BIMF) that allows utilising building information captured in product model data as a valuable source of background knowledge in information retrieval and mining. Central to the framework is a *four layered Bayesian Network* adapted from probabilistic Information Retrieval models developed in the 90s. Capturing, combining and visualising the results of various text and model analyses as well as representing aspects of the current mining context, the network allows for explicitly representing content of the repository in personalisable information networks. These networks enable not only the retrieval of information from the text documents but also the explicit interlinking of the document and the product model domain to also support the understanding of the available interrelations and the exploration of new mining and integration strategies. The paper introduces the principal approach, explains the components of the basic network and suggests several further extensions that are currently still under development.

1 INTRODUCTION

The standardisation of product and process information has been a major focus for overcoming interoperability problems and enabling integrated networked collaboration. However, in the practice of project-centred, highly fragmented sectors such as the Architecture Engineering and Construction (AEC) industries information exchange still heavily relies on isolated text documents. Even with an increasing integration of model-based systems with project communication platforms, a large amount of the business and engineering knowledge will remain captured in large document repositories (Froese 2004). Hence, in addition to the innovative planning and modelling techniques, possibilities to retrieve project knowledge from traditional text documents and integrate it with operational model-based information systems need to be further explored.

The knowledge in today's project repositories is difficult to access due to the project-specific organisation of the documents and the complexity of their mostly unstructured text content. Document management systems and project extranets provide standardised metadata sets for labelling document files, but detailed document schemata or even ontologies for a more comprehensive classification of the information items are still missing. Furthermore, due to the highly interdisciplinary and often ad hoc work organisation in AEC, the comprehensive annotation of document information is very complex and has remained an unsolved task so far.

Furthermore, with the increasing use of model-based planning system there is a need for integrating document information with the related information models to achieve consistent information bases. Most business and product information models provide classes to reference documents, but the efficient interlinking among the numerous documents and related modelling objects remains a challenge. In order to integrate document with operational model-based information, methods are needed to automatically identify, externalise and track information from common text documents in relationship with available product data classes and instances.

We consider both the knowledge retrieval as well as the information integration a *context-specific information mining task*. This means that, first of all, a more detailed analysis of the document content is required to compensate the absence of suitable structure and semantics. Methods of computer linguistic, information retrieval and text mining provide for a first identification of text content e.g. in the course of full-text search, entity recognition or text-clustering. However, for flexible and sustainable information sharing among the involved disciplines, projects and business functions the working context in which the information was generated (and the one it is currently needed in) needs to be considered as well. Corresponding background knowledge is re-

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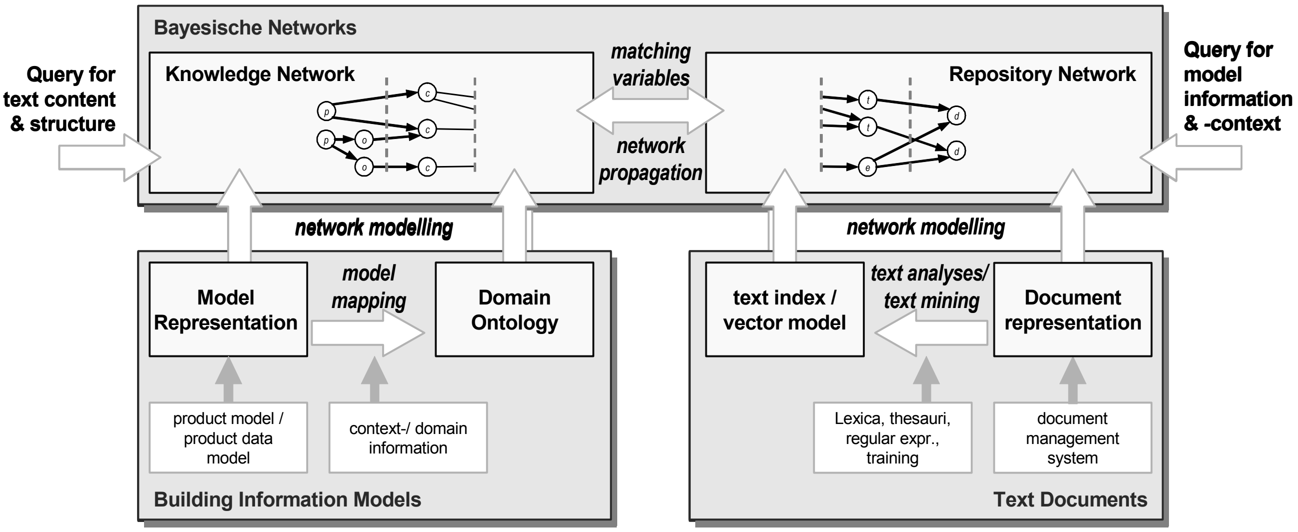

Figure 1: Analyses and Integration of Results in the Building Information Mining Framework (BIMF)

quired to take into account the varying structures, semantics, and granularity of the different disciplines' information models. This cannot be achieved solely by the currently available text analysis and mining techniques.

The goals of our research are to explore possibilities for accessing the AEC domain knowledge and project information stored in building information models (BIM) and utilise it in the processes of common text retrieval and mining. Standardised product data models such as IFC or ISO 10303-225 to a certain degree already enable the exchange of technical and functional descriptions of buildings and engineering structures, as well as the integration of heterogeneous software applications.

We argue that both the topology of the data models and the corresponding instantiated product models comprise general and specific AEC knowledge that can enable more focused, contextualised identification and reconfiguration of the document information. In contrast to specialised linguistic resources, building information models (1) do already represent existing, standardised models that are visualisable and shared among several AEC disciplines, (2) exhibit a notion of the AEC domain that correspond to the employed model-based systems, and (3) maintain continuously up-to-date context information on the project.

In our research, we explore the use of Bayesian Networks to represent both the results of statistical language processing and knowledge discovery as well as the deterministic model information. In the following sections we present the basic ideas, the architecture and the major components of the developed *Building Information Mining Framework* (BIMF) integrating the different components. More information on the developed framework is available in (Schapke & Scherer 2004) which provides also a detailed state-of-the-art analysis and further references.

2 RESEARCH APPROACH

The basic idea of the research is in the integration of existing analysis and modelling techniques into an overall *Building Information Mining Framework* that allows for bringing together different representations and methodologies from the separated document and model domain. This is achieved by means of a modular approach organising the necessary resources and the respective processing methods and tasks into three distinct, yet inter-related information spaces as depicted on figure 1. The integrating network enabling efficient utilisation of the individual analyses results is provided by the superordinate Bayesian Network space.

Various methods were reviewed and respectively selected for adoption to (1) externalise the content of text documents, (2) externalise the domain information from building information models, and (3) represent the knowledge on the text corpus and the application domain in a Bayesian Network. They are shortly reviewed below.

2.1 *Analyses of Document Repositories*

For the analysis of text information a variety of information retrieval and text mining technologies can be adopted. Most commonly a vector space model is used to represent content features and perform further analyses. However, while the different vector space models are usually limited to single representation schemes and an optimised number of document features, we pursue a more comprehensive representation to allow for a flexible interlinking with domain BIMs. Accordingly, our text analysis comprises:

– Normalisation, fragmentation and pre-processing of project documents to enable access to relevant text sections and more focused mapping to the model objects. Ready available text analysis tools such as converters and tokenisers can be adopted

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for specific document domains (cf. Cunningham et al. 2002). An increasing utilisation of standardised document schemata will be important to allow for effective filtering, segmentation and content classification within the industry.

– Identification of specialised terms and phrases to enable a more concise representation of domain-specific content. Methods for entity recognition are available in several text applications but current lexica, thesauruses and expression bases are limited to general constructs such as names and addresses. More comprehensive domain-specific linguistic resources such as the LexiCon (Woestenenk 2002) need to be developed. Information extraction technologies may also provide for identifying complex information units when the document type can be determined through prior classification or schema information.
– Further text mining approaches such as text classification and clustering are increasingly explored in AEC (cf. Caldas et al. 2002, Froese 2004). We intend to implement some of these techniques within the Bayesian Network Model, when a connection between the model and the text information has been established and the available domain knowledge can be considered.

2.2 *Analyses of Building Information Models*

The goal of the model analyses is to automatically create discipline-specific domain representations from building information models that can be used to describe user and task-specific 'search contexts'. Extraction of the domain knowledge can be pursued by translating existing BIM data into discipline-specific ontologies. This provides a method for selecting only descriptive concepts and relations, as well as for reconfiguring the model to fulfil additional modelling constraints of the Bayesian network space. Furthermore, the model-based information can be supplemented with additional data about typical appearances of terms or phrases that can be associated with each concept. However, the success of this approach is strongly dependent upon related developments in the areas of model translation, model mapping, multi databases and ontologies for information platforms in AEC (Hyvärinen et al. 2004). Model transformations can adopt and extend existing specifications (e.g. EXPRESS-X, VML, CSML) and related tools, interfacing respective ontology construction software to provide the final 'mapped' results.

2.3 *Creating Bayesian Network Representations*

The goal of the investigations for Bayesian network modelling is the exact and comprehensive representation, interlinking and weighting of the different analysis results and further context information into an integrated Bayesian network (Pearl 1988, Baeza-Yates & Ribeiro-Neto 1999). The advantage of that network is that it can be used (to a certain extend) to represent both the results of numerical and statistical methods for language processing and knowledge discovery, and the results of deterministic model information and reasoning. To limit the complexity of the network the context information is modelled with binary variables. In this context, the probabilities of individual variables can be regarded a measure for the relevance (or importance) of the model objects, concepts or document feature represented by these variables. By manual instantiation of an individual variable the respective search context and need for information can be described and the relevance of further concept and document variables can be determined through network propagation.

Here, different types of Bayesian networks and network configurations can be explored. Taking into account the specific characteristics of the analysed information domains we suggest to first distinguish between a knowledge and a document network. The separate presentation of different sources allows for successive, straight-forward modelling of the individual knowledge domains, and the various influences on the overall information mining process, respectively. A matching analysis is then performed to interlink the two networks.

3 THE FOUR LAYERED BAYESIAN MINING NETWORK

The most critical issue in establishing the *Building Information Mining Framework* is the combination of the document and the model world in a superordinate information space. As stated above, we explore Bayesian networks to integrate the statistical text analysis and the deterministic model analysis. Our *Bayesian Mining Network,* adapting and extending probabilistic Information Retrieval models developed during the 90s (Baeza-Yates & Ribeiro-Neto 1999, de Campos et al. 2002, Schapke & Scherer 2004), combines the knowledge and the document network as depicted in figure 2.

On four separate layers the developed network represents (1) the knowledge on the building information models (product model layer), (2) the discipline-specific domain ontology representation (concept layer), (3) the contents of the text documents (descriptor layer), and (4) the overall document collection (document layer). The combined network can be used, in an evidential reasoning process, to reconfigure the collected information to most effectively support various retrieval or mining approaches, i.e. the available structure and context information is canonized and weighted for a subsequent combined analysis.

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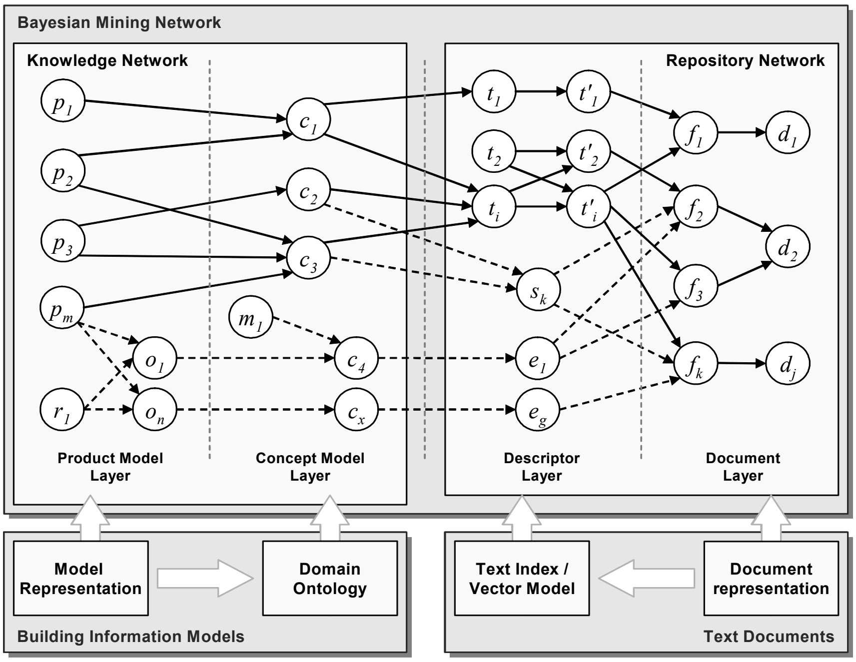

Figure 2: Analyses and Integration of Results in the Building Information Mining Framework (BIMF)

To validate the overall approach we have implemented a software suite named *dokmosis (Document and Knowledge Modelling Services)*. In the following subsections a first basic network configuration (depicted by the variables connected by solid line arcs in figure 2) that utilises selected text and model analyses is described in more detail.

3.1 *Constructing a Basic Repository Network*

The repository network is comprised of the document and the descriptor layer. In the basic version of the network it represents the knowledge on the document collection using document nodes d_j and fragment nodes f_k on the document layer, as well as descriptor nodes t_i on the descriptor layer.

The two layers are built using four text analysis modules of the *dokmosis* suite. Firstly, a collection module provides for importing documents and converting them to a common format based on the *DocBook* specification (see http://www.oasis-open.org). Secondly, a heuristic fragmentation algorithm is used to compile text paragraphs into equally large, self-contained text fragments; the resulting *part-of* relations are represented by arcs connecting the corresponding fragment and document variables. Thirdly, the fragment's text content is pre-processed, performing tokenisation, morphological analysis and stop-word removal. At last, by indexing the fragments a vector space model considering different term weighing can be built.

Based on the term weights the conditional probability distributions of the fragment variables are configured for exact Bayesian inference. Considering all index terms to be equally important we can assume a marginal probability distribution of $p(t_i{=}true)=1/M$ and $p(t_i{=}false)=1\text{-}1/M$, with M being the number of index terms for each concept node. For the possible value combinations of all $t_i \in d_j$ the conditional probabilities $p(f_k|t_1,\ldots,t_i)$ are computed by the sum of the respective normalized term weights (cf. Schapke & Scherer 2004). Thus, simulating a query Q by manually instantiating certain term variables, we obtain a posterior probability ranking of the variables that is equivalent to the fragments' ranking in classical information retrieval.

Furthermore, to increase the influence of the comparably few labelled concept nodes and, respectively, the recall of network-based information retrieval, term interdependencies such as term similarities and synonyms can be considered on the descriptor layer. To ensure a directed acyclic graph, the descriptor variables are duplicated and interconnected one-to-one. By inserting additional arcs and probability distributions the term similarities obtained from thesauri or by a term similarity analysis of the collection can be modelled.

3.2 *Constructing a Basic Knowledge Model Network*

The product model layer and the concept model layer together represent the configurable knowledge model used to trigger and control information retrieval and mining processes. In the basic version, the knowledge model network represents the user's knowledge via product model classes, denoted p_m, and engineering concepts c_x. The two layers are generated in the following consecutive analysis steps.

Firstly, the product model data to be considered is imported, transformed and represented on the product model layer. In the basic version the underlying knowledge model is restricted to a set of classes obtained from a product model server. For this purpose

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the *dokmosis* suite integrates a client to the *VooDaMaS* product model server developed in the iCSS project (cf. iCSS 2002), which has been complemented with methods to identify both the classes defined in an EXPRESS schema and those used in corresponding instantiated product models. For each class in the returned result set, an independent variable is added to the product model layer.

Secondly, ontological information is used to derive a discipline specific concept model from the available product model information. For this purpose the *dokmosis* suite uses an adapted, somewhat simplified version of the *ontology interpreter* developed in the EU ISTforCE project which enables mapping of the model information to an engineering ontology (cf. Katranuschkov et al. 2003). To achieve an easy to process 'flattened' discipline-specific network, the ontological mapping specifications are confined to 1:1, 1:C, and C:1 mappings that allow for filtering or aggregating classes from the original result set. Hence, for the time being, only Boolean relations interlinking corresponding model and concept variables are represented in the knowledge model network, while independence is assumed among *all* nodes on the same layer.

Finally, the mapping specifications are supplemented by lexical descriptors to label each engineering concept with suitable terms. Thus, in the basic network, the concept nodes essentially represent the names of selected product model classes.

3.3 *Combining and Querying the Basic Repository and the Knowledge Model Networks*

To enable adequate reasoning on the overall mining network, the knowledge model and the repository network are interconnected, matching the concept labels with the descriptor nodes. Based on the concept mapping logical operation can be modelled with the conditional probability distributions.

Whilst the presented basic mining network is relatively easy to establish and process, it already provides for some new possibilities to formulate queries and express information needs compared to pure text mining approaches. In parallel to initiating a full text search on the descriptor layer, discipline specific concepts or model classes can be instantiated. Exemplary data models as well as common engineering classification schemes can be used to visualise the indices on the three top layers.

4 EXTENDING THE BASIC MINING NETWORK

The basic mining network can be beneficially extended in several ways. On each layer enhanced representation schemes and interdependencies among the variables can be identified to increase the expressiveness of the mining network.

4.1 *Extensions to the Repository Network*

To account for annotations and other structural information on the document's content, we propose to consider a second representation scheme depicted by the variables s_k on the descriptor layer. We expect the content meta information to provide for evidence on the characteristic syntax and semantics e.g. of domain-specific documents such as specifications, punch lists or protocols, as well as the user's respective domain of interest (cf. Caldas et al. 2002).

A third representation schema denoted e_g is used to represent named text entities and content objects embedded within the fragments. The text entities can be identified through previously assigned annotations as well as further content analysis.

Currently, the *dokmosis* suite integrates two entity recognition modules. First, the text analysis module provides for direct, regular expression based entity recognition of e.g. persons, organisations, addresses, codes and regulations, scales, formulas. Secondly, an information extraction module based on the *SpecEx* Extractor (Grimme 2003), that identifies information elements such as actors, tasks and responsibilities within functional, full-text work specifications. Manually labelled work specifications are used to train instance-based classifiers for automatic annotation of respective tokens and phrases. The on-going prototype implementation will provide a first indication of the potentials of respective extractors.

4.2 *Extensions to the Knowledge Network*

Corresponding to the *entity representation,* an *object representation scheme* is introduced on the product model layer. Differentiating between model classes and instantiated model objects, denoted by the nodes p_m and o_n, respectively, more detailed background knowledge on a given project can be provided. Distinctive concept nodes are added to the concept model layer for every class and object node. Their interrelations are recognised via the corresponding product model root node. It seems reasonable to first limit the extension to *instance-of* relations. Typical model relations can be represented on the model layer as illustrated by the variable r_1 in figure 2. However, more comprehensive analyses and information deductions are required to obtain meaningful relations from the product model information to truly enhance information retrieval and mining.

The main idea of the enhanced concept layer is to allow for personalised configurations of the applied background knowledge, without having to change the original model-based information. Additional context and user information can also be utilised to

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re-label classes or alter discipline-specific concept views. To consider the influence of discipline-specific aspects without having to rebuild the concept model network, we introduce mental model nodes, denoted m_l, to allow for conditioning the relevance of each concept variable on distinctive mental models representing e.g. architectural, managerial or engineering domain views.

4.3 *Querying the Extended Mining Network*

The described additional representation schemes provide for numerous new ways to interconnect the variables of adjacent network layers. However, to limit the complexity of the network topology, we focus on two separated retrieval paths as illustrated in figure 2. The network based information retrieval of the basic mining network using product model classes is separated from the propagation of beliefs on respective instantiated product model objects. Furthermore, we assume the variables of different representation schemes on a layer to be independent among each other, even though possibly interrelated via variables of the preceding layers.

The explicit representation of modelling objects and text entities demonstrates very well the possibilities but also the challenges of directly interlinking product model and text information. Via the concept nodes product information can be explicitly connected with corresponding text elements to be automatically retrieved from the repository. The interlinking of the document and the model domain already supports collecting information elements such as punch list items or errors/omissions corresponding to certain building elements for subsequent information analysis. However, according to the various types of possible objects and entities, a set of similarity measures needs to be established to determine the probability that *'c-e'* node pairs really represent the same aspect. The previously applied ontology-based transformation to group, abstract or generalize model objects to meaningful concepts can greatly affect the possibilities to identify the 'best matches' among the concept and descriptor nodes.

5 CONCLUSIONS

Bayesian Network based information retrieval models have been identified as a very flexible technology that allows for representing various information resources and evidences to retrieve relevant information from document repositories. We argue that the presented approach provides a good basis to utilise appropriate background knowledge and additional context information in the processes of externalising information from respective AEC documents.

Due to the possibilities to encode the knowledge on the variables in terms of both causal relations and conditional probabilities, networks can be configured to support simultaneously logic operations and numerical mining techniques. This is an essential capacity allowing to interrelate the rather deterministic world of model-based systems with the rather fuzzy world of text and language processing.

By explicitly interlinking product model and document information we expect the mining network to support the understanding of available interrelations among the two domains, thereby revealing new retrieval, mining and integration strategies for more efficient and reliable information management.

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IS tools for knowledge management in public construction projects

N. Marja
The University of Vaasa, Vaasa, Finland

J. Päivi
Seinäjoki Polytechnic School of Engineering, Seinäjoki, Finland

ABSTRACT: This paper focuses on the possible tools of knowledge management by exploring offered, needed and wanted knowledge. We study knowledge management by exploring how the tools are utilized currently in case projects in Finland and how new tools could improve the processes. We also aim to study what kind of obstacles there are for IS tools utilization. New ways of organizing work are resisted and people very soon become cynical and unintended consequences of techno change failure hinder the success of the new change efforts. It is important to be aware of this and change efforts should be implemented in project work by letting the practitioners effect the change and select the way of working. We also found that often ICT have positive effects on the challenges but that often there is a critical mass problem, where the benefits are not yet gained if there are not sufficient users.

1 INTRODUCTION

The article is based on the findings of the PROLAB-project. The project seeks to find solutions for how information can effectively be used in project management, especially in construction projects, what kind of procedures help the management of knowledge and how the obstacles to efficient ways of administrating the information can be removed. This paper is based on four case studies.

The paper focuses on the possible tools of knowledge management by exploring offered, needed and wanted knowledge. We study knowledge management (KM) by exploring how the tools are utilized currently in case projects in Finland and how new tools could improve the processes. We also aim to study what kind of obstacles there are for information system (IS) tools utilization. We aim at exploring what kind of tools can improve success in projects. The research is qualitative, aiming at exploring the IS tools of knowledge management in construction projects. The paper is based on four case studies in public construction projects in Finland.

Knowledge management (KM) is according to Brelade and Harman (2001) obtaining and using resources to create an environment in which individuals have access to information and in which individuals obtain, share and use this information to raise the level of their knowledge. In addition to this individuals are encouraged and enabled to obtain new information for organization. Egbu (2001, p.126) argues that KM should be understood to mean the processes by which knowledge is created, acquired, communicated, shared, applied and effectively utilized and managed, in order to meet existing and emerging needs and to identify and exploit existing and acquired knowledge assets.

Since the 1960s, information technology (IT) has become an all-pervasive force in the business world, superseding more conventional tools for data storage and communication. It has been argued that IT has the potential to "redefine the management and control of global basis through the removal of barriers such as time and distance" (Egbu 2000, p.109).

Naaranoja et al. (2005) have studied how difficult it is to know what kind of knowledge you need in a project and how people filter the information they don't want to learn. This filtering may also include issues that they should learn. People do not utilize all the available knowledge resources. These resources might be people or tools that give new knowledge, e.g. on the state of the building they are renovating. The offered knowledge may not be trustworthy, or you don't need the knowledge at that moment. They also tried to find out how knowledge resources are critical and why they are accessed or, even more importantly, why they might not be accessed and how managers can know what offered knowledge they should take seriously in the project environment. Their conclusion is that a more relevant question is how the manager facilitates the learning in the team and makes people to learn from

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each other. The project manager is not able to select what knowledge is reliable, but he should be able to know how the project is organised and who knows what and therefore who is able to select what offered knowledge should be taken seriously.

Love et al. (2004) argue that rework is an endemic problem in building construction projects in Australia. Research has shown that rework is the primary cause of time and schedule overruns and quality deviations in projects. Delays and cost overruns are seemingly the rule rather than the exception in the construction industry. Design changes are frequent, generating costly ripple effects that create delay and disruption. Projects often appear to be going smoothly until near the end when errors made earlier are discovered, necessitating costly rework. Various industry development initiatives have focused on addressing the symptoms rather the causes of the industry's problems.

2 METHOD

The paper is based on literature review and four case studies in public construction projects in Finland, in three municipalities. The number of inhabitants in these towns or municipalities varies between 23 000 to 57 000. The four construction projects that are researched here are:

- Renovation and partly new construction of a school that had mould problems, total area 3000 m^2 and budget 2 7 000 000 euros. Project started 1998 and ended 2005.
- Hospital for senior sitizens, the renovation of the nursing home, total area 7 000 m^2 and budget 5 700 000 euros. Project started 1996 and is still going on.
- University project, 24 000 m^2. Alteration of an old factory into a university and partly new construction. The project started 1997 and was finished February 2004. There were 10 interviews in the construction company, one designer, one end user and the project manager.
- Renovation / partly new construction of a nursing home, total area 3500 m^2. Construction stage started March 2003 and ended February 2004. The case study is based on interviews of 7 construction company employees.

We used theme interviews as a means of collecting information, but we have also collected artifacts of the projects such as drawings, memos, and observed the meetings in two projects. In addition, action research is going on in two towns – the aim of this action research is to find out new ways of organizing knowledge management in the construction projects. In the PROLAB project we studied also other case studies than the four that were selected in order to focus on both the pre-construction and construction stages.

The interview material was scanned by marking not only what the interviewees talked about IS but also the challenges that might be solved by IS. The used classification of the challenges is design changes, construction changes, client, design team, site management, subcontractor, project scope, contract documentation, project communication, procurement strategy and design management. The classification was made according to Love (2004) who aimed at building a holistic rework reduction model. It provides a platform in the context of the challenges of project management, reducing rework in construction projects. From the data we perceived how the IS-tools are utilized currently in case projects in Finland and what kind of tools can improve success in projects and how new tools could improve the processes. We also aim to study what kind of obstacles there are for IS-tools utilization.

3 GENERAL PRINCIPLES OF KNOWLEDGE MANAGEMENT

Knowledge is often defined to be meaningful information. Knowledge is derived from information. What makes the difference between data and information is their organisation and the difference between information and knowledge is their interpretation (Bhatt 2001). Knowledge is the understanding one gains through experience, reasoning, intuition, and learning. We expand our knowledge when others share their knowledge. New knowledge is created when we combine our knowledge with the knowledge of others. Wisdom and insight can be included in the definition of knowledge. Wisdom is the utilization of accumulated knowledge (Cong and Pandya 2003).

Quinn et al.(1996) divided the knowledge of an organization onto four levels: (1) knowing what: cognitive knowledge; (2) knowing how: the ability to translate bookish (knowing what) knowledge into real world results; (3) knowing why: the ability to take know how into unknown interactions; and (4) caring why: self-motivated creativity, this level of knowledge exists in a organisation's culture.

It is recognised that good knowledge management does not result from the implementation of information systems alone (Grudin 1995; Davenport 1997; Stewart 1997). However, the role of IT as a key enabler remains undiminished (Anumba et al 2000; Egbu 2000). IT should be understood less in its capacity to store explicit information and more in its potential to aid collaboration and co-operation between people (Egbu and Botterill 2002). Dougherty (1999) argues that IT should be seen as a tool to assist the process

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of KM in organisations. Such a process relies more on the face-to-face interaction of people than on static reports and databases (Davenport and Prusak 1998). Some organisations have developed software to encourage social interaction in organisations in the hope that a unique forum for tacit knowledge exchange will be established.

Alavi and Leidner (1999) asked managers about their key concerns about knowledge management. The managers expressed concern primarily over the cultural, managerial and informational issues (Figure 1). In terms of the culture, the managers were concerned over the implications for change management, the ability to convince people to volunteer their knowledge, and the ability to convince business units to share their knowledge with other units. Concern was also expressed over how to implement the knowledge management system effectively (Alavi and Leidner 1999). These concerns are all relevant for construction projects, especially because the project environment always bring together people not only from various units but from various companies.

The construction industry provides customized solutions for clients. That is the reason why the knowledge management solutions between clients and construction professionals should focus on sharing knowledge through person-to-person contacts and ICT enabled communication. The co-operation between professionals is more standardized and the codified strategy might be useful in some parts of their work. In this paper we focus on improving knowledge management in construction project by utilizing information systems.

INFORMATION

- Building vast amounts of data into usable form
- Avoiding overloading users with unnecessary data
- Eliminating wrong/old data
- Ensuring customer confidentiality
- Keeping the information current

MANAGEMENT

- Change management implications
- Getting individuals to volunteer knowledge
- Getting business units to share knowledge
- Demonstrating business value
- Bringing together the many people from various units
- Determining responsibility for managing the knowledge

TECHNOLOGY

- Determining infrastructure requirements
- Keeping up with new technologies
- Security of data on Internet

Figure 1 Key concerns related to knowledge management (Alavi and Leidner 1999)

4 IS TOOLS FOR KNOWLEDGE MANAGEMENT

Information system (IS) combine organisational, human and information technology based resources to generate the effective and efficient collection, retrieval, communication and use of information. Information technology (IT) serves IS by supporting business operations and enabling new ways of carrying out organisational activities (Barrett 1995).

Laudon and Laudon (1998) classify IS for knowledge management into four main categories:

1. those for creating knowledge (knowledge work systems): these support the activities of highly skilled knowledge workers and professionals as they create new knowledge; CAD systems, analysis systems, estimating systems. Increasingly, these systems are being integrated both within and across disciplines, thereby facilitating the flow of information
2. those for processing knowledge (office automation systems): these help disseminate and co-ordinate the flow of information in an organisation - word processing, spreadsheets, imaging and web publishing, electronic calendars, desktop databases. These systems are now routinely used within construction organisations to ensure the smooth running of businesses
3. those for sharing knowledge (group collaboration systems): these support the creation and sharing of knowledge among people working in groups - groupware, intranets, video-conferencing, document management systems, bulletin boards, shared databases, electronic mail systems. The use of these systems is growing in the construction industry, but the emphasis has been more on supporting intra-organisation groups rather than virtual project teams that have members drawn from several organisations
4. those for capturing and codifying knowledge (artificial intelligence systems): these provide organisations and managers with codified knowledge that can be reused by others in the organisation - expert systems, neural nets, fuzzy logic, genetic algorithms, intelligent agents. They enable the setting up and maintenance of knowledge bases that preserve knowledge/expertise that might otherwise be lost when a key member of staff is no longer available.

Construction organisations need to view IT as an enabler, which should be part of an integral multi-faceted KM strategy; develop and implement an IT infrastructure for KM which is tailored to suit the needs of the organisation and implement an appropriate training programme that educates the organisation's employees on the benefits of KM, and

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in the use of any supporting IT systems (Carrillo et al., 2000).

Knowledge work systems

Product modelling is a mean of creating new knowledge with the aid developed CAD-systems. Product models make construction plans more effective and competent during construction project and the whole life cycle of the building. Kuhne and Leistner (2002) conclude that there is substantial potential for optimizing management processes in the construction industry when using a product model. The various potentials have been arranged into three areas: collaboration, data processing and controlling.

Office automation systems

Word processing, spreadsheets and other office automation systems are widely used systems. There are numbers of document models and sheets for reports prepared. Also timing is often made by project planning systems. Regulations and documents are often stored in intranets. But the use of electronic calendars and intranet use as publishing and discussing tools is not very common.

Group collaboration systems

Collaboration is a fundamental aspect of project-based work and it is therefore recommended that organisations pay attention to the different types of collaborative technologies that exist.

According Egbu and Botterill (2002) there are good experiences about virtual teamwork stations included desktop video-conferencing equipment, multimedia e-mail, shared chalkboards, a document scanner, and tools to record video clips, group-ware and web-browser. Although it is arguable whether these technologies capture or distribute structured knowledge, many would contend that they are useful at enabling people to transfer tacit knowledge. Perhaps the potential benefits of using such technologies are not fully understood and organisations are more incremental in their implementation of IT.

Artificial intelligence systems

Neural networks have been described as a statistically oriented tool that excels at using data to classify cases into one category or another. Other data mining tools include artificial intelligence tools as well as conventional statistical analysis. Strong proponents of these tools advance the view that the pattern identification and matching capabilities of software can eliminate human intervention. It could be argued, however, that an intelligent human is required to structure the data in the first place, interpret data and understand identified patterns; and of course make a decision based on the knowledge generated (Egbu, Botterill 2002).

5 OBSTACLES

The construction industry does not understand as a whole the need for computable information - the industry's mindset needs to be shifted from pictures to information models. This is a shift that all industries experience. Once the value of a modelling is recognized – and the models of buildings are created – new forms of value can be unleashed.

The obstacles can be categorized into three different levels: 1) individual level (e.g. project team member, procurement manager), 2) organisational level and 3) network level. The levels of the adoption decisions have been discussed within the innovation diffusion theory literature in the form of optional, collective and authority adoption-decisions (Rogers 1983; Engsbo 2003). The projects are realised at the network level.

The obstacles can be divided into four main categories:

1 technical: continual demand for upgrading hardware and software is the greatest obstacle according to Samuelson (2002). There is a lack of supporting infrastructure for security or privacy. Legacy systems and/or standards are needed to be able to develop the systems

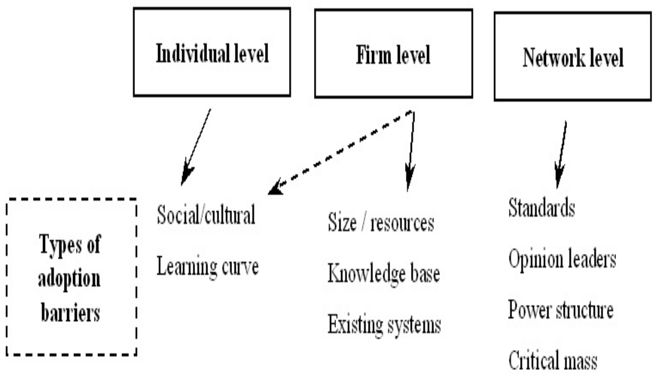

Figure 2 Links between levels and adoption barriers. (Engsbo 2003)

2 human: lack of knowledge of the possibilities and overabundance of information are among the main obstacles to ICT use (Samuelson 2002: 17). Cynicism and defeatism are unintended consequences of techno change failure, preventing the success of the new change efforts (Markus 2003). In addition, there are obstacles such as the lack of project-centric or senior executive commitment; loss of personal benefits from contacts with pre-existing business network; inconsistency with existing strategies, and cultural or internal resistance

3 economic: the strategic objectives are not clear (Love 2004). Investment costs are too high

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(Samuelson 2002). The network affects the utilization of ICT (Bansler and Havn 2004, p 271, 272). The key challenge is to obtain a "critical mass" of users. Many new technologies fail to obtain critical mass and simply flop. The problem is the "chicken and the egg" paradox: many users are not interested in adopting the technology because the installed base is too small, and an insufficiently small number of users have adopted the technology (Bansler and Havn 2004, p 271, 272). Other economic obstacles are investment costs justification, unclear benefits, time or resource constraints, uncertainty or risk aversion; and perceived no-win situations for the individual firm.

4 information or knowledge resources: There is not enough information or knowledge available about certain issues such as how to accept electrically a delivery or also that the security issues are even more important than before since a virus may attack even if there is a firewall.

6 THE CHALLENGE OF REDUCING REWORK IN CONSTRUCTION PROJECTS

The end users of the case construction projects had often experienced communication problems. They did not understand, for example, the drawing symbols of the electric conduits and they experienced confusion when every special designer introduced their design papers. The users pointed out that real size mock ups helped them to understand what was going on. Also the end users had difficulties in expressing their current and future needs.

The designers said that they had to wait too long for the final plans of the main designer. They longed for a controlled timetable for design. Also competition on price was found to be a reason for poor design quality. The designers also talked about the reasons for changes:

- special designers don't always understand the needs of the end user.
- end users change their minds
- designers don't always understand each other
- solutions are not introduced properly for end users.

The designers often talked about commitment and the need to deliver information to every party that might need that information.

The project managers frequently talked about losing the goal of the design and how they did not manage the design process well enough. Also they could tell that document management was not done as well as it could be. The checking of the solutions should be made properly – the designers couldn´t see their own mistakes. The design contracting was also discussed. The best design group has also worked together previously. Maybe it would be best to make a design agreement with the group of designers and not with every designer separately. The project managers also told about the difficulties they had in producing working drawings since the changes were realised at the very last moment in the requirements. Design schedules were seen as challenging: how to give end users enough time to comment on the solutions and the professionals to double check the solutions.

The contractors found out that the design quality was not good enough – when the work starts there are a lot of details lacking. The site managers wanted a better relationship with the designers. At the moment the designers communicate with the site in site meetings, by phone and by fax. The information doesn't flow. On site the personal contacts effect the information flow. The work is not often planned at a reasonable level. The contractors explained that if they could be involved during the design process there would be less mess during construction. Quality systems require bureaucracy that is partly very good and partly the benefits are not visible from the process point of view. According to the contractors most of the extra costs incurred are due to poor design. However, they could recognise some points in how they could improve their own work: change the management, detailed scheduling their own work, documenting difficult situations, and information flows inside the company.

Analyses from the needed, wanted and offered knowledge points of view pinpoint that collaboration systems are the main tool in offering knowledge, but it does not ensure that the knowledge is in the kind of format that it is learned in order to get the wanted or needed knowledge. In addition the needed information might not exist in the collaboration systems. The needed knowledge could be in the artificial systems so that a party would get it whether he wants it or not. The main challenge is how to motivate the designer to utilize the knowledge of the end-user, though it is time consuming and requires a lot of co-operation. We did not find any specific tools that support this motivation.

The collaboration between the site and designers could also be improved by videoconferencing technology in the future. The project intranets could be developed to support the learning of each party, not only the learning of the end user, but also the construction professionals.

The companies are at the moment also starting to create environments where best practice stories are gathered. In the interviews this was seen as a good opportunity by not only giving the template and example documents to the other parties, but also information on possible difficulties and how to avoid them.

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Quite many of the problems in our case studies concern the design phase. Product modelling is one way, but not yet a common way, to enhance the construction planning system. Some pilot projects test product modelling, and the use of IFC specification is under development. Product modelling does not separate the plans of the different designers but it adds to the coordination and communication between designers who usually come from many firms. The use of product models helps the customer orientation as well. 3D visualization decreases the jargon problems between the client and construction professionals. By means of product modelling it is possible to check the constructability and interoperability of plans by model-checker software. 4D-design helps to optimize the schedule. So the product model could be the answer to many designers´, clients´ and contractors´ problems.

Kuhne and Leistner (2002) conclude that there is substantial potential for optimizing management processes in the construction industry when using a product model. The various potentials have been arranged into three areas: collaboration, data processing and controlling. The use of product models for defining a common project language illustrates a basis for well-functioning communication between the project participants and quick availability of data in order to avoid delays and incorrect deliveries. Product models give the chance to estimate time and cost expenses, productivity in e.g. heat flow calculations and bearing capacity, giving a view of a project's life cycle and facility management information. Monitoring and overview of the total project from a cost and time viewpoint, analyses and evaluation, and project-wide usage of product model data simplify the tasks of the project controller, and visualization; at the present time the technical-constructive planning is based on alphanumeric data, it is of an abstract nature and possesses no direct graphical representation, but geometrical and spatial representation is becoming more and more significant for humans in trying to understand and control large projects with complex structures.

7 CONCLUSION

The four case studies showed that the main challenges of knowledge management in construction projects are the requirements of management and constructability analysis of the design and communication during the construction. For example, the professionals do not always want to spend time with the real problems of a customer, though it is obvious they would need this knowledge. We did not find any tools for this motivation purpose. Currently the offered knowledge during the design stage is not in the kind of format that the client would get the knowledge he/she wants or is able to understand that he/she needs. The ICT solutions are able to support in this process by giving visualisation tools and giving advice on what kind of questions need to be answered in each stage of the construction process.

We studied what kind of obstacles there are for information system (IS) tools utilization. The obstacles can be categorized into three different levels: 1) individual level, 2) organisational level and 3) network level. The case construction projects happened in the interorganisational network. The obstacles can be divided into four dimensions: technical, human, economic and information or knowledge resources. Due to the resistance to change and the past failures of techno change the project people very soon become cynical and the success of the new change efforts are not realised. We also found that often ICT have positive effects on the challenges, but that often there is a critical mass problem, where the benefits are not yet gained if there are insufficient users.

In the introduction we promised to discuss what kind of tools can improve success in projects. According to our studies this can be obtained by enabling the learning in the team and making people learn from each other. Nobody is able on their own to select what knowledge is needed, and the project team should be able to know how the project is organised, who knows what and thus who is able to select what offered knowledge should be taken seriously and what knowledge is trustworthy and what kind of extra knowledge is still needed.

The used ICT systems of the case projects were moderate. The benefits of the most modern tools could not be tested. However, this research shows what kind of challenges there are in all projects – the challenges that could or are being partly solved by ICT. Most of the challenges can be found also in projects where there are better ICT solutions in use. It would be interesting to study the practises in projects that have a proper databank in use and study the benefits of such tools. Part of the interviewees had utilised such tools and, in addition, we have made interviews in other case projects in which there has been a project intranet in use. According to our research they had failed to gain all the benefits we have proposed in this paper. How the benefits are really gained and how the change efforts should be made is a subject of future studies.

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Using experience based cases to support construction business processes

F.L. Ribeiro
Instituto Superior Técnico, Departamento de Engenharia Civil, Secção de Estruturas e Construção, Lisboa, Portugal

ABSTRACT: Many business processes in the construction supply chains involve creation and consumption of massive amount of knowledge. Some construction organisations may use such knowledge as a competitive differentiator. The benefits that an organisation in the supply and value chain reaps from relevant experiences will also be beneficial to the organisation's clients, suppliers, and business partners. However, there is normally a lack of explicit knowledge about their business processes.
Recent research indicates a trend toward increased emphasis on a smooth integration of knowledge and business processes (O'Leary and Studer 2001; Lee and Wang 2001; Glushko *et al*. 1989). The real issue for construction organisations is how to gather, organise and reuse the knowledge generated by previous business processes to beat competitors. Case-based reasoning is a technology for problem solving based on recall and reuse of specific experiences. Case-based reasoning offers techniques for acquiring, representing and managing previous experiences, augmenting a set of specific experiences with generalised knowledge and formalising a typically informal body of knowledge. This paper argues that experience-based continuous learning is essential for improving business processes in established areas of construction business. It presents an approach to the implementation of the experience-based organisational learning using case-based reasoning processes.

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1 INTRODUCTION

Since a construction supply chain spans over multiple organisations, knowledge management happens in the background –in real time. It is done by everyone as part of the day-to-day business. Thus, knowledge and experience are becoming critical success factors for an enterprise's business processes.

Recent research indicates a trend toward increased emphasis on a smooth integration of knowledge and business processes (Glushko *et al*., 1989; Lee and Wang, 2001; Smith and Farqukar, 2000; O'Leary and Studer, 2001). Besides, the importance of capturing and representing knowledge-intensive business processes as part of the organisational learning processes is recognised (Tautz, 2001). The real issue for construction organisations is how to gather, organise and use the knowledge generated by previous business processes to beat competitors, bearing in mind, however, their project-by-project mode of operation.

Case-based reasoning is a technology for problem solving based on recall and reuse of specific experiences. Case-based reasoning offers techniques for acquiring, representing and managing previous experiences, augmenting a set of specific experiences with generalised knowledge and formalising an otherwise typically informal body of knowledge.

This paper argues that experience-based continuous learning is essential for improving business processes in established areas of construction business. It presents an approach to the implementation of the experience-based organisational learning, using a case-based reasoning approach.

2 KNOWLEDGE A KEY FACTOR IN CONSTRUCTION BUSINESS PROCESSES

The role and importance of knowledge as a key source of potential advantage for construction organisations have been addressed by several authors (Egbu *et al*., 1999; Kulunga *et al*., 1998; Quintas *et al*., 1997).

It is recognised that in many construction organisations, there is normally a lack of explicit knowledge about their underlying processes, products and technologies. Usually, such knowledge is built up through individual learning from experience of the people involved. The discipline of organisational learning tries to improve the scope for individual (human) learning in the interest of a whole organisation. Besides, improving group learning also includes documenting, acquiring and representing relevant knowledge, and storing it to reuse and share it in a distributed corporate memory (Egbu, 2000).

Business transactions are accompanied by various issues in order to assure follow-up and action, such as the required ordering information, technical specifications, organisational and legal prerequisites, delivery procedures and definition of results. Each side in a business transaction develops their own business processes in order to facilitate and assure that the client/customer needs are fully satisfied within the supply chain (Vrijhoef and Kostela, 2000).

A business process is "a set of one or more linked procedures or activities which collectively realise a business objective or policy goal, normally within the context of an organisational structure defining functional roles and relationships" (Lawrence, 1997). Any business in the construction supply chains, (ranging from a construction contract to the supply of building components for a project), can be viewed as a set of processes. A single business process can be anything from a work order to a detailed design. For example, in a business transaction involving the contracting of work by a contractor to a subcontractor, the main processes may include: preparing production documents and specifications; selecting a subcontractor; negotiating; contracting; supervising; accepting. In the same transaction, the subcontractor may develop the following processes: preparing proposal; preparing production documents; and executing.

Many business processes involve creation and consumption of massive amounts of knowledge. Therefore, capturing and reusing such knowledge and experience is essential for the effectiveness of business transactions in the construction supply chains. Some organisations in the supply chain use their knowledge as a competitive differentiator, some sell it directly, and others offer services and technology to enable their clients to improve their own knowledge management. Although, the construction supply chain is different for each project, the experience-based knowledge will be pertinent for all participants. Thus, the benefits that an organisation in the construction supply chain reaps from the experience-based knowledge accumulated along its projects will also be beneficial to the organisation's clients, suppliers, and alliance partners.

Construction organisations are all under pressure to cut costs, stay competitive in their markets, and penetrate into new markets. Therefore, enabling construction organisations to gather, organise, share and reuse the experience of their business transactions is seen as important to competing in the current economy. However, knowledge and experience from a construction organisation perspective involves the implementation of knowledge in such a way that it adds value to the organisation. The technology available today allows organisations to easily share the knowledge they create with their business partners (Piatetsky-Shapiro, 1999). For example, knowledge acquired from analysing a financial or marketing database could contribute to revising business practice and influencing management policy.

3 CAPTURING EXPERIENCE KNOWLEDGE INTO BUSINESS TRANSACTIONS

Business processes are increasingly being used to capture and store experience (Funk, 2001). Some processes have been refined and improved over long use and capture the experience gained by people handling them. They are an important source of lessons learned (successes and failures). Besides, business processes may capture lessons learned in a wide area of applications, e.g. product specifications, planning, budgeting, and inspection.

A business process consists of a set of activities that are carried out to reach a specific goal. To implement a business process, people have to communicate and collaborate. To carry out an activity within that process, people need specific skills and knowledge as well as concrete information as an input for the task at hand. This knowledge should be attached to the activities carried out as part of the business process in question, thus showing that the knowledge is goal-oriented and focused on what is needed to perform the job. Therefore, business processes may capture experience and lessons on a wide variety of issues, and if reused can be a key to an organisation's success. The captured experience and lessons are expensive to gain and are often acquired over a long period of time, and so building experience bases is an important issue in most business areas of a construction organisation. Thus, business transactions allow organisations to capture enormous amount of knowledge.

A construction project generates a lot of information available for reuse. Construction organisations must learn to gather and share intelligence. As part of engineering the business, organisation, planners capture business processes in models and implement them as enterprise applications. Besides, many construction companies have people working on different construction projects. Savings are considerable if lessons learned from prior transactions can be transferred and reused efficiently between those people using proven techniques such as case-based reasoning, as we will now show.

Cases have long been recognised as a valuable knowledge source and a potential tool for collecting, representing, storing and sharing knowledge (Leak and Sooriamurki, 2002). Every previous process can be captured and stored as a case in an experience base. Cases may also store additional information on

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where, when and how many times the case has been reused.

In today's economy, construction companies want to maximise their margins. Integrating, accumulating and reusing experience can be a cost effective way to maximise margins. Gathering, representing and reusing business process knowledge in cases is become easier as vendors line up with case-based reasoning (CBR) software packages. CBR approach offers new opportunities to transform transaction information generated in the construction supply chains into business intelligence.

4 WHY THE CASE BASED REASONING MODEL

Case-base reasoning (CBR) is a problem solving paradigm that is able to utilise the specific knowledge of previously-experienced, concrete problem situations (Aamodt and Plaza, 1994).

In CBR systems, knowledge is embodied in a library of cases. Each case typically contains a description of the problem, plus a solution and/or the outcome. Single cases may be kept as concrete experiences, or a set of similar cases may form a generalised case. Cases may be stored as separate knowledge units, or split up into subunits and distributed within the knowledge structure. A typical case is usually assumed to have a certain degree of richness of information contained in it, and a certain complexity with respect to its internal organisation.

In the CBR approach, a case represents a problem situation. A previously experienced situation, which has been captured and learned in a way that can be used in the solving of future problems, is referred to as a past case. Correspondingly, a new case or an unsolved case is the description of a new problem to be solved.

At the highest level of generality, a general CBR cycle may be decomposed into the following four processes (Althoff, 1989):

1. Retrieve the most similar case or cases
2. Reuse the information and knowledge in that case to solve the current problem
3. Revise the proposed solution
4. Retain the parts of this experience likely to be useful for future problem solving

Many CBR enterprise applications have been developed to capture experiential knowledge in order to support future decision-making (Leak et al., 2000; Sengupta et al., 1999; Watson, 1997). Examples of such types of systems includes: HIPCAP (Weber et al., 2001) and CALVIN (Leak et al., 2000). HICAP is a multi-modal reasoning system for active lesson delivery. CALVIN captures and delivers lessons about where and how to find information relevant to the user's decision-making task. Thus, CBR provides a technology for lessons-learned systems (Bagg, 1997; Weber et al., 2001).

Lessons learned from prior business transactions constitute validated working knowledge, derived from successes or failures that, when reused in the future, can impact on an organisation's processes (Tautz, 2001). Lessons learned can be used for reducing costs, improving quality, and/or increasing decision-making speed. They have been used extensively to support collection and dissemination of knowledge (Weber et al., 2000).

The lessons learned from past business transactions include both lessons learned about the transaction domain and lessons about how to find information that is useful to the problem-solver – information about resources that are useful in particular contexts. Typically, case-based lessons – learned - support reuse by capturing solutions for previous problems and providing them as starting points for future business transactions. They provide help about how to perform the supporting business process to address novel transactions.

Case-based reasoning (CBR) offers techniques for acquiring, representing and managing previous experiences, augmenting a set of specific experiences with generalised knowledge and formalising a typically informal body of knowledge. CBR is a technology for problem solving based on recall and reuse of specific experiences.

Some of the characteristics of a domain that indicate that a CBR approach might suitable include:

1. records of previously solved problems exist;
2. historical cases are viewed as an asset which ought to be preserved;
3. remembering previous experiences is useful;
4. specialists talk about their domain by giving examples;
5. experience is at least as valuable as textbook knowledge
6. case library can be developed incrementally

A very important feature of CBR is its coupling to learning. Learning from experience in CBR happens as a natural by-product of problem solving. Learning is an intrinsic part of CBR, because the solutions to past problems and their outcomes are stored as cases to extend the reasoner´s knowledge (Wilson et al., 2000).

Since CRB approach provides the capability for continuous learning in an enterprise environment, we believe that cases encapsulating business process knowledge, and lessons learned for guiding business processes, have the potential to significantly aid in finding needed solutions and information, both for novices and experts. Therefore, CBR approach can be of significant importance to allow experience to be effective in the kind of innovative setting that currently is expected of the construction industry.

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5 A CASE BASED FRAMEWORK

CBR systems as currently developed tend to fall into three categories (Sengupta *et al*., 1999): *task-based*, *enterprise-based* and *web-based*. Typically, *task-based* implementations have addressed applications goals based only on the constraints imposed by the reasoning task itself. Recently, there has been an increasing trend to incorporate CBR into enterprise applications to leverage corporate knowledge assets (eg. Weber *et al*., 2001; Kitano and Shimazu, 1996). Currently, CBR *web-based* applications are taking advantage of the recent developments in knowledge representation and sharing on the world-wide-web (eg. Gardingen and Watson, 1998; Doyle *et al*., 1998). However, integrating CBR implementations with enterprise systems imposes standardisation constraints.

The *enterprise-based* framework that we propose and which is being developed combines process-specific knowledge with models of general domain knowledge and with lessons that were learned during practical application of the knowledge. With this approach, the CBR framework, besides acquiring experience cases, should also acquire domain and process knowledge. The framework includes collecting, documenting, representing, and storing such knowledge in the form experience cases in an experience library, which is an organisation's memory for relevant knowledge and experience. Knowledge (in the form of process and models) can be enriched by explicit experience drawn from as lesson learned over time.

What knowledge can be stored as a "case"?

- Background knowledge that is required to reach a specific goal.
- Business process knowledge (procedures, working instructions).
- Lessons learned during practical applications of process knowledge (practical knowledge or skills directly observed from participation in a particular task of a business process including guidelines, observations and problems).
- Context information such as information about the project, contract or transaction.

Cases should be structured as business process packages in an experience base (EB), which is an organisation's memory for relevant process knowledge and lessons learned (figure 1). The aim is to increase the effectiveness of individual human learning for whole organisation.

Within the EB included in our framework, all kinds of knowledge and lessons learned that are necessary for daily business should be stored as cases using CBR technology (figure 2). Thus, each business process package should be implemented as a "case" based on a structured CBR approach. This includes a domain ontology for modelling different types of case concepts and case attributes, together with the respective indexes and similarity measures, as well as relations between cases. A business process package may represent a process-step (e.g. Inspection, kick-off meeting) or a process (e.g. bidding, budgeting). Each business process package should have at least one objective or goal which it was established to achieve.

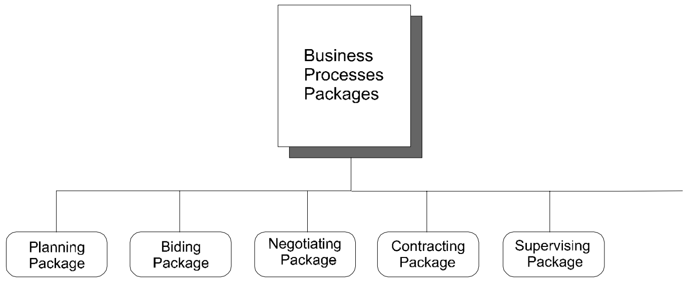

Figure 1. A view of the business processes packages

The goal of the EB is to categorise business process packages based on certain features.

The framework shown in figure 2 must operate in conjunction with enterprise database systems and be integrated within the corporate Intranet to allow people to share the EB resources. The framework can be accessed via a general proposal browser. The enterprise CBR framework consists of five components: CBR engine, Experience base maintainer, Web server, Interface to legacy systems and a General-purpose browser.

At the core of the framework are the CBR engine and the EB. The CBR engine should have the capability to reason over multiple local case bases. Commercial tools available for the CBR engine include the CASEADVISOR and RECALL. The experience base consists of several case bases storing process packages in the form of cases. Cases can be structured in the case base using a partonomic hierarchy because a business process package is a complex set of information and lessons.

The Experience Maintainer module is critical for the EB maintenance over time including extracting, updating and revising cases.

6 CONCLUSION

The CBR approach has been applied to capture and share experience-based knowledge in order to aid future decision-making in several areas. Therefore, CBR supports knowledge reuse by capturing solutions from prior problems and lessons gained from practical application of knowledge. Capturing and managing process knowledge and experience plays a key role in improving construction business processes. Process knowledge and lessons learned from practical application of process knowledge can be captured and organised in the form of cases in an

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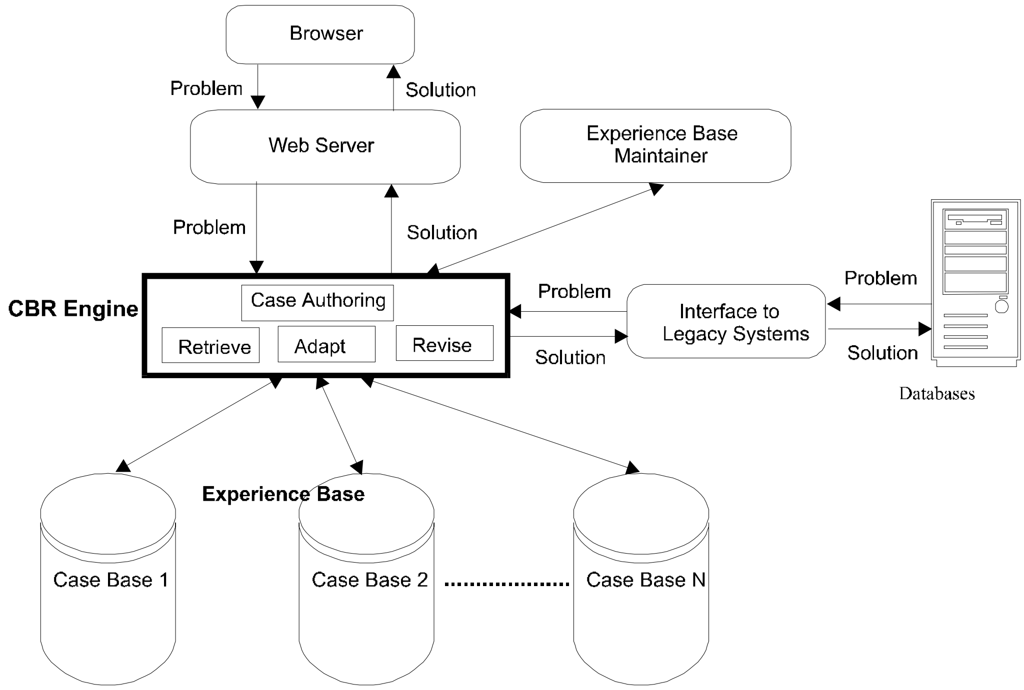

Figure 2: A case based framework

experience base. Cases are recognised as a suitable source of knowledge within an enterprise application.

The importance of the CBR approach for capturing, documenting and sharing business process experience has been highlighted in this paper. Continuous accumulation and reuse of prior process experience is an adequate way to manage and improve business processes within the construction supply chains. Individuals and organisations can take advantage of the remarkable possibilities of accumulating, reusing and sharing knowledge and experience gained from prior transactions. CBR can facilitate content gathering, organisation, browsing, parametric search, and in general, more intelligent access to online information and services.

In this paper we presented an enterprise CBR framework to capture, represent, store and reuse these experiences. At the core of such a framework are the CBR engine and the EB. The proposed framework can be integrated within an enterprise information technology environment and implemented using a commercial CBR tool.

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Web-based Interactive Support for Combining Contextual and Procedural Design Knowledge

J.-H. Lee & Z.-X. Chou
Graduate School of Computational Design, NYUST, Touliu, Taiwan

ABSTRACT: Design study can take design as a process in the form of observing what designers do and how they tackle their tasks. The content of designer decisions and the organization of the process can be corresponded to contextual and procedural design knowledge respectively and they are typically inspected in design process. In this paper, we build a web-based interactive computational tool for designers to support their design process by integrating contextual and procedural design knowledge model. We use a scenario-based analysis to model the contextual design knowledge and the concept of Petri-nets to model a graphical workflow of procedural design process. To exemplify and illustrate our concepts, we focus on a sign design process, even though the system can be applied to a wide variety of design domains.

1 INTRODUCTION

We can examine design as a process by observing what designer do and how they tackle their tasks. When implements to designing are intended, the content of the designer decisions and the organization of the process and have to be concurrently considered, and these two types of knowledge, named *contextual* process-oriented decisions and *procedural*, are typically inspected in a design process (Horváth et al. 2000). The process used to design a product strongly influences the manifestation of the designed product (Horváth et al. 2000). Currently there is much research, available in the literature and from industry, on the structure and kinds of tasks used during designing. However, it is not easy to gather appropriate information within a reasonable amount of time, for the following reasons. First, it is innately complex to consider both the contextual and procedural aspects simultaneously. Second, most designers tend to use paper-based media and manual methods, which can result breaking continuity of thinking in the design process. Third, the information on designing is disorganized and sometimes too abstract to be captured. These problems can be partially overcome through computational support. This requires a better understanding and formalization of the context of design processes from an information theoretical background. For this purpose, we use a scenario-based analysis to model the contextual design knowledge, and the concept of Petri-nets to model a graphical workflow of procedural design process. These two knowledge models are integrated in an interactive tool to support design activities and assist designers.

In this paper, we build a web-based interactive computational tool for designers to support the design process by integrating contextual and procedural design knowledge models. We use a sign design process for illustrating our concepts. First, we attempt to do knowledge acquisition for the sign design process from experienced designers as well as from a literature survey. After the information has been gathered, we use scenario-based analysis and Petri-nets to model the phases of the design process in parallel, and match each one-by-one. Using the framework, we try to validate the approach by designing and implementing an interactive computational prototype, and illustrate how the prototype works through concrete examples. Figure 1 shows the concept diagram for combining contextual and procedural design knowledge.

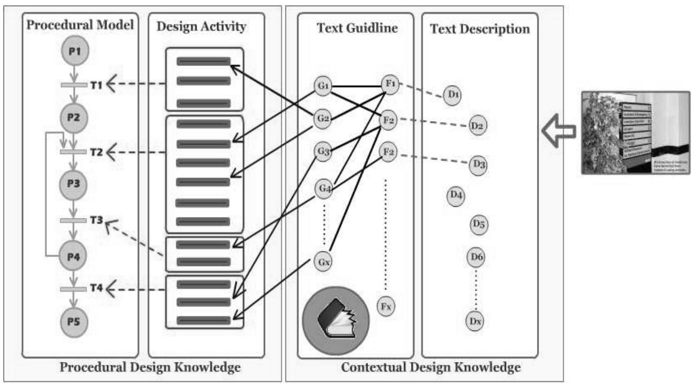

Figure 1. Concept diagram for combing procedural and contextual design knowledge

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2 BACKGROUND

2.1 *Overview of Sign Design Process*

As mentioned above, using paper-based media and manual methods would breaks continuous thinking for a process. To solve this problem, contextual process-based analysis is proposed. In order to develop sign design process, interview with the domain expert and reviewing literature were conducted. Figure 2 shows a typical sign design process, which can be divided into five phases: client requirements, design, protest, produce and maintain.

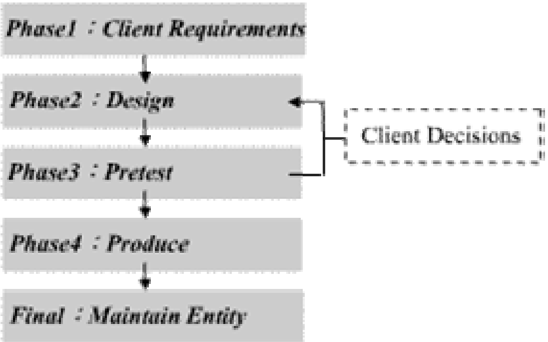

Figure 2. Typical sign design process

There are brief descriptions for each phase:

- *Client Requirements:* In this stage, designer gets environment information and user requirements from client and decides sign types, their positions and sign quality.
- *Design Phase:* Designer considers pictogram design, content text, and letterform. After that, the designer arranges the layout of pictogram and letters, decides color usage, and makes samples to use in the next phase.
- *Pretest Phase:* Designer uses samples to test the visibility in the real environment and check if proprietors accept it or not. If the test is passed, the designer draws working drawings. Otherwise, the designer has to redesign them.
- *Produce Phase:* If all design cases are passing through examinations, the designer sends working drawing to manufacturer to produce entities.
- *Maintain Phase:* Designer has to periodically maintain signage.

For the next two sections, we discuss two knowledge models in design process: contextual design knowledge and procedural design knowledge.

2.2 *Contextual Process-based Design Knowledge*

In general, the design process is evasive and has a number of communication behaviors among different stakeholders. To deal with such an ill-structured and complexity problem, we take a scenario-based design (SBD) approach. "Scenario is stories that about people and their activities, and support reasoning about situation of use, even before those situations are actually created" (Carroll, 2000). SBD manages the complexity of design problem solving by concretization and uses scenarios describing situations at many levels of detail from different perspectives (Rosson and Carroll, 2002). Figure 3 shows an overview of the scenario-based design framework.

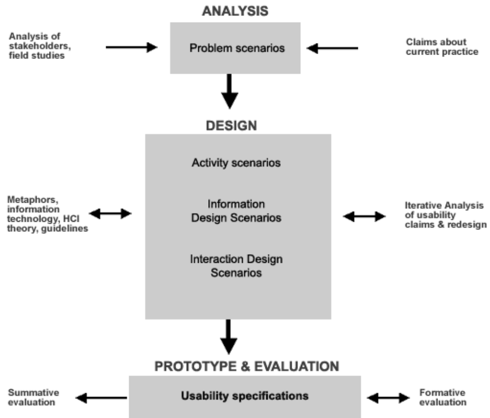

Figure 3. Overview of the scenario-based design framework (Redrawn from Rosson and Carroll, 2002)

This feature of SBD makes ambiguous and dynamic situations easy to evoke reflection in the design process by embodying concrete design actions.

We develop design scenarios, each of which describes a specific phase corresponding to that of the sign design process (Figure 4). The design scenarios can help to extract contextual design knowledge from domain experts and to define functionalities and requirements of a system meant to support the process.

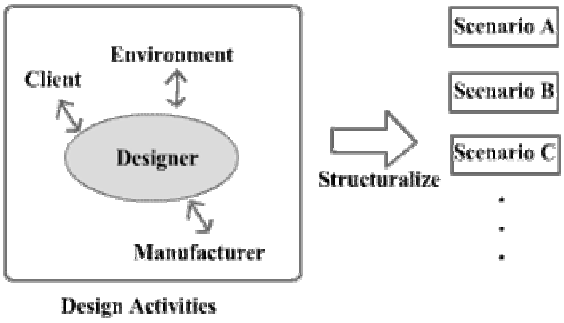

Figure 4. Structuralize designer activities into scenarios

Each design scenario can be decomposed into several sub-scenarios, each of which has a more detailed design task description. Figure 5 shows an example of scenario descriptions for each phase.

Using SBD approach, the unstructured design process can be structuralized and formalized so that we can call *contextual process-based* design knowledge. Figure 6 shows the association between sign design process and scenarios.

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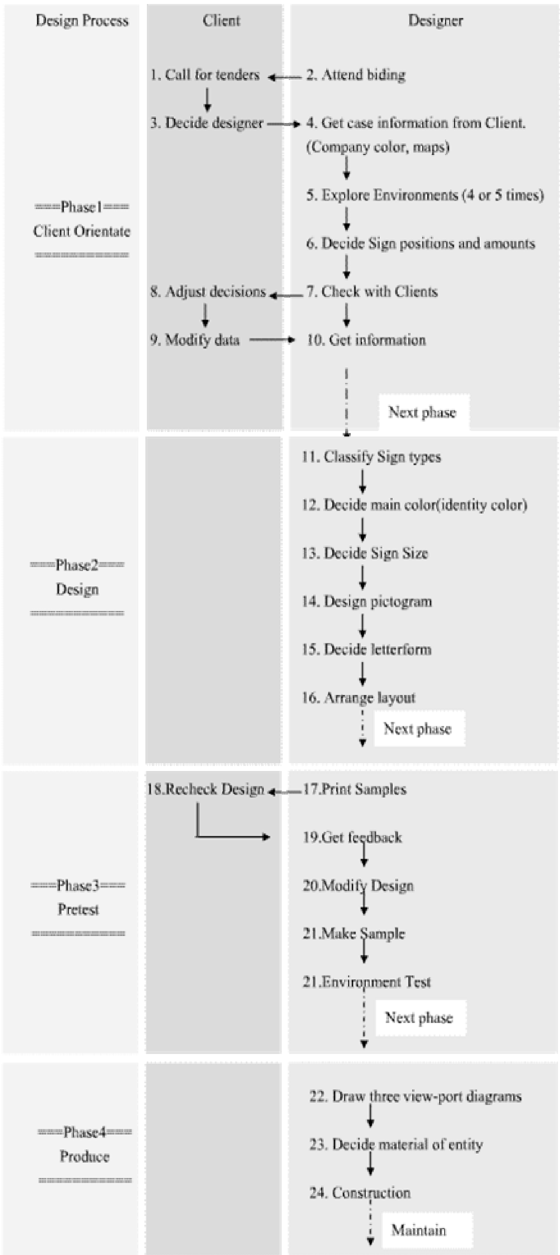

Figure 5. An example of scenario descriptions for each phase

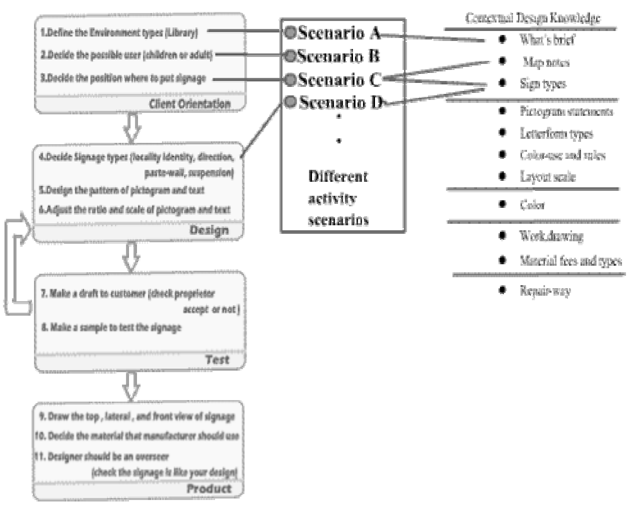

Figure 6. Sign design scenarios mapped to design process

2.3 *Procedural Design Knowledge*

To support the computer mediated selection of design actions and generating a straightforward net of activities, we have to better understand and formalize the context of design processes based on information theoretical principles. It has become accepted that the structural aspects of a design process can be captured by various network representations (Horváth et al. 2000). Up to 1996, more than 250 Workflow Management Systems (WFMSs) are under development. Among a lot of methodologies, there are several good reasons to explain why using Petri-net-based WFMS can benefit (Aalst, 1996). Petri-net is a graphical oriented language for design, specification, simulation and verification of systems. It is in particular well-suited for systems that consist of a number of processes which communicate and synchronies (Jensen, 1997). Figure 7 shows the basic graphical symbols used in design process with Petri-net.

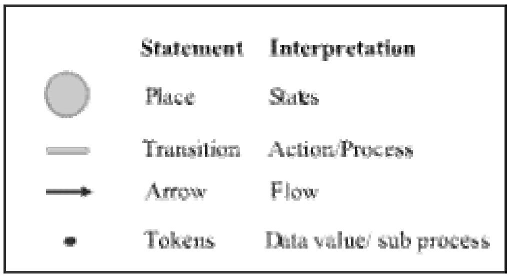

Figure 7. Basic graphical representation of Petri-net

The first reason to using Petri-net is the fact that process logic can be represented by a formal but also graphical language. Figure 8 shows how the six workflow primitive identified by the design process can be mapped onto Petri-nets: AND-join, AND-split, OR-join, OR-split, Iteration and Causality.

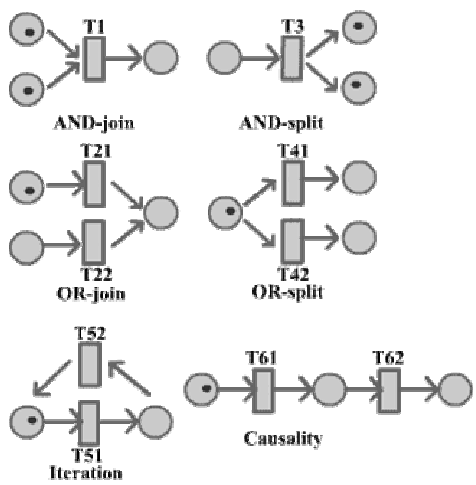

Figure 8. Workflow primitives represented by P-nets (Redraw from Aalst, 1996)

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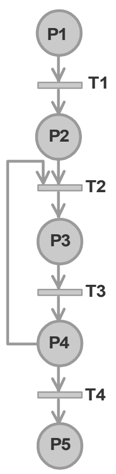
The second reason is that in contrast with many other process modeling techniques, the state of a case can be modeled explicitly in a Petri-net. While other event-based modeling techniques cannot explicitly model the states between subsequent transitions, in Petri-nets, the tasks are modeled by transitions and intermediate states are modeled by places. Using Petri-nets would easy to show each tasks with sub-process.

The third reason is that it contains abundance of analysis techniques. Based on different requirements and situations, users can use different types of Petri-nets to analyze their systems (Aalst, 1996). Figure 9 shows the sign design process drawn by Petri-nets.



Place	Interpretation
P1	An case submit
P2	Previous investigation finished
P3	Signage design finished
P4	Test Signage ok
P5	Case end

Transition	Interpretation
T1	Previous investigation
T2	Design signage system
T3	Test sample
T4	Produce entity

Figure 9: Sign design process with Petri-nets

Each state (P) represents a phase of sign design process and transition (T) represents the actions to be done between states. For example, when designer acquires a design case (P1), he/she has to do environmental investigation to get client's requirements (T1). P2 shows the state that the previous investigation task has been finished. In this process, the designer can start to draw some sign designs (T2). After the designer finishes designing the signage, which changes to a state named signage design finished (P3), the designer prints samples to client to get their opinions (T3). P4 shows the state that the test has been passed. If so, the designer sends the working drawing to manufacturer to make real entities (T4). Otherwise, the designer has to go back and re-design the signage (T2). This is an iterative process until the client satisfied with the design. Finally, when the process has finished, the state is changed to P5, which means the design case is over.

A state comprises several sub-states, each of which has a set of associated main tasks, and so on. Therefore, the whole Petri-net diagram is accumulated grown up and mapping with appropriate Petri-net symbols are required.

3 INTERGRATING PROCEDURAL AND CONTEXTUAL PROCESS-BASED DESIGN KNOWLEDGE

In Figure 10, we show a conceptual framework in parallel and matching the contextual design knowledge with the procedural design knowledge. That is, the design process scenarios are mapped with the Petri-nets that can be assisted by the main phases of design process.

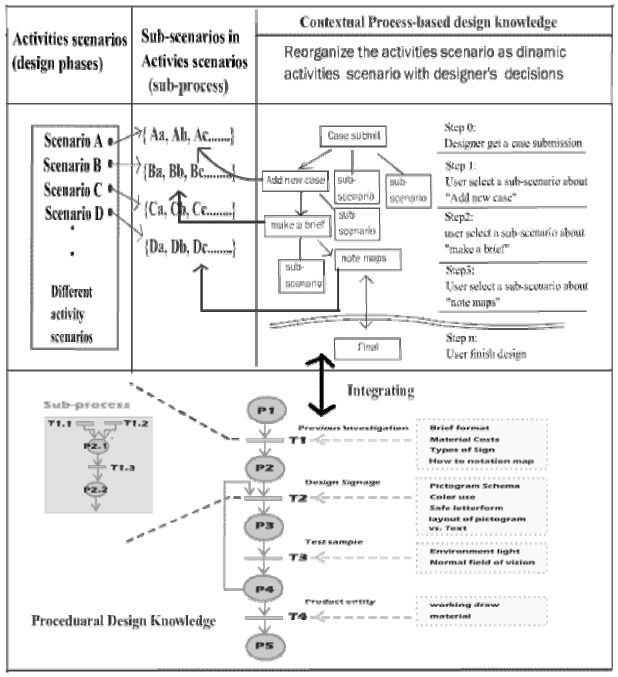


Figure 10. Integrating procedural and contextual design knowledge assisted by the sign design process

The top of Figure 10 illustrates the decomposition of the sign design scenarios. The whole sign design process can be captured by a sufficient number of design *scenarios*. A design scenario, in turn, can be expanded into more detailed *sub-scenarios*, each of which has a set of associated *design moves* that the respective process should accomplish. According to the designer decisions to be made, the shown hierarchical tree generates different alternatives, which is so called *dynamic design decision scenario*. Each hierarchical step represents a corresponding sub-scenario, which is selected from a set of sub-scenario shown in the top of Figure 10. Therefore, the whole procedure from an initial state (step 0) to a final result (step n) generates a unique customized scenario for the designer dynamically.

The bottom of Figure 10 shows the procedural design process represented by Petri-nets. The dynamic design decision scenario tree is mapped onto the design process with Petri-nets. The designer's states and actions are captured and represented with places and transitions of Petri-nets diagram. Each pace and action, respectively, can also expanded into several sub-procedures to describe more details.

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4 PROTOTYPE IMPLEMENTATION

Our system is divided into three parts, which include tasks controller module, data management module, and a graphical user interface (GUI) application. Figure 11 shows the architecture of our system.

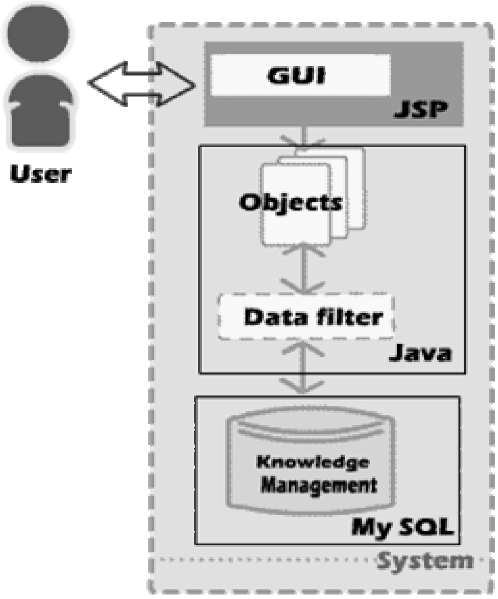

Figure 11. System architecture

Since we want to make a web-based interactive tool for collecting and sharing design knowledge efficiently, the prototype has been implemented by Java, an object-oriented language, to fully take advantage of accessibility through multiple platforms and capability to connect the system in any place. We use Java Server Page (JSP) to make GUI and link to MySQL to manage our design knowledge.

The GUI of our system includes five parts: (A) Displaying the design process by Petri-nets diagram, (B) Selection menu of design tasks in the graphical design phase, (C) Main window for a design task, and (D) List of what-to-do of the design task (Figure 12).

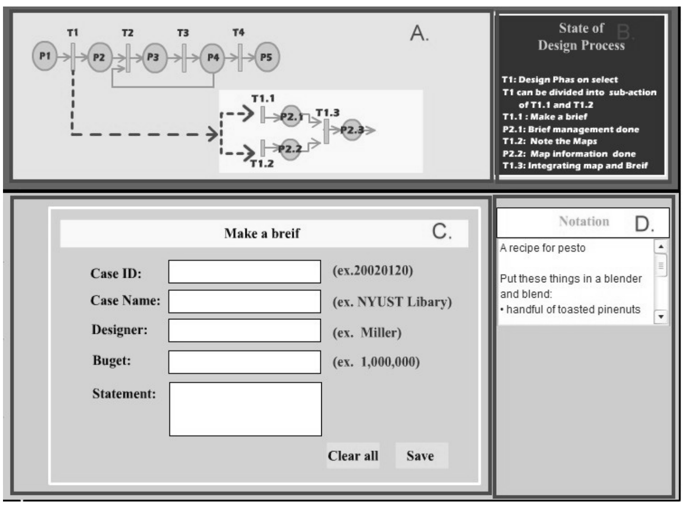

Figure 12. Four parts of the system GUI

Designer can start with selecting a transition of the graphical design process from A. After that, the area B shows the detailed design tasks of the selected transition. When the designer selects a task from B, the main window displays to ask the user for several decisions (C). Area D is the part for providing all what-to-do list of the specific design task. When the designer has finished the task, he/she can push 'Save' button to store the information. In a similar fashion, the user can iteratively assign his/her each decision until all works are done. Using this new tool the designer does not lose the continuity of his/her design process as well as knowledge and tasks for each phase without interruption.

Figure 13 shows the overall workflows between the user and the system.

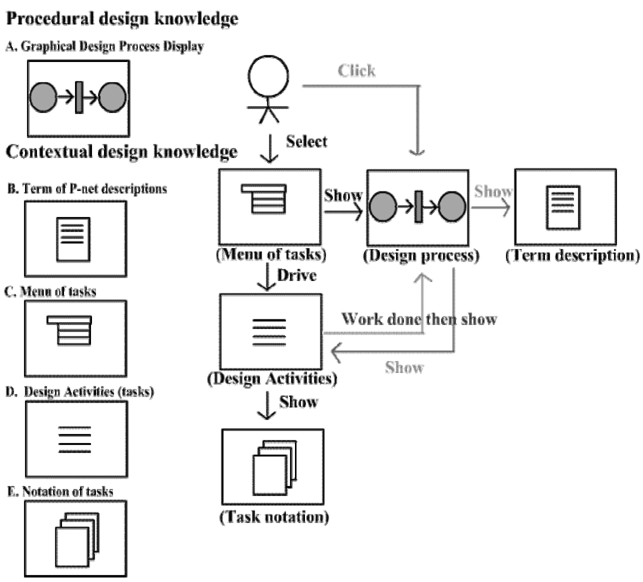

Figure 13. The user workflow interacting with GUI

5 CONCLUSION

This paper describes a web-based interactive system to support the sign design process by integrating procedural and contextual design knowledge models. This new tool can offer a promising application for the design process because it can overcome the limitations of the current problems mentioned in Chapter 1. The advantage of a computational support tool is that users (most likely, designers) can keep continuity of their design knowledge without interruption through the interactive features of the tool. The interactive computational aspect can also be helpful in dealing with the complexity of considering various types of knowledge. Another advantage using the computational tool is that it can be helpful for novices who are not familiar with the specific design process. Design knowledge extracted and converted from expert designers would directly be useful to share with others.

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Collaborative e-learning in Architectural Design: knowledge sedimentation in atelier activity and virtual workshop: IUAV – experimentation 2002-2004

V. Spigai
University IUAV of Venice, Faculty of Architecture, Department of Construction Building, Venice, Italy
C. Stefanelli
University IUAV of Venice, Faculty of Architecture, LAR - Department of Architectural Design, Venice, Italy

ABSTRACT: In architecture, as in other applied disciplines (engineering, medicine, chemistry, experimental physics, etc.) the learning process mainly focuses on a continuos interaction between theoretical knowledge, notions that are acquired through example, through advice of the most capable ones and, above all, practice in the discipline itself. In consequence we have lower possibilities of a collective use and difficult sedimentation of the experience acquired through the design process.

How can all this knowledge and know-how activity be recorded, selected, enjoyable and re-used in different context through an expert web-based system able to store the experience acquired?

In Venice, during the last three years, we tried to recreate this tradition through a web based collaboration system called TDraw, *Telamatic Drawing system*, that is an asynchronous collaborative method organized as a virtual class to which students and professors get on different levels and share graphic files that can be corrected and marked up by the teachers and can be visible to each student of the class; all communications and notes shared during the whole design activity are preserved. The signed/selected works, the typical errors, the exemplar solution represent the greatest effort in teaching the generative process of a project and can be considered as the core of knowledge transmission.

This paper describe how to store and re-use the knowledge and the know-how transmitted through an architectural Course by the classification of the knowledge elements associated to the project and its formative steps. We have been creating a model of decomposition of the architecture complexity in order to create a kind of general memory able to gather the experiences, to automatically refresh its knowledge base on its experience, and to offer it on the web.

This system - called WITarch, *Web Interactive Archives of Architecture*, becomes then a dynamic archive of data, samples and case study, supporting the TDraw system, for the consultation and research through the concepts and key-words ordered according to the semantic-perceptive structure realized on a semantic base. Starting from the first collaborations with the researchers of the Greimas School in Paris, in the first half of the Eighties, prevalently in a linguistic-semiotic field, we have been creating a model of decomposition of the architecture complexity. This model has been interpreted as writing/re-writing through perceptive elements (expressive segments of an architectonical language) of a statement containing cultural, ideological, functional, distributive meanings through spatial structures (topological relations) following geometries normally used in architecture. That memory can be connected on the web to other records of data, both as architecture documentation, (authors, etc.) then as a reference to the knowledge patrimony of industries producing building components.

The system, in its new version, has been working since the year 2002-03 at the IUAV in Venice and in the Faculty of Architecture and Engineering of Venice, Ancona and Pescara inside the WINDS consortium (EU, IST - V Framework Program).

1 SCIENTIFIC STARTING-POINT

In school, in the university and in the world of industry, in many applied sciences (surgery, chemistry, genetic experimentation, experimental physics, engineering, computer programming, laboratory and experimental studies on models in different technical and scientific sectors) and in many applied arts (scenography, lighting design, crafts, interior design, fashion, furniture design, production industry for construction and mechanics), the transfer of knowledge occurs only partially through lessons in the classroom.

It is well-known, in fact, that students in such fields of study learn by means of continuous interaction between theoretical knowledge (from lessons) and concepts acquired through examples and advice from experts, and especially through practice on the

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field (guided with the teacher and/or technical experts that are directed personally and exclusively to the individual student, staff, and workers.

In the domain of scholastic education, in laboratories and in the classrooms of Technical Institutes, Institutes of Arts and Universities, in specialized courses and masters, and in developmental courses in collaboration with the industry, the knowledge of operative-applicative disciplines and projects is transferred only partially through written texts and technical manuals.

A big amount of learning is entrusted to practical exercises conducted with various methods and instruments according to the discipline, characterized by the constant commitment of large amounts of time and energy to every single student to develop his/her personal, individual and specific preparation. Such an accumulation of didactic experience generally gets burnt into the training of the individual. In some cases they are recorded, enabling them to be handed down and entrusted on the average to the majority of obsolete and ineffective cases.

For example, regarding architecture, (the discipline to which the interests and expertise of our research group are primarily directed), even today the didactic transfer methods of theories and design remain assigned principally to a visual-oral tradition (conference with projected images) to practice in the studio (exercises, ex tempore, workshop, conducted collectively in the drawing classes) and to projected exercises executed by students individually or in a group at home and periodically submitted for revisions by the teachers.

All these methods of transfer of the *know* and the *know how* of architecture have great difficulty in being established in a unified and shared body of ideas. The difficulty is even greater than for more solid fields, due to the scientific establishment and traditional technical-training practices divided by contents of theory (for example, courses and practical studies of science of construction and rational mechanics, applied chemistry /stoichiometry).

In fact, the architecture project- even due to the inconsistent theories of the subject-creates a moment of great effort of synthesis, in which various knowledge tied to artistic-poetic inclinations (ideas, social and cultural messages of the project) as well as to technical inclinations (functionality, habitative well-being, constructibility) but also to knowledge of the different levels of the project (from urbanistic responsibilities, to the choice of materials, of details, of components produced by the industry) - are gathered to merge simultaneously, even daringly, in the synthesis projected since the first layout on the drawing board.

How should the multiple experiences be monitored in such ways? How is it possible to record this activity, to select it, use it and make it beneficial in an expert system capable of assisting and monitoring the multiple experiences?

The peculiarity of teaching in applied disciplines resides greatly in the physical support of the student-teacher interaction, which consists of scripts, prototypes, handmade products, or presentations (artistic, sporty, etc) produced by the individual student.

In architecture, the presentation generally consists in an illustrated paper/composition. The corrected and revised paper, marked with suggestions, annotations and notes from the instructor, represents an inalienable moment of synthesis in the teaching and is a very powerful didactic instrument.

With reference to these settings, and to the questions based on them, this research is directed particularly to the following sections:

1- e-learning. The recent evolution of e-learning in disciplines that largely use the technique of "learning by doing" in construction of virtual environments with student-teacher interaction, performed according to synchronous methods or according to methods extended internally in advances systems (collaborative manipulations on the web, between students and teachers, collaborative production of papers, advances systems of mark up);

2- protocol analysis. Monitoring systems and protocol analysis of generative processes of the project (design flow). Recording and description of the flow of typical and significant concepts that are at the base of the solutions operated by expert teachers. Every flow is connected to a particular problem or objective. Every flow contains in its development multiple references to relevant cases and concepts. This representation can be used as a foundation for comparison and as an element of reference in the valuation of the flow of projects effectively used by students.

3- interface between monitoring systems and systems of the solidification of knowledge; possibility to create interface systems online.

2 THE FIRST TDRAW SYSTEM: PROJECTION COLLABORATION AND COOPERATION ONLINE

The educational development passes inevitably through communication of knowledge and operative know how with a relevant flow of ideas and abilities from the expert (teacher) to the student. The complex path of reception and view of papers and their corrections, validations of methodological and enlightening elements, needs constant references to previous experiences, experimental cases etc. Particularly in architecture, in the correction-revision phase, the instructor, describing the better strategies to the solution in relation to the project, making suggestions, references, technical foresight, advises

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possible choices and the text references to which the student can find the necessary documentations.

The critical interiorization of the ensemble of stratagems carried our is the foundation on which one builds the cultural and technical knowledge of the student. We know that this process is widely destructured and left up to the practice and experience of the teacher. On the other hand, the new interest towards economies of scale caused by the introduction of teaching at a distance in all sectors of education, points out the problem of analyzing and rationalizing these cognitive processes that traditionally happen only in presence.

In regard to the enunciated questions, our research is directed to the construction of an e-learning system based on the idea of "virtual studio" intended as a didactic environment (virtual classroom) as well as an ensemble of instruments of student-teacher dialogue for a practice of revision at a distance of the papers by the students and on the experimentation of the system itself.

In such a direction, in the last four years, it has been pointed out and experimented a didactic model centered on a kind of online classroom, that can be fixed in certain locations within the university (such as in appropriately equipped computer classrooms) but also in private terminals dispersed in the region. This system of revision at a distance, named TDraw system (1) has been the first operative experiment of exercises online in Italy in the Department of Architecture and has been successively inserted in the European research system WINDS, inside the V program quadrant IST-CEE (2).

TDraw is not an e-learning system. It rests on an e-learning course (online lessons in the virtual university WINDS) but can also be complementary to a normal course according to the "blended" method defined by users time after time. In fig. 1 the site is represented that in the last academic year had hosted fives courses and laboratories of IUAV, all users of the TDraw service (3).

Beginning from 2001, the TDraw system has been used by about 300 students from different educative courses, of which more than 100 in the year 2003-2004. Among the research objectives of today there is the extension of the system to other institutes and to experiment with it in different contexts and not only at the university level. To this proposition, a collaboration has recently been initiated with the Istituto Tecnico "I.T.I.S. Severi" of Padua (programming language, with exercises regarding the Pascal language). (4)

Also due to the collaboration and experimentation of the system by different users (5), the research group of Venice suggests today to create an upgrade of the system which represents an ulterior way to achieve the following goals:

- structure of "knowledge management" that contains a base of understanding like case studies, best practices, etc. shared between the students and instructor
- the insertion of "knowledge manager" in architecture in TDraw
- the usage of the preceding point in order to operate the realignment of knowledge in such a way as to have the foundation of understanding evolve in a natural and continuous manner

However, TDraw, through the recording of student-teacher discussions, is potentially a monitoring accumulation and organizational system of the knowledge used in the teaching of applied disciplines.

As implied by point 1, even for the complexity within the methodology of architectonic projections, its characteristics seem to be able to easily extrapolate themselves from architecture to other disciplines; in the majority of less complex cases with less unstable statutes (applied technology and arts, engineering, dentistry, surgery, electrotecnics, precise mechanics, etc) that find in practice, in student-teacher example-imitation and in practical exercises, a fundamental moment in the educational formation of the student.

At the end of the solidification and rationalization of the flow of education at the start of 2004, an interactive relational archive named WITarch (6) was integrated in TDraw. The system archiving of such particular forms of knowledge and ability seem to have a potential grounded and epistemological value and to line interests for the didactic scope for improvement (from the pupil's point-of-view) as well as the scope of an evolution of the disciplinary contents (from the instructor's point-of-view).

3 THE MANAGEMENT OF KNOWLEDGE IN THE TDRAW METHODOLOGY: THE COMPLEMENTARY SYSTEM WITARCH (7)

A designed course represents, as it has been said, an effort of synthesis in which different abilities and understandings unite. The student-designer, in order to make them merge and interact in a designed exercise, generally refers to:

- his/her own synapses (individual and personal information, notions, intuition);
- explicit knowledge, the education based on the world of architecture- but also of painting, music, the natural world, etc.- understandings that are traceable and quantifiable and that are transferred through diverse media (by printed texts to internet sites) and are accessible in consolidated "repositories" (libraries, archives, etc);
- tacit knowledge, which is the know how transmitted at the drawing table in a collaborative interaction between the student and teacher, groups of students, groups of designers and which is based on the comparison of experiences and imitation.

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This knowledge is "tacit" which is subliminal to the experiences (of studio practices) and in the traditional didactics of projection it is not formally transported in any medium; therefore, it is not collectively useable at different times.

The aim that brought to the integration of WITarch into the TDraw system, was to understand if and how it is possible to render explicit the tacit form of understanding of collaboration by way of:

– conserving the liberty of the authors with the process to use communication protocols, consolidated and natural (the table, sketch, non-verbal communication);
– rendering the contents and flow of tacit knowledge useable even tto users who are strangers to the process, even in different locations and time.

The activity of the TDraw classes has permitted, in the span of four years of activity, to accumulate an enormous quantity of data that presents hints, indications, and suggestions related to the questions pertaining to the project. This material, the recording of the activity of a community of designer-students and a designer-teacher expert, strongly outlined in the pedagogic point-of-view, is presented as very destructured, at first impression, confusing and difficult to consult with. We asked ourselves if and with what methods this wealth of knowledge- in the traditional didactic activity, destined to be erased after use- could be reused and exploited in different contexts; for example, as a new offer within a course.

However, the very nature of the education acquired through studio-practice is nonlinear and this difficult to organize, carrying the risk of reducing it into a list of abstract rules for the project-design or into a manual.

For such reasons, we developed the indexation system WITarch that provides the possibility to navigate in a personal manner through the internal contents.

Such occurs through concepts that refer to other concepts and which tend to guide and produce the associative process that the student, measuring himself/herself on a projected exercise in the special and stimulating environment of the virtual classroom, puts into action during the brainstorming phase of ideas and solutions to the proposed theme.

In the indexation system, having identified the number of the exercise and the brainstorming phase, the instructor assigns one or more keywords to objects which will gradually accumulate in the system.

This indexation motor refers to the decomposition model on a semiotic basis that recaptures the lucid and always valid intuitions of Hjelmslev, revived by Greimas and his young students at Scuola di Parigi in the 70’s. the model was later ulteriorly adjusted with the decisive influence of the work of Thurlemann (Greimas’s student) in the visual arts field and was reworked by our group in Venice starting from 1980. Successively, it has been experimented for more than ten years in didactic studies in projection laboratories and graduation labs in an extended experimentation involving visual arts, urban projection and building-scale architecture by IUAV.

In the software adjusted for the implementation of WITarch and its consultation exist therefore two types of keywords: the first type, elementary but essential, associates student names to the number of the exercise and paper correlated. Such information is directed to who, taking the course or single unit, finds themselves having to elaborate on analogous exercises etc. The second type, of more general and theoretical interests, refers to: theoretical concepts, significance and a profound sense of the project, constructive and architectonic typologies, perceptible materials (texture, color, etc), geometry, form, conformation, syntactic structures, projected actions, compositive operations in the composition and manipulation of the project (deformation, superposition, addition, subtraction, stretching, scaling, etc), architectonic, historical and geographical references, instruments and techniques of the plan, recurring errors and didactic suggestions, etc.

4 THE DIDACTIC-PEDAGOGIC MODEL: COOPERATIVE LEARNING AND LEARNING BY DOING

The pedagogic premise of the integrated TDraw-WITarch program is the model of the constructivist matrix in which the context of learning and the collaboration among students and teachers and among students themselves all have a great importance. Learning is a social process and communication and collaboration define the learning environment.

This model implies a projection and expenditure specific to the contents and the regard for certain necessary conditions for an effective collaborative learning experience:

– members of the group must have a common base of understanding and a shared objective
– interactions must be developed in an environment of respect and trust and in a climate of informal communication
– there must be a tutor present to organize, monitor, and facilitate the development of the activity and the atmosphere of collaboration
– the building of knowledge must be active and learning is obtained through the involvement of the student and the class
– the solutions to the problems are not intended to verify an understanding already acquired but to comprehend the significance of the contents and to create a new understanding
– the presence of feedback is necessary; the exchange of reciprocal observations and impressions within the group

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– it is necessary the definition of an ontology and the sharing of such can occur through the negotiation of the significants.

The psychologists Carl Rogers and David Kolb were the first to create the theory of “learning by doing” by affirming that learning is easier when the student participates in the educative process. This process has to be based on solutions to problems through experience (experimental learning) and on the ability to self-evaluate the results.

Beginning with these considerations we attempted to define a dimension in which the users interact and work together to reach a common goal of individual understanding as a result of group work. We asked ourselves about the role and contributive value of each in the construction of the elaboration of the contents and in particular in the process that leads to the definition of new contents through the integration of contribution from the class in its own course of brainstorming.

At the base, there is the intention to rationalize and organize the knowledge by ways of memorization, indexation, reuse of solutions (Design Cases) and projected processes (Best Practices). The cases crystallize significant “stories” of the project, choices, failures, technical options etc. The relationship between categories and cases is thus the same between general knowledge (conceptual) and episodic knowledge. The previous is more universal and common to a vast number of examples, the latter is more particular and related to a specific event; cases and categories become efficient instruments for the knowledge of the domain (knowing-that). The process will capture the dynamism of the evolution that from the conceptual phases of formulation develops into the solution.

5 FUTURE INTENTIONS AND POSSIBLE DEVELOPMENTS

The research described up till now has attempted to create and implement an educational program from case-study, learning objects and reasoning cases gathered from projected experiences in the laboratories or studios. In other words, the formation of a general memory of a course with a projected character, able to gather and solidify the didactic experience, to update and self-teach, on the basis of experiences, the education system and to supply it online.

Such memories of the course entrusted to a simple instructor and assistants, could be connected among them to form a memory of the department or faculty; in fist analysis organized by disciplinary sectors (for example, building versus plant design) but maybe also with transversal perspectives (hospital projections: building and plant design).

Furthermore, such memories can be connected to other databanks for architectonic documentation (history of architecture, authors, urban geography, etc) as well as in reference to the accumulations of knowledge of the productive industries for construction components. The connection can be made through the study of appropriate interface systems between keywords of the integrated TDraw-WITarch program and the keyword programs of the integrated databanks. (fig 6)

6 CONCLUSIONS

In the last two academic years (2002-2004) the online revision of the exercises of the students and the Institution of the virtual class TDraw became services that accompany the normal conduction of the courses.

Such habitual practice has been the object- exploiting the asynchronous aspect of the TDraw system to guarantee the complete documentation of the interactions between students and instructors or the virtual drawing table- of a monitoring of such interactions in statistically relevant quantities. The availability of this documentation consented to the selection and filing of the most interesting educational moments and, in so doing, to perfect the logic grid of concepts and terms that could have better indexed the rich flow of information (written and graphic) that characterize the corrections of the projected papers.

The experimentation in the last year has also consented to highlight certain substantial requisites for the perfection of the interface software and of the virtual class while the layout of the WITarch program of the settling of experiences has been consolidated.

To sum things up, the principal goal and the originality of our approach to e-learning in architectonic projections is- other than the one previously describes to adjust an apparatus capable of managing the student-teacher relationship through computer technology- simultaneously, thanks to the characteristics of such a system, to gather prominent experiences and to pour them back out currently in a system of knowledge open to the use of the scientific community.

Thus, a system implementable in time and gifted with automatisms capable of acting out a certain range of self-education.

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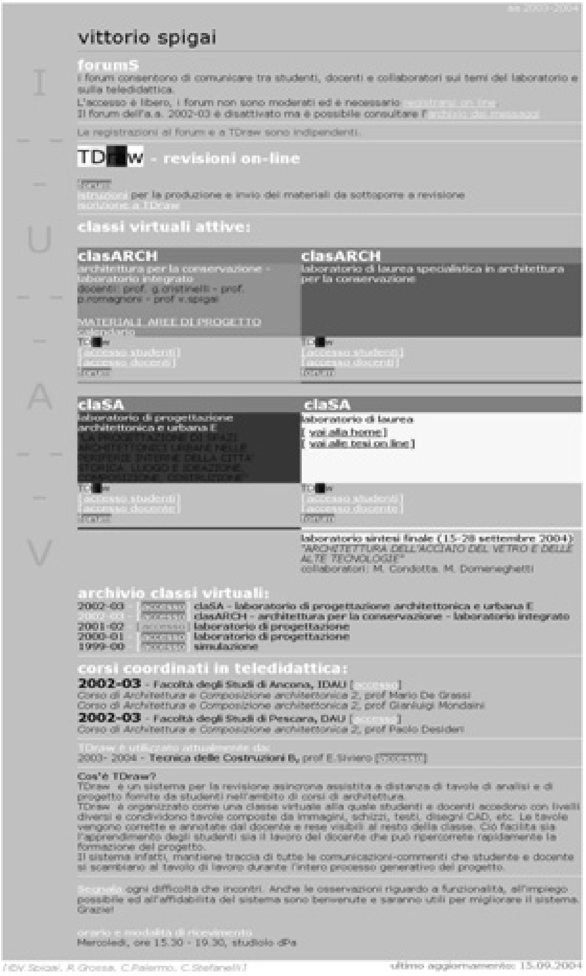

Fig. 1 - The site of the six courses and laboratories of IUAV active in TDraw in the academic year 2003-2004 (prof. V. Spigai and E. Siviero)

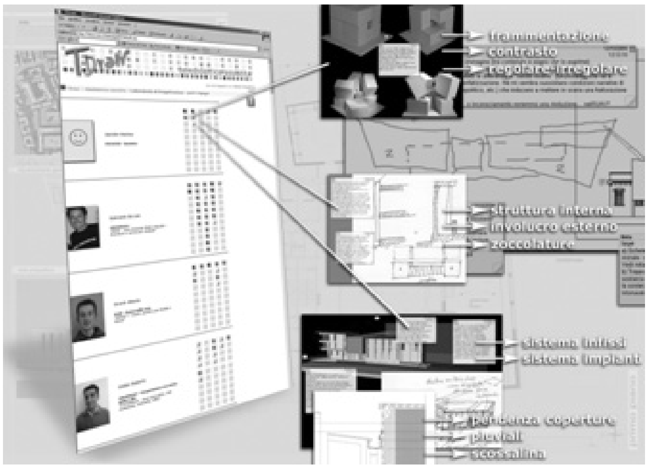

Fig. 2 - TDraw is a system for the asynchronous assisted revision at a distance of analysis tables and of the projects produced by the students in the architectonic courses. TDraw is organized as a virtual class to which students and instructors can access with different levels and share graphic files that are corrected and annotated by the instructor and made visible to all the students in the Course. The system maintains a trace of all the communication-corrections that the student and instructor exchange at eh work table throughout the Course: the materials are organized by stages that correspond to units in the course. At the end of the revision, the instructor associates one or more concepts to the significant corrections according to a system of indexation that refers to the semiotic model of the basis of knowledge.

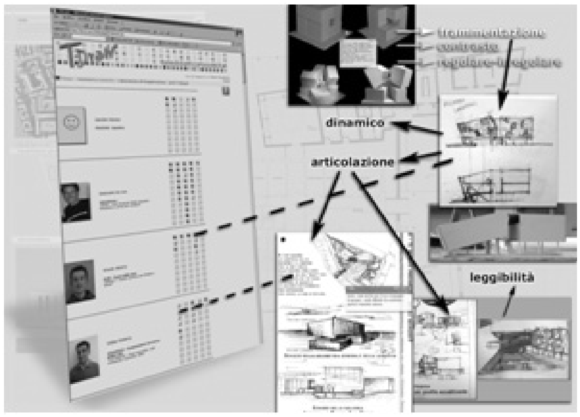

Fig.3 - In the WITarch program,; each object mastered in the virtual studio practice is connected to one or more concepts according to the projection of significance in one of the dimensions of the deconstruction model at the base of knowledge. Each concept recaptures the other concepts and objects through relations between concepts of the ensemble. Each user can, therefore, question the archive with a simple necessity (a concept), moving according to the semantic proximity of the concept, explore the semiotic category of the object or run through paths already explored by other users.

Fig. 4

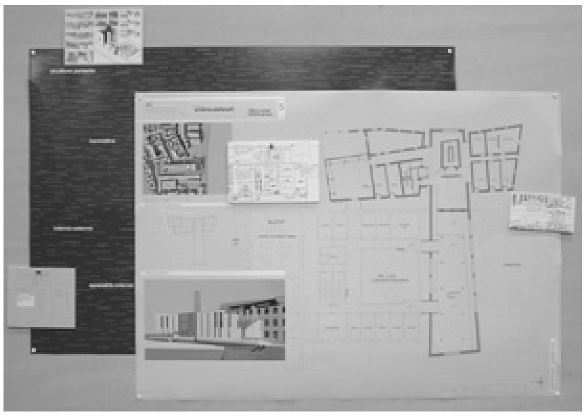

Fig. 5 - An example of projected experimentation with the assistance of the integrated TDraw-WITarch. (this is a project for the enlargement of the IUAV branch near the venetian ex-cotton mill of St. Marta). The reading is on three levels: the first (dark table) represents an image of the cloud of concepts to which one touches to receive hints, suggestions, advice; the second (light table) represents the projected expense; the third (windows) represents the result of the research consultation within the archive of corrections made during previous courses.

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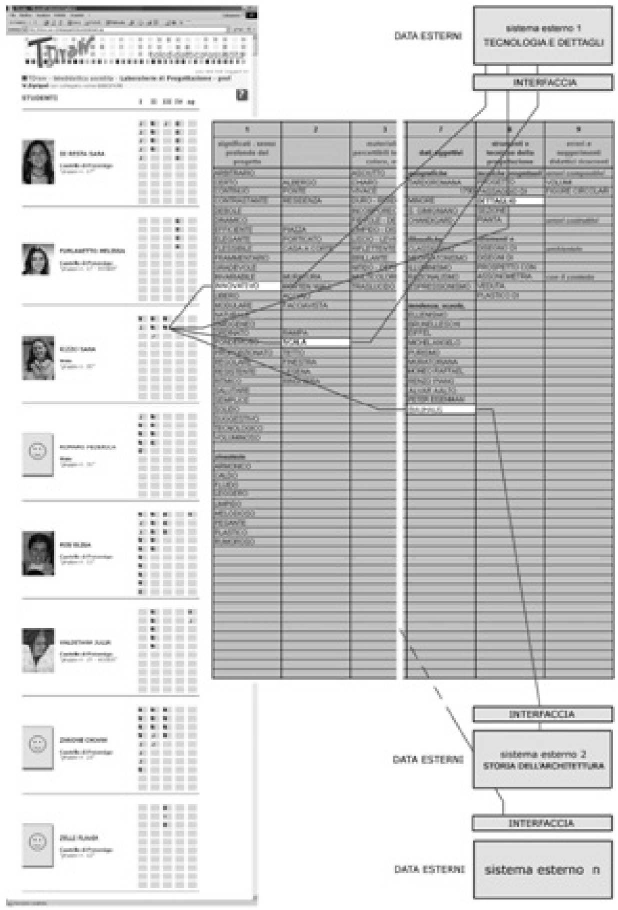

Fig. 6 - Model of links and interface between interactive archive WITarch and other external systems of data filing.

7 NOTES

1) TDraw is an acronym for Telematic Drawing. For a complete elaboration of the specific techniques and communication characteristics and collaboration of the TDraw system, refer to articles of previous Didamatic Conventions 2002 and 2003.
2) The research “WINDS- WEB BASED INTELLIGENT DESIGN TUTORING SYSTEM IN ARCHITECTURE AND ENGINEERING” - coordinated by prof. Mario De Grassi- IDAU - Department of Engineering in Ancona, was financed internally by the CEE program: Information Societies Technology (IST) - Fifth Framework Programme, European Commission, 1998-2002 and 2002-2004. Twenty-seven institutes collaborated to the research from European universities, research institutes (METE s.r.l., CNR- Institute of Psychology) and software and computer programme production companies Nemetschek and FIT.
3) The WITarch research - Web Interactive Archives of Architecture, closely interrelated to the WINDS program, has obtained cofinancing from the Miur inside the following researches:
a) “Definition of the didactic environments for teaching assisted architectonic projection using intelligent tutorial systems” - MURST ex 40% 1998-2001.
b) “Architectonic projection and industrial production for components. Towards an integration for new languages and constructively advanced formats” - MURST ex 40% 2000-2002.
c) “Didactic and collaborative projections online. Virtual laboratories at a distance, implementation systems of the tutorial experience in e-learning integrated with systems task knowledge” - COFIN MIUR 2003-2005
4) The section of the experimentation concerning the student-teacher interaction online was accomplished by the WINDS research of the Multimedia Section of LAR - Laboratory of Research in architectonic projections for the Department of Architectonic Projections of IUAV, under the supervision of Roberto Grossa and specific contributions from Cristina Stefanelli and, for the software elaboration, of Ciro Palermo of SINT- Computer and new technological services- IUAV.
5) In the academic year 2003-2004 the TDraw method was used for the first time in an Construction Science course, prof. E. Siviero - IUAV.
6) WITarch - abbreviation of Web Interactive archives of Technology and Architecture. The logical model for the construction of such memory recaptures the orientation of a previous research on the construction of informative interactive archives for architectonic projections in collaboration with IDAU of Ancona and IUAV of Venice (cfr. Spigai V. (1994), Comporre per framment di memoria, “Research department CNR - Progetto finalizzato Edilizia”, Ancona). Matteo Vairo and Cristina Copetti, with the collaboration with Alessandro Ghedin and Alessio Bolgan who significantly contributed to the WITarch research, with the consultation of Roberto Grossa and Ciro Palermo.
7) points 3 and 4 were written by C. Stefanelli.

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Infrastructure Lifecycle Management

U. Forgber
conject AG, Munich, Germany

ABSTRACT: Over the last ten years, the Architecture Engineering and Construction Industry (AEC) came under the growing influence of web based project portals and hereon constitutive software services. At first, research projects utilized the internet as an infrastructure to distribute collaborative environments to dedicated communities (e.g. research, development, application in practice [Kohler 1997]). Soon after, the most promising rudiments found their way into the real world and became - in many ways - supplement to the existing world of desktop- and client server based software structures. As a niche entity, many project portals world wide gained momentum and became every day tools for project collaboration, process support and embedded applications.

We witnessed the birth of a new generation of software, where principles of application service providing (ASP), platform embedded services (service oriented architecture (SOA)) and central data, information and document management took over [Erl 2004]. At the mean time this new generation of software started a process of extinction to classical client server based software architecture.

This keynote shall focus on the potential and major side effects of this development, where data integration over the object live cycle becomes natural and single services disclose more and more useless, if not integrated in an object life cycle oriented approach. More over, the introduced concept of Infrastructure Lifecycle Management (ILM) has the potential to reshape the general approach of developers, owners, service providers and software vendors.

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1 THIRD GENERATION SOFTWARE

To better understand the current paradigm shift we briefly need to take a look at past and present software concepts. *First generation software* was workstation- or single CPU centred and is well known as application software for all sorts of office applications (MS-Standard), games and data storage in a stand alone environment. Underlying data or documents are proprietary and hard to exchange with other applications or users in different locations.

Second generation software is enterprise centred. Typical client server technology enables the distribution of software among different users in a concluded network. Enterprise resource planning (ERP) systems are exemplary and currently dominate the IT world in medium and large enterprises. There is a large correlation between industrial production concepts, the underlying line organisation and this software approach, focused on application within an organisation. Recurrent processes dominate production, accounting, billing, time recording (e.g. automotive, durable goods).

Third generation software is project oriented and focused on inter organisational integration. Flexible user management, communication and information interchange among highly distributed teams in real time are key. We are no longer talking about single applications or monolithic software, instead underlying platform structures emerge into project centred operating systems. Again, there is a correlation between a major shift in the economical world and this technical development.

Whereas large and line based organisations dominated the economical world 30 years ago (44%) they are since then on a constant decline. On the opposite, medium sized and project centred organisations since then have gained more then 100% in share (figure 1). Even within large corporations, line based production structures vanish in favour of project oriented approaches under participation of many external participants (e.g. chip design, pharmaceutical research, software development).

It is evident that in single, line based organisations, it was a tempting OPTION to work on one platform (ERP) in order to allow standardisation, portfolio analysis, or to reduce ramp up costs for new employees. In project teams, composed of participants from many different organisations, it is rather a MUST to utilize a single platform structure in order to avoid fragmentation, redundancies or waste of time in ramp up and coordination.

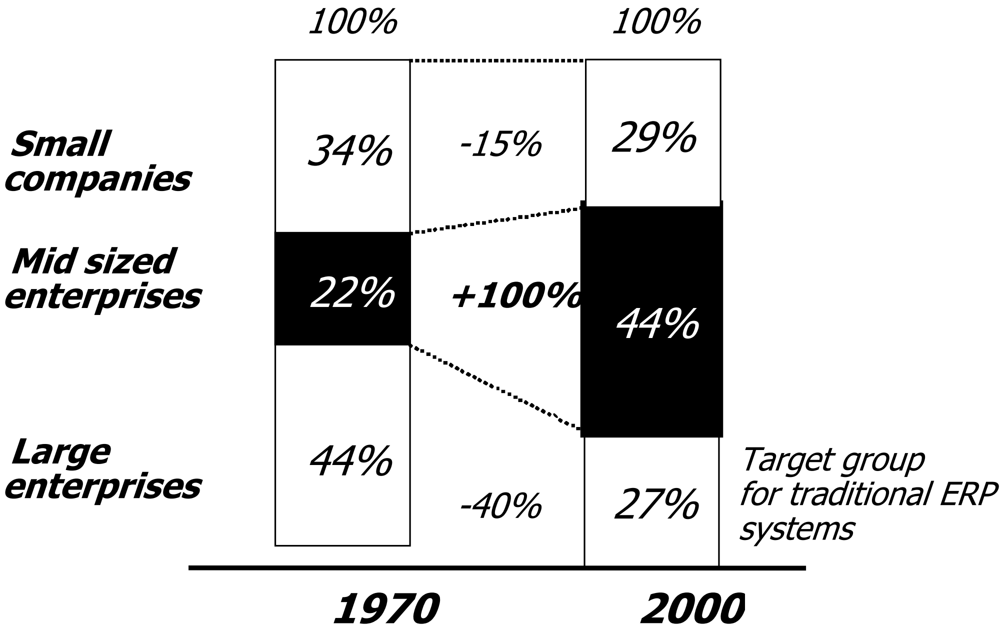

Figure 1. Employees by company size in Germany (source: conject AG)

2 INFRASTRUCTURE LIFE CYCLE MANAGEMENT

Platform structures for project work must consider all phases of the project life cycle. In AEC projects, this makes perfect sense if one considers integration from the project point of view. Project participants join and leave over the phases develop-, plan & build- or operation. But they all share the need for consistent data and transparent general conditions. An infrastructure life cycle management approach addresses these needs by providing a platform over all life cycles of the project.

With early approaches of project portals or the currently emerging ILM platform structures one can recognize this development on the process- and data management level. Even though progress over the last 5 years was very different from what many of us – mostly the academic observer – hoped or expected, ongoing changes in the AEC industry where and still are very fundamental. Ten years ago, did anyone talk about business process automation in planning and construction? Ten years ago, did anyone seriously talk about data integration over the project life cycle? In the academic world YES! In the practice world NO! It was not even technically possible. Here it was no topic at all! With emerging platform technology [Gawer 2002] the generation of ILM will conduct the final transition to integrated data management and services.

To better understand the impact of this transition it is worthwhile to look also at the overall marked size for software. Currently, the marked for application software is about 30 billion €. This is about half of the marked for enterprise internal software (e.g. ERP) which stands globally for abut 60 billion € per annum. ILM addresses a totally new software marked, as we discussed previously now focused on projects and their participants. With a few reasonable assumptions (figure 2) it makes sense this marked will be by far larger then the previous two. This is not only because of the share of the work-

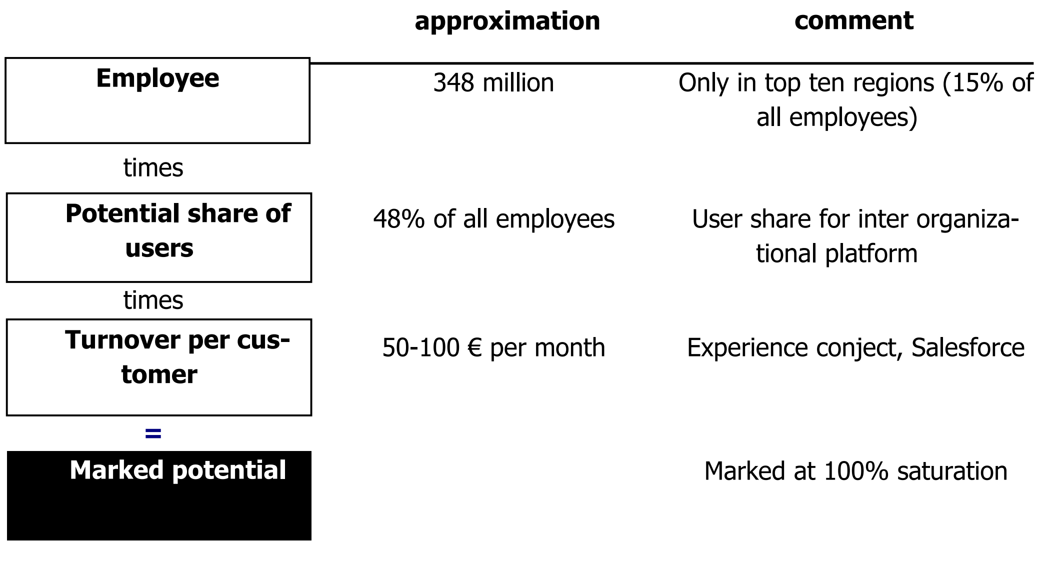

Figure 2. 100-200 billion marked potential in top 10 regions (source: conject AG f

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force affected (app. 350 million people in all industries world wide) but also because of the integration potential of platform structures. ILM platform structures have the nature of operating systems and therefore integrate already additional services (and will much more in the future) that also generate revenue. It is thus plausible to assume that in the future revenue will be generated per user.

3 COMMUNITY BUILDING

Unhindered development of next generation ILM platform structures requires communities of significant size. Over the last years, professional web portals created and expanded such communities. How do communities grow? In the AEC industry this mainly happened in the periphery of large scale projects, such as the BMW plant in Leipzig, Germany where more then 700 hundred project participants where coordinated through a single platform and over 4 years. In fact, large scale projects have already adopted platform structures at first for data exchange and communication as a standard. Subsequent, more and more value gets altered such as print services, bidding or proprietary services e.g. for cost control.

However, the focus is still limited to a.) large- and more and more medium sized projects and b.) to the phases of *development- design and build*. There is still a disruption between the *design- and build* phase and the phase of *operation*. Technically, this disruption is no longer necessary. But in practice, the user communities of the phase *design- and build* and the phase of *operation,* are in tradition almost not interconnected in terms of processes and integrated planning approaches. This downside can now be overcome through technical enhancements [Keller 2004]. Especially questions of document structuring and data modelling – that typically arise during early project stages– trigger advanced concepts and the community interchange in a broader sense. Therefore, lanners, engineers and their clients more and more take into account the requirements of the phase of *operation* – the communities get more and more interweaved.

For the AEC industry it can be summarized that demanding communities (as driving force for ILM platform structure development) emerge in three steps:

– *Critical Mass Achieved:* Complex problems in large projects require adequate technology
– *Additional Value Provided:* Platform with critical mass attracts additional services
– *Life Cycle Addressed:* Centralized data structuring requires a life cycle oriented approach

4 THE NEXT TEN YEARS

Over the next ten years we will witness a sustainable development of platform structures towards a project life cycle oriented environment. In the near future this development will be feasible through more competition among existing and new providers of platform structures [Gawer 2002]. The technology will be pure web based respectively attached to mobile devices of all types. Competition and further demand will lead through several phases of consolidation to only a few remaining providers of operating system like platform structures.

This software world will not be a reborn, monolithic - Microsoft like - world. Instead it will be much more infrastructure oriented. The impact for our professional life in the AEC industry is and further will be three fold, namely there will be:

– a revolution in software infrastructure
– an entirely new class of software applications in form of web services
– a new generation of consulting services providers.

The revolution in software infrastructure will be characterized by integration. Today collaboration is document- and communication centric. Over the next years, documents will be constantly replaced by modelled data (digital object files), not too far by integrated product model approaches such as today's IFC's. The product model kernel of a project will be part of the infrastructure, accessible to process engines and third party services (e.g. web services). In addition, communication will be entirely integrated into this new world. The future ILM platform will comprise all sorts of channels for communication such as today's IP telephony, video conferencing, desktop sharing and blog bound instant messaging.

Today's software applications do not take advantage of centralized data. Through the aggregation of project information in a single environment, application developers will shift there efforts to the development of web services that take advantage of platform centric stocks of data and the opportunity to interconnect with platform processes. Also, structures for GRID computing (currently under development in several international research projects [inteliGrid]) will be utilized to leverage computing power available over the net [Kurzweil 2000]. This will lead to the gradual disappearance of "install software". Users will get used to this "pay per use" terms and conditions.

How will this impact the professional life of traditional service providers and consultants in the AEC industry? Technology is not everything and human expertise will not be replaced over the next ten years. However, the emerging ILM technology already has significant impact on traditional job descriptions and professional opportunities. At this point only two opportunities shall be discussed.

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Most needed is the redefinition of current service profiles, which are also subject to a more life cycle oriented approach. For example engineers do have a usually good understanding of later phases of a building but typically do not (or are not allowed to) utilize this knowledge in their work. The more life cycle oriented the central object file or later object model will be, the easier the redefinition of service profiles will become. They are – in significant respect – dependent on the level of data integration.

The availability of ILM platform structures – the only limit is net access – again brings in the global scale [Kelly 1994]. Future contract assignment will be much less dominated by geographic restrictions then by compatibility to required experience in networked work structures, given service profiles and process standards.

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The Job Profile of Construction Informatics

R. Steinmann
Department of Civil Engineering, Munich-University of Applied Sciences
& Nemetschek Technology GmbH, Munich

ABSTRACT: For a couple of years construction informatics is in a continuous process of a mutation. For the sake of new topics, traditional areas are loosing their relevance. At the same time severe changes on the market can be observed. These trends are opening the discussion on the job profile of construction informatics. Do we offer the right education to meet the new requirements from industry? What is the proper profile of construction informatics?

1 THE ROOTS

While thinking about the current situation of professionals employed in the fields of construction informatics and guessing future trends, it's probably a good idea to have a look backwards to the roots.

Without any doubts, Konrad Zuse is the father of what is called "Bauinformatik" in Germany or "Construction Informatics" as a global common denominator. During the years, while I was leading software development at Nemetschek, I had the great pleasure to meet Konrad Zuse and had the opportunity to talk with him. He explained to us, that his driving motivation was always to find better ways to operate structural analysis and to unburden humans from being calculation slaves.

First of all, Zuse had to invent a machine, which could help him to meet his goal. He also had to invent a programming language before he was able to implement analysis algorithms. Today we have computers and advanced software development environments, but what are the main goals of professionals for construction informatics? Is it still algorithms for computational structural analysis? Sure, up to a certain extend, but isn't there more in the meantime? Which skills should universities and departments for construction informatics teach in order to provide to their students a pole position for the start into their career? What is the job profile of construction informatics?

2 FROM COMPUTATIONAL STRUCTURAL ANALYSIS TO THE WIDE PLAYING FIELD OF ICT IN CONSTRUCTION

For many years the computational implementation of structural analysis was the main field of construction informatics which had it's peak with the introduction of Finite Elements. During this long phase construction informatics was mainly driven by civil engineers, which resulted e.g. into the German tradition of "Bauinformatik", still being the home base of IT-driven civil engineers.

An important milestone was the moment when CAD became adapted and implemented for the construction sector. Latest at this moment civil engineers lost their exclusive domain and architects entered the arena, claiming their fields of CAAD. While in Germany "Bauinformatik" still is the domain of civil engineering faculties, in other countries architect's faculties started to work on various issues in construction informatics, which then also swapped over to German architect's faculties.

Another important milestone was marked when database technologies left their research cocoon and became usable for application developers. Databases turned out to be an ideal platform for the development of cost estimation applications. This domain, however, again was pushed mainly by civil engineers. Some architects entered this arena implementing software applications to support tendering.

For quite some years, civil engineers and architects were happily developing their applications on their islands, while subtly the integration virus escalated and infected more and more victims. At a specific infection rate suddenly it turned out, that more and more players, like building service engineers,

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entered the playing ground and that construction informatics had to deal with the whole mass of complexity of construction projects.

Last but not least the still young profession of facility managers joined the game, realizing that they have to digest what is left at the end of the data food chain. Today they are trying to influence the ingredients of the construction informatics menu so that the meal causes less stomach ache to them.

For a couple of years, web technology is itching to boost the situation and at least achieved the awareness, that information can be shared in a construction project. This cognition, together with the impacts of the integration virus is leading to the understanding, that a lot of time and money is wasted by multiple data-re-entry into the various software applications.

3 SOFTWARE MARKET

The situation on the software market in construction informatics has to be rated very differentiated in each country but in general underwent a dramatic change during the last years. E.g. in Germany the time of prosperity for AEC-software was between 1985 and 1995 providing excellent carriers for "Bauinformatiker", but since then changed into a radical process of consolidation. This was driven by the economic stagnation, which hit especially the construction sector, and it was driven by the fact, that the pioneers of AEC-software companies have about the same age and one after the other went to retirement and had to find a solution for his company, which quite often ended-up in take-overs. Today, in Germany there are much fewer companies, where a construction informatics alumni could find a job as a programmers and the opportunities are reduced even more, as the companies more and more are forced to outsource their programming capacities into cheaper countries. So these careers are still there, but not necessarily in the ancestral countries.

In countries, where the economy and the construction sector is doing well, and where people are proud enough to not only accept software of global players, we even can observe construction informatics start-ups. There are very unique examples e.g. in the European Nordic countries.

4 CONSTRUCTION INFORMATICS IN RESEARCH

One field, where one may find a job in construction informatics is research, however, the number of available jobs is quite limited compared to the numbers of alumni. Trying to find out the job profile for a researcher in this niche I collected the following list of buzzwords while surfing through offers of universities and papers of the known appropriate conferences, like this one. This list does not assert it's claim to be complete, so please accept my appoligies if you do not find your research area there.

- CAD
- CAAD
- CAX
- Finite Elements
- Computational Mechanics
- Conceptual Design
- Facility Management
- Web based virtual ...
- Object Oriented …
- Building Elements/Components
- Product Modelling
- Process Modelling
- STEP
- IFC
- Data Integration
- Building Lifecycle
- 3D
- 4D = 3D + Time
- 5D = 4D + Cost
- Mulit Agent Technology
- Change and Dependency Management
- Knowledge Based ...
- Executive Kowledge Management
- Workflow Management
- Concurrent Engineering
- Ontologies
- Dictionaries
- Constraint Checking
- Education
- Mobile Computing
- Multi Media
- Mobile Media
- …

The reason for this list is to show, that the research in construction informatics is very diverse and with this it is difficult to define a job profile for this field.

In general a candidate should be up-to-date with the State-of-the-Art of current IT-technology, she/he should be able to learn easily any IT-technology she/he is not familiar with, she/he should have analytical skills and of course she/he needs to be very inquisitive.

5 CONSTRUCTION INFORMATICS IN INDUSTRY

As shown above, not only in research but also in industry, the fields of construction informatics are very diverse. So how to define the right job profile for an alumnus? As the market situation is different in each country it's also difficult to define a job profile which fits everywhere.

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One source to define the changing requirements from industry, which skills they need, is the evolution of the topics for diploma theses which I received during the last ten years. However, it does only reflect the situation in Germay.

The trend is clear: less and less topics for heavy software development. While ten years ago, software companies quite often hired diploma candidates for real software implementation projects, this is an exception, today. One reason of course is the fact of outsourcing programming resources to other countries, however, the other reason is, that nowadays a programmer has to know much more about the technology around him, before he is able to program the actual application. The entry level has become much higher compared to earlier days, where it was sufficient to write proper Basic or FORTRAN code and just compile and link it. For data exchange one wrote a simple ASCII-file with some key-words and copied it on a floppy, while today a novice has to understand a pretty complex software development environment, and for data exchange he needs to understand XML and ideally SOAP and please also web-services, before he can start to concentrate on his actual application. To write a user-interface using .NET and C# is very effective compared to earlier C++ -days, and much faster than figuring out a console-masque with ASCII-codes in the early days, but again, one has to read quite thick books before one reaches high performance.

Does this mean, we have to get rid of programming skills in our job profile?

For a "normal" alumnus (not IT-driven) finding jobs like construction site manager, quantity surveyor, maybe even structural analyst we could discuss, whether they need programming skills.

However, an other trend can be identified observing my topics for diploma theses: some light programming skills are very welcome. Quite often industry is asking for a solution based on ACCESS integrating some other applications and suddenly the standard assistant is no longer sufficient and some VBA-programming is required. An other upcoming trend is the adaptation of CMS (content management system) which can be done up to a specific level with the standard functions, but as soon as a database has to be linked in, this can only be done with some programming.

With this one part of the profile are basic skills in programming: one should understand data-types, data-structures, the principles of object-oriented code, implementing algorithms, relational databases and how to deal with XML between databases, spreadsheets and other applications.

Another trend in the diploma theses are requirement analysis. More and more companies are eager to implement ICT-infrastructure but do not really understand their internal problems and are overwhelmed by the various offers from the market. Therefore their first step is to make a stocktaking, then develop from this a requirement analysis, followed by a market survey and finally the implementation of the selected system. A student who is performing well by doing this job in the framework of his diploma theses, very often has a job for grant, afterwards.

This brings us to the next part in the profile: skills in structuring complex structures and setting up analysis. In addition so called soft skills are very helpful, because in the role of being a student she/he has to get the information out of professionals, usually overloaded by their daily work.

Other topics in the diploma theses quite often are dealing with problems in data exchange and data integration. This does not only matter the settings for a DXF-data exchange between different CAD-applications, but also which alternative data-formats are available and what can be achieved with them. Quite often the setting-up of a working data-flow between the different participants of a building project is regarded as a real challenge. And this includes not only CAD applications but also the integration of other so called downstream applications like cost estimation, energy simulation, facility management and so on.

Professionals are foreseeing the need for a new job-type: The Construction Informatics Data Manager. A student, who is collecting according knowledge already during his studies and who is performing well in a diploma theses related to such a project, has really good opportunities for a future career. In addition she/he should have profound knowledge of available web technologies.

6 CONCLUSION

Traditional areas of construction informatics, like implementation of analysis algorithms or Finite Elements have lost their weight for the benefit of new areas in this field. Especially the challenges in industry coming from the implementation of ICT in companies and from data integration in construction projects are offering new opportunities for alumni of construction informatics.

Instead of deep and specialized skills in software engineering a list of all-round skills seams to be a key to success:

- Understanding of
  - Basic programming
  - Processes in building industry
- Experience with AEC-applications such as
  - Building component based CAD
  - Cost estimation
  - Project management
- Knowledge in
  - Light weight programming
  - Database-technology

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- XML
- Web-technologies
- Data formats for applications in building industry
- Standard data formats

There is the opportunity for a new job-type which is currently required more and more from industry: The Construction Informatics Data Manager.

7 BACKGROUND

The author studied civil engineering and worked for over ten years in the software development of Nemetschek as software engineer and head of development. He was involved in projects of 3D CAD, visualization and animation, building component based CAD, cost estimation, facility management. After he accepted the call to professorship for "Bauinformatik" at the Munich University of Applied Sciences, he acquired many national and EU research projects together with Nemetschek. He is also involved in the International Alliance for Interoperability (IAI) et al. acting as international coordinator for the software implementation of the Industry Foundation Class (IFC).

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Towards Semantic Grid in Construction Informatics

A.B. Cremers, S. Alda & U. Radetzki
Department of Applied Computer Science, University of Bonn, Germany

ABSTRACT: Civil Engineering increasingly requires efficient Virtual Organizations of heterogeneous partners and facilities. Mainly four software architecture paradigms originating from the area of distributed computing have influenced the implementation of supporting software systems for Virtual Organizations: Grid, Peer-to-Peer, Agent as well as Web Service architectures. Each architecture paradigm accounts for different technical aspects that promote the realization of such software systems. The unification of these paradigms towards an integrated architecture has, to date, not been achieved. This keynote paper summarizes the state-of-the-art architecture paradigms and proposes elementary design issues for an integrating architecture. This architecture incorporates ontologies for regulating the communication and interoperability among different services. An application scenario finally demonstrates the usage of such an architecture.

1 INTRODUCTION

The analysis of different software paradigms originating from the research area of distributed computing constitutes one of the major research topics in today's construction informatics. The incentive for the investigation of these paradigms can be justified by the way of organizing up-to-date projects in civil and building engineering: a huge number of dispersed project partners and external experts collaborate in terms of temporary *virtual organizations* (VOs) aimed to accomplish a common goal. VOs also make use of *publicly available resources* such as services, autonomous checking algorithms, or hardware cycles, facilitating the concurrent execution of design activities or computations. Existing implementations of VO-like structures range from supporting planning activities in structural design (e.g. [Alda *et al.*, 2004], [Meißner *et al.*, 2003]) towards distributed, autonomous computations such as fatigue analyses ([Jelic *et al.*, 2005]).

As yet, existing virtual organizations have to tackle with problems like heterogeneous software installations, incompatible document exchange formats, untraceable resources, or coordination problems. Although the premises have been recognized and fairly understood, the above mentioned problems constrict the appreciation of virtual organizations in both scientific and industrial field.

This keynote paper outlines the four major influencing architectural styles from the field of distributed computing that are recently adopted for implementing VOs: agent-based, Peer-to-Peer, Grid as well as Web Service architectures (see section 2). A thorough inspection reveals commonalities and also differences among these notions. For instance, while agent-based architectures feature the *mobility* of code and data as a way for migrating computations, all other approaches rely on stationed services for local computational resources that can be discovered and used by other VO nodes. Although standardization endeavors (e.g. for service interaction and discovery) have been carried out individually (especially for Web Services), no universal standard has yet been established allowing for the mediation among the four architectures.

This paper claims that existing approaches for distributed computing should not be regarded as isolated applications, but rather as single integral parts of a complementary architecture. A complementary or *integrating* architecture can utilize a plethora of different VOs that, in turn, can be deployed for many problem classes in the area of construction informatics. As an essential requirement, an integrating architecture should incorporate a common vocabulary or so-called *ontology* so that even different or incompatible services (e.g. an agent and a Peer service) can communicate exactly with each other without any loss of semantics. Ontologies not only increase the interoperability between services, but also improve retrieval capabilities of services and resources within VOs. Design issues and suitable application scenarios for an integrated architecture are illustrated in section 3.

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2 STATE-OF-THE-ART

2.1 *Interoperability: Web Service Architectures*

Web Services are a new kind of web-enabled applications. They are self-contained and self-describing entities that can be published, located, and invoked across the web [Tidwell, 2000]. Web Services support distributed computing and offer the possibility to create modern *service-oriented architectures* (SOA). One of their key aspects is to provide a broader interoperability between providers, applications, and platforms than previous standards like CORBA have achieved. In order to reach this goal, several standard are proposed by the World Wide Web Consortium (W3C) meeting the Web Services Architecture (WSA) [Booth *et al.*, 2003].

Web Services are build on technologies like XML, XML Schema and XML-Namespaces. The basis technologies for communication, definition, and discovery are SOAP, *Web Services Description Language* (WSDL) and *Universal Description, Discovery and Integration* (UDDI) [Curbera *et al.*, 2002]. On top of these specifications Web Services allow the creation of business processes (workflows) through the *Business Process Execution Language for Web Services* (BPEL4WS).

2.2 *Integration of Resources: Grid Architectures*

While Web Services offer a standardized platform for building (technical) interoperable service-oriented software, *Grid architectures* additionally are concerned with coordinated resource sharing and problem solving in dynamic, multi-institutional VOs [Foster *et al.*, 2001]. These VOs encompass individuals and/or institutions involved in *sharing* their (computational) resources. Resources to be shared contain computers, software, data, and storage.

Achieving interoperability of these heterogeneous Grid resources is an essential pre requirement for Grid architectures in order to support VOs. Therefore the Grid community that is, the *Global Grid Forum* (GGF) released the *Open Grid Service Architecture* (OGSA) as well as the *Open Grid Service Infrastructure* (OGSI). These standards specify the interfaces of so-called *Grid Services* as well as lifetime management, notification and other aspects of their Grid resources [Foster *et al.*, 2004].

The specification of Grid Services is based on the established Web Services standards, mainly WSDL. Owing to proprietary enhancements of the WSDL specification, Grid Services were incompatible with general Web Services. The recently proposed *Web Services Resource Framework* (WSRF) re-factors the OGSI taking into consideration new developments of the Web Services Community in order to release a Web Service as well as Grid Service compatible standard [Czajkowski *et al.*, 2004].

2.3 *Autonomous Computing: Agent Architectures*

The benefits of *pro-active and autonomous agents* for handling complicated problem solving and planning assignments have been elaborated extensively in the area of artificial intelligence (see [Russell and Norvig, 1995] for an overview). The relatively novel approach to adopt software agents as an architectural style for distributed systems has resulted from modern programming languages like Java that allowed the straightforward implementation of the key characteristics of agents. In addition, standard protocols like the FIPA convention [FIPA, 2002] have emerged for normalizing, in particular, communication between agents. Agent communication is based on so-called *speech acts* accomplishing an almost "human" interaction between agents. Recent agent platforms (environment in which agents operate) like JADE also allow for the *migration of agents* (including data and code) through several network hosts enabling flexible computations on remote sites.

2.4 *Self-Organization: Peer-to-Peer Architectures*

The Peer-to-Peer architecture style describes a distributed architecture consisting of equal clients or so-called *Peers*. Peers are capable not only of consuming, but also of providing computer resources like data, legacy applications, or even hardware resources. Resources are encapsulated by *Peer services*. Peer Services can be published throughout a given Peer-to-Peer network, whereas the Peers themselves are responsible to manage the publication and the discovery of Peer services. Depending on the structure of the topology, a Peer-to-Peer network can encompass several well-know super Peers for a better maintenance of Peers services. The topology of Peer-to-Peer networks is *dynamic*, which results from the volatileness of the constituting Peers, as these mainly correspond to volatile and potentially unreliable nodes (e.g. PC, notebooks). Existing frameworks and architectures (e.g. JXTA [Sun, 2005] or DeEvolve [Alda and Cremers, 2004]) enable single Peers to organize into so-called *Peer groups*. These self-governed *virtual* communities can share, collaborate, and communicate in their own web without a central authority. The purpose is to subdivide Peers into groups according to common interests, competencies, or knowledge independent from given organizational or network boundaries.

2.5 *Semantic Issues: Ontologies*

Future developments in the field of service-oriented computing should consider semantic issues. Semantic description is required for annotation of services and their resources to support both semantic discovery and semantic interoperability in VOs and workflows used within VOs. For example, identification of relevant services should be done through semantic descriptions rather than syntactic definitions. Today,

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neither WSDL nor UDDI support semantic issues. Semantic aspects can be defined by *ontologies*. An ontology is an explicit specification of a conceptualization, while a conceptualization specifies objects, concepts and relationships that hold them in some area of interest [Gruber, 1993]. Technologies for specifying ontologies are well known in the field of Semantic Web applications. Based on the *Resource Description Framework* (RDF) and RDF *Schema* (RDFS) the W3C released the *Web Ontology Language* (OWL) as a standard for Web ontologies. This language is used by several groups in the context of Semantic Web Services. They use OWL for annotation, discovery and interoperability of semantic enriched Web Services [Paolucci *et al.*, 2002] [Radetzki and Cremers, 2004].

3 PROPOSAL OF AN INTEGRATED ARCHITECTURE

3.1 *Design Issues*

The different software paradigms described above claim different aspects within distributed computing and VOs. Additionally ontologies are seldom considered while standardization of technologies for these paradigms. On this account we propose a *Next Generation Semantic Grid* which integrates several software technologies in conjunction with ontologies. Fig. 1 illustrates an integrated view of this proposal. The basis of this architecture is the Web Services technology which provides standards and basic interoperability in service computing. On top of these standards Grid Services allow building VOs w.r.t. resource sharing in VOs. Mobile agents act as autonomous entities within the Grid solving problems without user intervention. Finally the Peer-to-Peer paradigm enables VOs w.r.t. users groups or interests. That means for instance, different Peer groups can be created in different project phases.

Orthogonally we require ontologies on every level of this software architecture in order to express semantic issues. This topic is represented in Fig. 2.

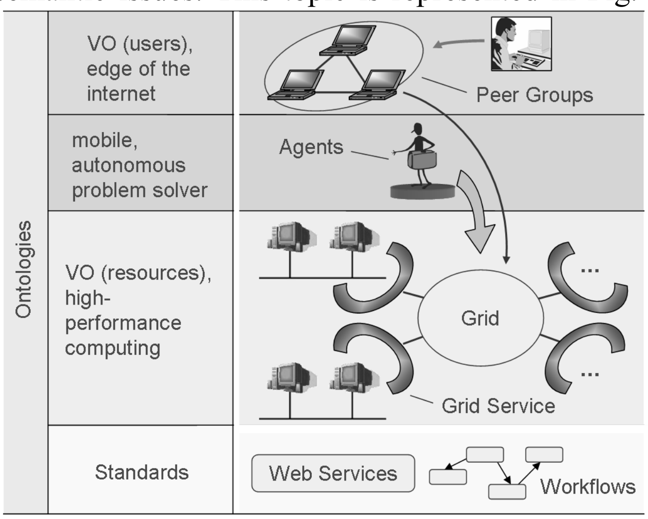

Fig 1. Integrated view of Next Generation Semantic Grid.

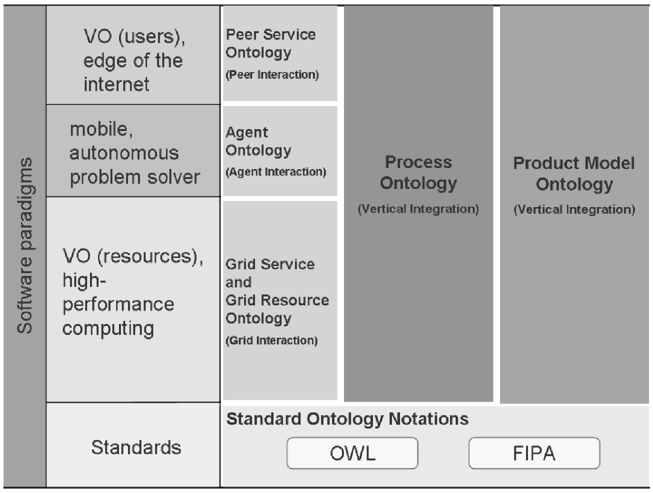

Fig 2. Ontologies w.r.t. integrated software paradigms.

Here OWL and FIPA support basis standard description languages. Moreover, FIPA announce that FIPA agent technology and Semantic Web technologies will be interoperable in future. These languages can be used for annotating and describing services as well as processes (workflows). On every level of the software paradigms we require special ontology-based description languages. These languages contain concepts and relationships which are needed for the specific layer. For instance, on the Grid layer we demand ontology description of the Grid Services and Grid resources. Today, basis ontology description languages are available for Semantic Web Services and Service-Mediators [Martin, 2004] [Radetzki *et al.*, 2004]. Additionally there is the need for a process ontology as well as a product model ontology which are software paradigm layer independent (*vertical integration*). The process ontology describes how the different components fit together in one VO, while the product model ontology defines a common structure for objects and data which are produced and exchanged within a VO.

3.2 *Application Scenarios*

A *Next Generation Semantic Grid* architecture as proposed in section 3.1 has the potential to enhance a plethora of concurrent planning and management activities in construction engineering projects that are carried out in terms of VOs. Foreseeable, future projects in this area will exhibit a broadening demand for collecting, maintaining, and evaluating massive amount of computational data. This data will result not only from the VO's core processes (e.g. partial building or structural design models, and simulation models that are generated within virtual planning organization), but also of accompanying management activities like facility and risk management. The avail of an integrating architecture for supporting facility management is illustrated briefly by the following example.

Facility management as a strategic management activity aims at optimizing the administration and

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maintenance of buildings within an enterprise [Kolbe *et al.*, 1997]. The key task of an adequate Computer Aided Facility Management (CAFM) system is to gather and to structure (heterogeneous) data that, in turn, serves a Facility Manager as a foundation for further analyses. The majority of current CAFM systems only allow for inputting and examining data manually. Apparently, for future application scenarios, massively distributed and more extensive and more precise data may be gathered from different sites, in order to run highly concise analyses and future predictions about the state of all building of an enterprise. Data may be entered manually by arbitrary end-users (Peers) and also derived automatically by autonomous agents that interact with local sensors (e.g. light, fire, or temperature sensors). The analyses will no longer be conducted and reported by the facility manager alone, but also by analysis routines that run simulations and sensitive analyses with respect to the derived data. Grid VOs are then responsible for providing the massive storage and cycles required for processing the data. On top of the integrated architecture, a common ontology is instrumental to increase the interoperability between potentially heterogeneous data formats.

4 CONCLUSION

Processes and product models for Civil Engineering, object-oriented software technologies, and Internet Information Systems have greatly improved recent contributions of Construction Informatics for the global and dynamic challenges that construction enterprises are facing today. Aspects of efficient cooperation will become more and more important and constitute future topics in this area. The present paper has discussed various aspects that are essential for the evolution of Virtual Organizations. We have shown that Web Service, Grid, Peer-to-Peer, and Agent technologies together with ontologies are complementary technologies for Next Generation Semantic Grids that will meet the demands of future VOs. In fact, the challenge from interdisciplinary applications such as facility management turns out to be a major reason for the integration described here.

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Logic of Processes in Civil Engineering

W. Huhnt
Institute of Civil Engineering, Berlin University of Technology, Germany

P. Racky
Institute of Construction Management, University of Kassel, Gemany

S.M. Holzer
Institute of Mathematics and Engineering Informatics, University of the Federal Armed Forces Munich, Germany

1 INTRODUCTION

Processes in civil engineering are characterized by specific peculiarities. Projects are executed individually, and principles of mass production are not applicable. Contracts are concluded in which companies act in different roles from project to project. Local conditions influence a project. Constructions differ in design and building technique. Different types of buildings are planned and constructed by specialists working at different locations in different companies. The specific peculiarities are considered in project preparation phases where work plans are written out and rules for coordinated project work are determined and documented.

A significant task in project preparation phases is the specification of schedules. Software tools are available for scheduling. However, the methods implemented in these tools do not support the development of processes. They are used to document the results: tasks can be subdivided into subtasks and ordered on a time scale with the option to specify interdependencies so that schedules can be specified.

The workshop discusses a different approach where processes in civil engineering are treated in two steps. The first step addresses the logic of a process (planning). The second step addresses ways to assign time and resources to a process (scheduling). Other disciplines like software engineering profit from this distinction. In the workshop, the necessity, the usability, and the consequences of this approach for projects in civil engineering are discussed.

2 THESES

The workshop covers three presentations, and three papers are related to the workshop, Huhnt (2005), Racky (2005), Holzer (2005). Each paper addresses one of the three theses that are formulated and presented:

Thesis 1: Methods in civil engineering are necessary to generate individual processes with a correct and consistent logic.

Present scheduling techniques do not make use of a distinction between the logic of a process and its schedule. The sequence of tasks is specified on the basis of human experience only. As a consequence, the logic of processes cannot be checked formally so that their correctness and quality in civil engineering projects need to be checked by human beings. This is prone to errors, and the effort of work is enormous. For instance, typical planning processes cover more than 1.000 tasks and 10.000 documents. Checking the sequence of tasks of such processes requires huge effort; tracing effects of subsequent modifications becomes nearly impossible; and the complexity of projects in civil engineering will increase in future so that methods are necessary that guarantee for logically correct and consistent processes. An approach for construction processes is presented where the sequence of construction tasks is determined based on a task-oriented approach.

Thesis 2: A correct and complete monetary valuation of construction work requires methods, which focus on the functional logic of all building elements.

Turn-key construction projects show an enormous number of interfaces between the different building elements and work packages. In the estimating process, all these interfaces have to be valuated with costs. Often current practice in estimating shows, that structure and course of the estimating process are not derived logically from the object, i.e. the building, which has to be dealt within the process. This holds the risk of an incorrect process output, i.e. construction costs. In the workshop the idea of an interface-oriented approach to estimating is presented. This approach helps to prevent interface costs from being incompletely estimated and to control the complexity of the project in the estimating process.

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Thesis 3: Weights of processes can be converted into costs so that the determination of processes and their sequence can be formulated as an overall optimization problem.

The main obstacle towards monetary planning and monitoring of a construction project is presented by the total lack of a mathematically formulated cost model. The basic problem is constituted by the fact that resource allocation, scheduling, and cost are not simply sequentially dependent on each other, but rather interlocked. An attempt will be made in the workshop to outline the basic mathematical model of construction cost generation, thereby opening the way to future cost control and optimization.

The need of new methods for process planning based on logical considerations is described in the workshop. The consequences of this new approach are discussed with respect to the work of construction managers and specialists in computer science in civil engineering.

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Generating Sequences of Construction Tasks

W. Huhnt
Institute of Civil Engineering, Berlin University of Technology, Germany

ABSTRACT: Construction processes require preparation phases where among others the sequence of construction tasks has to be developed. This sequence of tasks cannot be transferred automatically from project to project. Specific peculiarities of projects need to be considered so that individual follow up charts need to be set up. In practice, follow up charts are developed that describe the sequence of tasks in different levels of detail. The quality of these follow up charts depends on the experiences of construction managers. Software tools do not support the development process of these charts; they document the result, the follow up charts themselves. Therefore, completeness and logical correctness of these charts can only be checked by inspection. This paper presents a modeling technique where the sequence of construction tasks results from a task-oriented specification. Each construction task is modeled individually by describing its preconditions and its results. The interdependencies between the tasks are calculated from the task-oriented specification based on relational algebra. The task-oriented specification consists of a description of the prerequisites and the results of each task. All interdependencies are calculated based on this specification. A specific topological sort algorithm based on graph theory determines the sequence of tasks. The advantage in using the presented modeling technique is that logical correctness and completeness can be guaranteed. A practical example is presented.

1 INTRODUCTION

Construction processes in civil engineering are characterized by specific peculiarities. Their complexity does not allow for specifying an overall process model that is valid for and can be adapted to each project. In addition, an optimal construction process cannot be derived based on optimal partial processes only. It is well know from mathematics that local optima do not guarantee for a global optimum so that optimal partial processes do not guarantee for an overall optimum as well. Also low detailed descriptions of processes cannot be used to generate high detailed process models. It can be shown in mathematics based on hierarchical graphs that high detailed processes can be mapped onto low detailed processes. The inverse procedure, mapping low detailed processes onto high detailed processes, is not defined. There is no mapping rule that can be used to derive high detailed processes from low detailed ones.

As a consequence, construction processes need to be prepared individually. Especially the sequence of tasks needs to be worked out for each project. Construction processes are so called ad-hoc processes; and it is also known in other disciplines like software engineering that ad-hoc processes need to be prepared individually.

In civil engineering, work plans document agreements and rules for the execution of projects. These work plans cover descriptions of tasks, responsibilities, deadlines, budgets, and also the sequence of task is described as target values for the execution of construction processes (cp. DBV (1998)). Of course, software tools are used to specify schedules. But the use of these software tools has serious disadvantages. The user specifies tasks and their duration. In addition, interdependencies can be modeled. However, there is no necessity to specify all interdependencies, and the number of interdependencies is in general so high that the effort of specification is unacceptable. As a consequence, not all interdependencies are documented. In general, subsequent modifications are necessary, and existing interdependencies might influence the modifications. If these interdependencies are not documented, they might be lost so that incorrect schedules will be the result.

The present paper discusses an approach specifically focused on construction processes where all interdependencies between tasks are captured. However, the interdependencies between tasks as

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well as the sequence of tasks need not be specified by the user, they are calculated based on some task-oriented user input. Each construction task is modeled individually. Beside construction tasks, components are considered that are built or modified during the execution of the project. The user has to specify relations between tasks and components, for instance the components that are created during the execution of a task. Based on this input, interdependencies between tasks are calculated and a sequence of tasks is determined.

The advantage of the presented approach is the availability of the theoretical background that is used for calculating the interdependencies between the tasks and the sequence of tasks. Specifying interdependencies between construction tasks is not the duty of a construction manager any more. Like in structural analysis, a construction manger specifies some input, and he has to evaluate the results, in this case the sequence of tasks. This requires a rethinking in the area of construction management. The logic of construction processes is determined, and its correctness and completeness with respect to the user input can be guaranteed.

2 MODELING TECHNIQUE

As an assumption, construction processes can be described by

– components,
– construction tasks, and
– relations between and in construction tasks and components.

A building can be described by its components, and the presented modeling technique requires all components to be named.

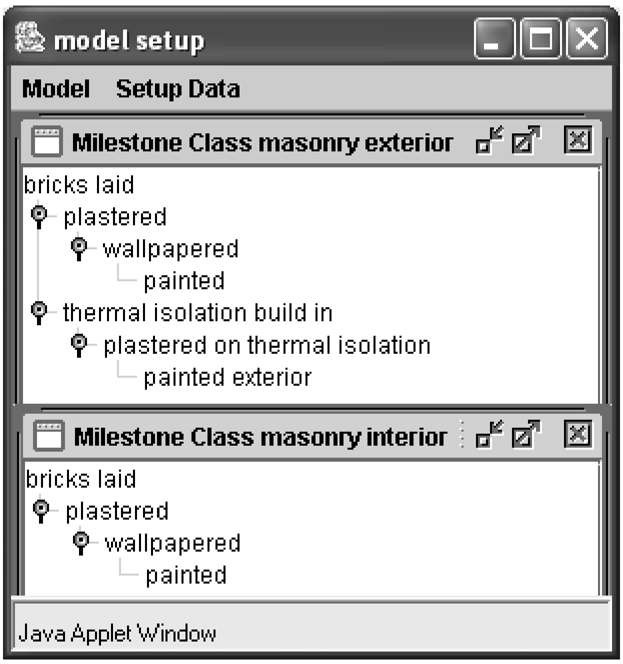

Figure 1. Milestone classes

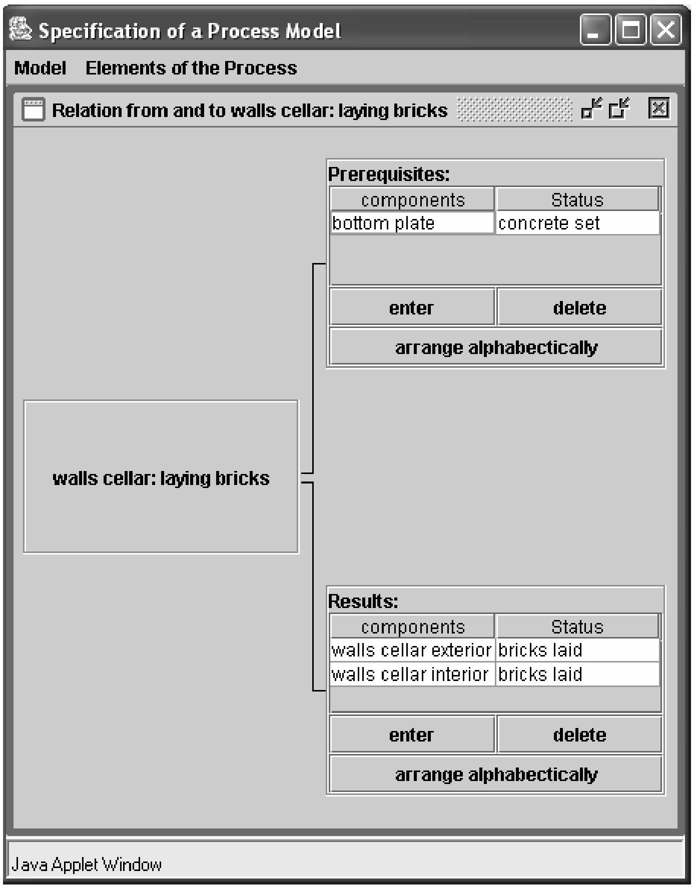

Figure 2. Specification of relations between components and tasks

In general, components will have several states during the execution of a project. For instance, the bricks of a wall are laid first, than the wall is plastered, and than it is wallpapered and painted. Milestone classes are introduced in the modeling technique to describe the states of components. These milestone classes are specified for different types of components. In general, components have different surfaces whereas each surface will have different states. This is considered in the modeling technique, and trees are used to specify the states and the sequence of states for types of components.

Figure 1 shows two examples of milestone classes. The states of all surfaces of interior masonry pass through the same states. Therefore, this milestone class consists of a sequence. Exterior masonry needs a thermal isolation outside and the identical states like interior masonry inside.

The presented modeling technique requires all construction tasks to be named. Two relations between tasks and components need to be specified. One relation describes the prerequisites for the execution of a tasks, the other relation describes the result. Both, the prerequisites and the results are components in a specific state. Figure 2 shows an example. The task “wall cellar: laying bricks” requires the bottom plate in the state “concrete set”. As the result, the exterior and interior cellar walls achieve the state “bricks laid”.

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3 THEORETICAL BACKGROUND

In a first step, relations between tasks are calculated based on the specified relations between tasks and components. Two rules are evaluated for this purpose:

1 Consider a task T that has a component C in state s_r as a result: All tasks that have the component C in state s_i as a result where s_i is in the milestone class of C on the path from s_r to its root have to be executed before task T.

2 Consider a task T that has a component C in state s_p as a prerequisite: All tasks that have the component C in state s_i as a result where s_i is in the milestone class of C on the path from s_p to its root have to be executed before task T.

Based on these two rules, relations between tasks are calculated the describe tasks that have to be executed before other tasks.

The relations between tasks can be sorted topologically if they do not cover a cycle. Cycles can occur if a task T1 requires a component C1 in state s1 and has a component C2 in state s2 as its output whereas another task T2 requires C2 in state s2 and has C1 in state s1 as its output. Such a situation is shown in figure 3. These conflicts can be solved if the affected tasks are executed in parallel. The affected tasks that have to be executed in parallel can be replaced by a major task so that cycles can be avoided.

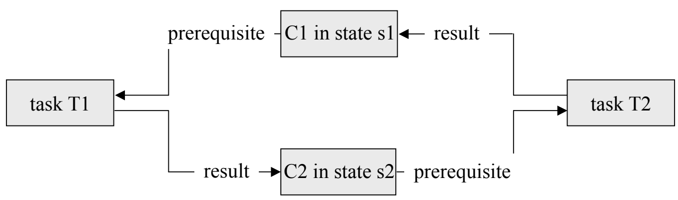

Figure 3. Cycle in a construction process

In general, several solutions can be determined as a sequence of tasks where all relations between tasks are considered. A topological sort algorithm based of the breadth-first-search is chosen for the determination of the sequence of tasks. This algorithm guarantees the lowest number of logical steps, and each task is inserted at the first logical step when it can be executed (cp. Pahl Damrath (2001), Turau (1996)). Such a solution needs to be evaluated by a construction manager. The algorithm considers interdependencies calculated from the relations between tasks and components only. Further interdependencies might exist, e.g. the availability of special equipment does not allow the execution of specific tasks in parallel. Such interdependencies are not jet considered so that the calculated sequence of tasks can only be regarded as a proposal. It needs to be edited, and a construction manager can select another solution from the solution set. Each sequence of task that covers no cycle is a valid solution. Cycles can be checked based on topological sort algorithms as presented in Turau (1996).

4 EXAMPLE

The modeling technique has been tested using realistic examples. Figure 4 shows some construction tasks that have been modeled. Figure 5 shows some components of a building. The calculated sequence of tasks is shown in figure 6.

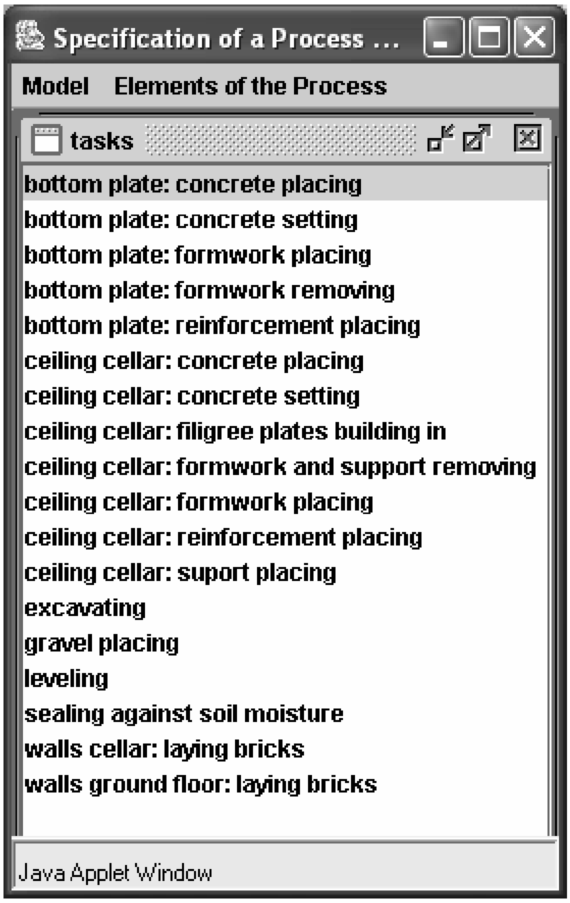

Figure 4. Construction tasks

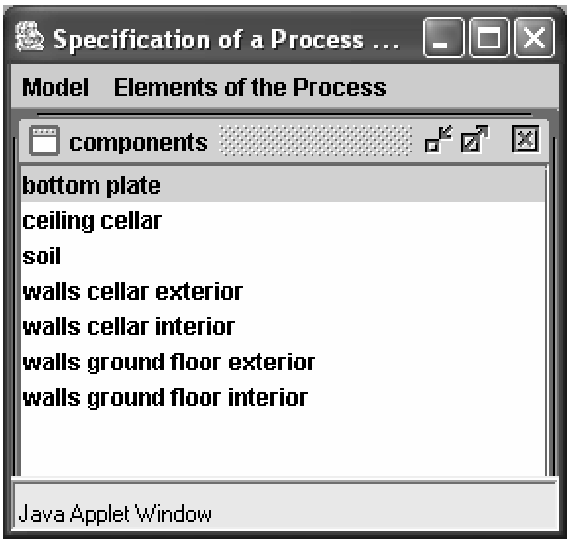

Figure 5. Components

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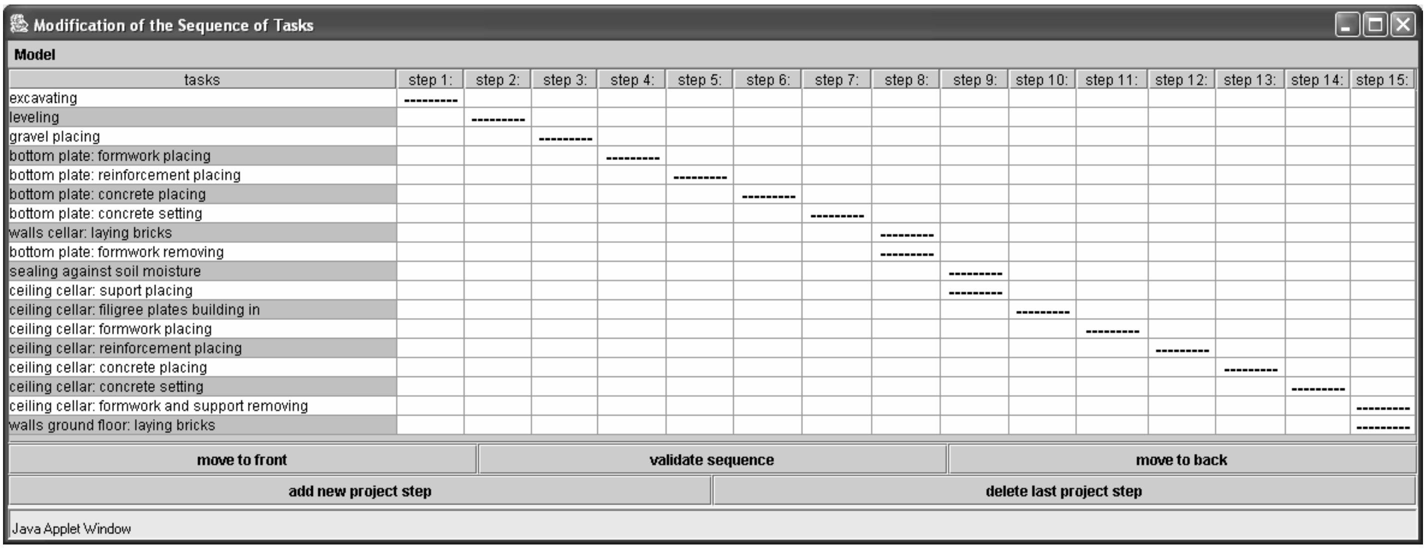

Figure 6. Calculated sequence of tasks

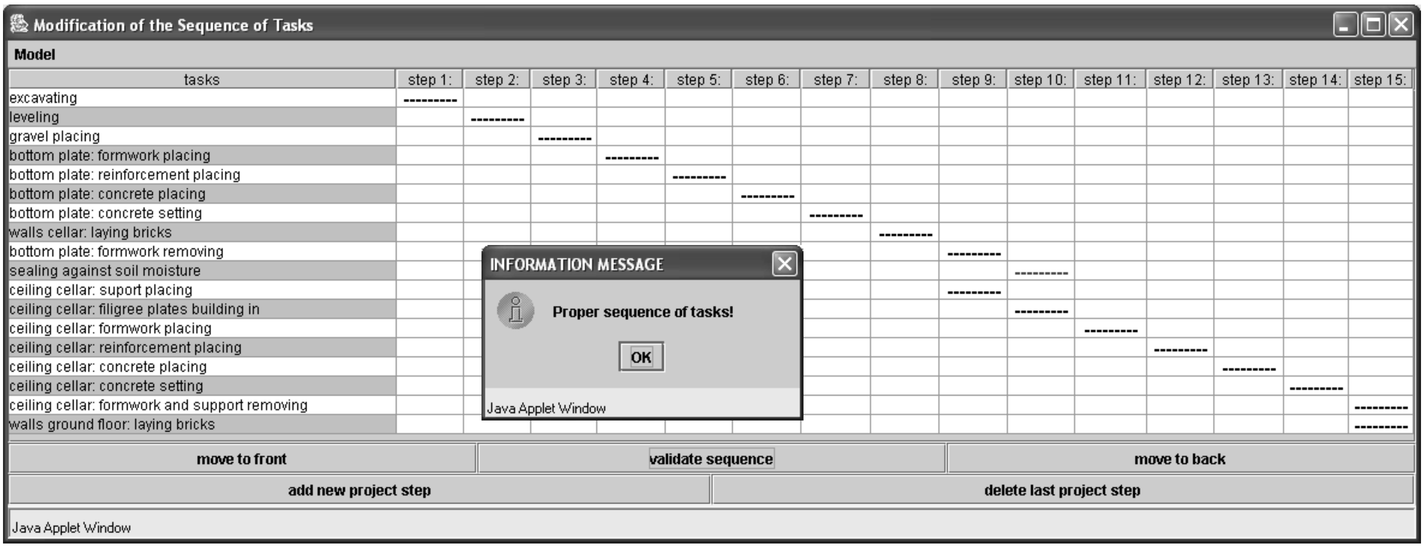

Figure 7. Modified sequence of tasks

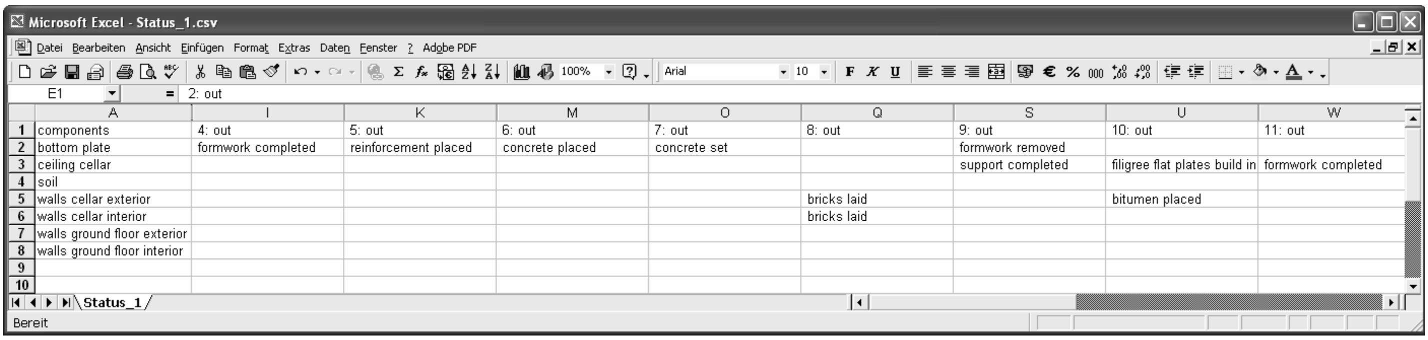

Figure 8. History of components

The sequence of tasks can be edited. Tasks can be moved backwards or forwards. It can be checked whether the modified sequence of tasks is valid. Figure 7 shows a modified sequence of tasks. Two tasks have been moved backwards. These tasks do not have any direct successors so that there is no conflict with existing relations between tasks. The modified sequence of tasks is valid.

The sequence of tasks can be evaluated. Figure 8 shows an extract of the history of components. The states are shown for specific project steps only. The displayed values are the states of the components that are achieved at the end of each project step.

The example presented in figures 4 to 8 covers a small number of components and tasks only. Realistic projects in civil engineering consist of several hundreds of tasks and components. Print outs are necessary for the evaluation of these processes, and in general several pages with a size of DIN A 0 are necessary to present the sequence of tasks and the history of the components.

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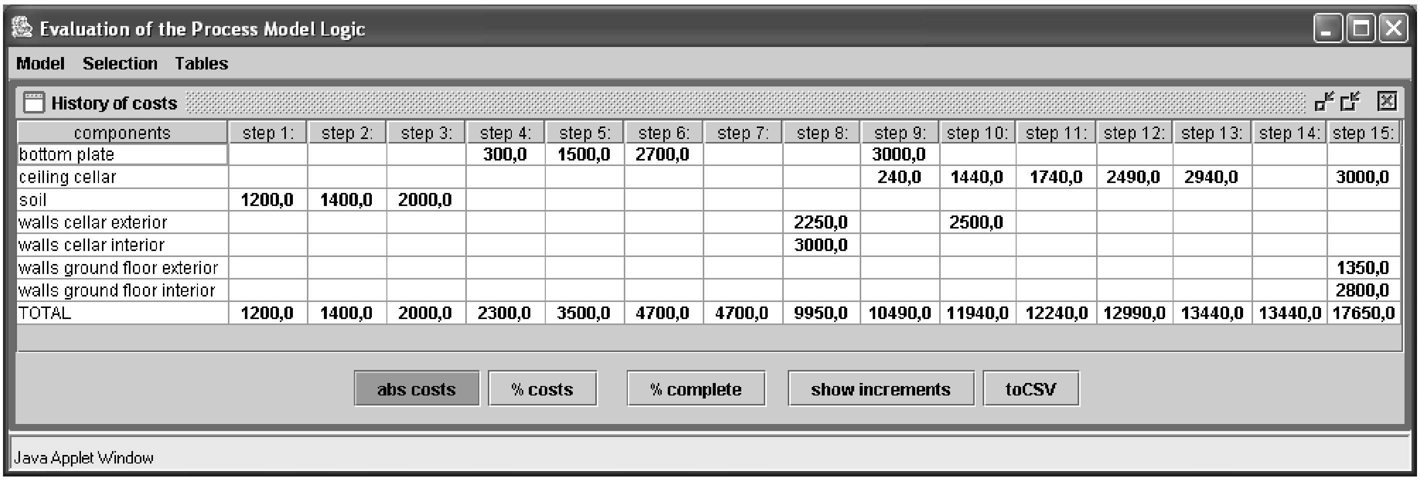


components	step 1:	step 2:	step 3:	step 4:	step 5:	step 6:	step 7:	step 8:	step 9:	step 10:	step 11:	step 12:	step 13:	step 14:	step 15:
bottom plate				300,0	1500,0	2700,0			3000,0						
ceiling cellar									240,0	1440,0	1740,0	2490,0	2940,0		3000,0
soil	1200,0	1400,0	2000,0												
walls cellar exterior								2250,0		2500,0					
walls cellar interior								3000,0							
walls ground floor exterior															1350,0
walls ground floor interior															2800,0
TOTAL	1200,0	1400,0	2000,0	2300,0	3500,0	4700,0	4700,0	9950,0	10490,0	11940,0	12240,0	12990,0	13440,0	13440,0	17650,0

Figure 9. History of costs

5 WEIGHTING

The determination of the logic of a sequence of tasks as described in section 3 is a first step in preparing construction processes. The sequence of tasks can be evaluated so that the planned history of the components can be determined. The planned history of the components can be regarded as basic information concerning the quality that has to be achieved. However, project management requires three different types of information:

- quality,
- costs, and
- deadlines.

Costs and deadlines can be included into the modeling technique by weighting components and tasks. Components in specific states are the products of construction activities. Achieving a specific state requires financial effort. This can be expressed by weighting each component with its individual price.

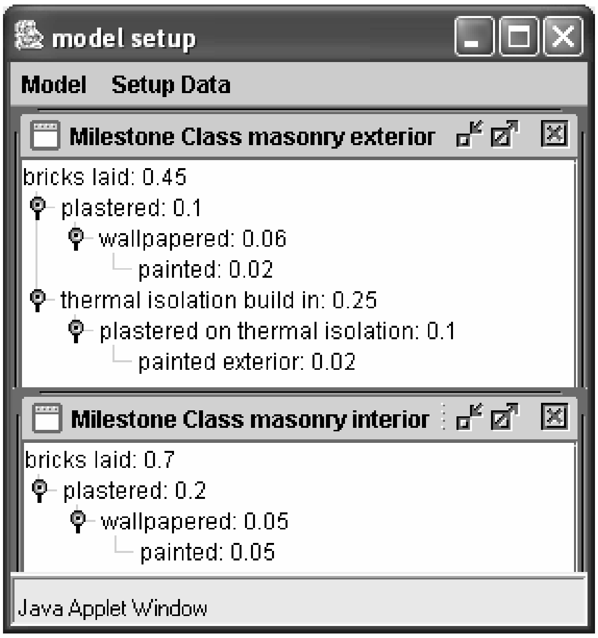
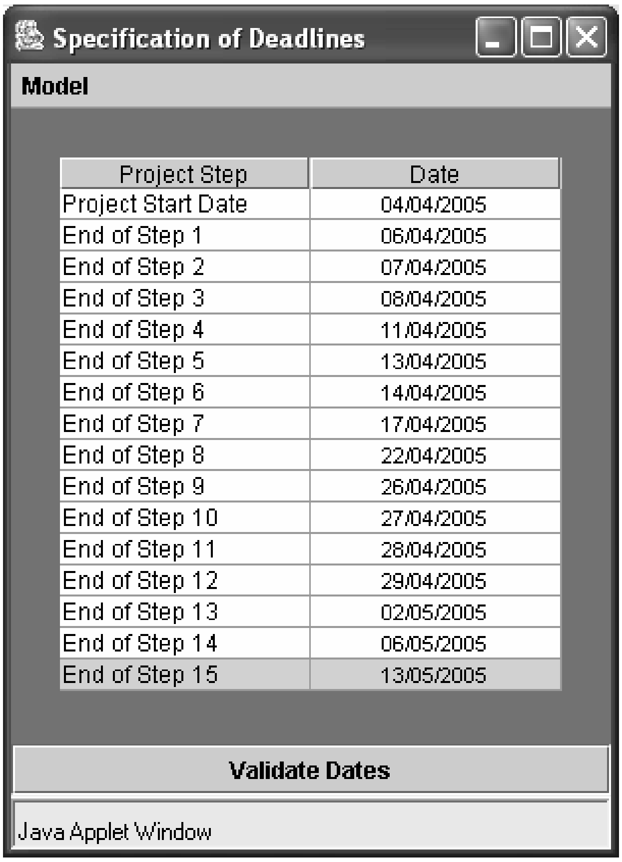


Figure 10. Weighted states

As part of the milestone classes, percentage values can be specified that describe the effort that is necessary to achieve a specific state. Figure 10 shows these values for the milestone classes that have been developed for components of the type "masonry exterior" and "masonry interior" (see figure 1). As a consequence of weighting components with their prices and states with a percentage rates, a history of costs can be determined. Figure 9 shows an example.

Deadlines can be specified for the beginning to the project and for the end of each project step. Figure 11 shows an example. As a consequence, the sequence of tasks and the history of components, and costs can be mapped onto the time scale.



Project Step	Date
Project Start Date	04/04/2005
End of Step 1	06/04/2005
End of Step 2	07/04/2005
End of Step 3	08/04/2005
End of Step 4	11/04/2005
End of Step 5	13/04/2005
End of Step 6	14/04/2005
End of Step 7	17/04/2005
End of Step 8	22/04/2005
End of Step 9	26/04/2005
End of Step 10	27/04/2005
End of Step 11	28/04/2005
End of Step 12	29/04/2005
End of Step 13	02/05/2005
End of Step 14	06/05/2005
End of Step 15	13/05/2005

Figure 11. Specification of deadlines

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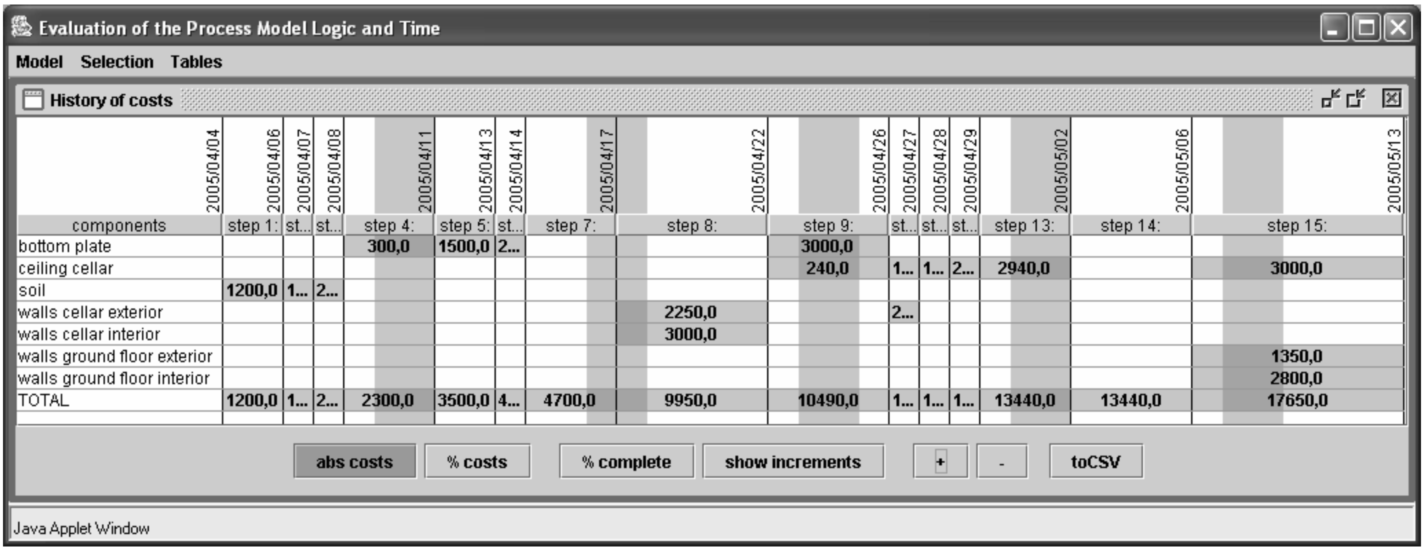

Evaluation of the Process Model Logic and Time

Model Selection Tables

History of costs

	2005/04/04	2005/04/06	2005/04/07	2005/04/08	2005/04/11	2005/04/13	2005/04/14	2005/04/17	2005/04/22	2005/04/26	2005/04/27	2005/04/28	2005/04/29	2005/05/02	2005/05/06	2005/05/13
	components	step 1:	st...	st...	step 4:	step 5:	st...	step 7:	step 8:	step 9:	st...	st...	st...	step 13:	step 14:	step 15:
	bottom plate				300,0	1500,0	2...			3000,0						
	ceiling cellar									240,0	1...	1...	2...	2940,0		3000,0
	soil	1200,0	1...	2...												
	walls cellar exterior								2250,0		2...					
	walls cellar interior								3000,0							
	walls ground floor exterior															1350,0
	walls ground floor interior															2800,0
	TOTAL	1200,0	1...	2...	2300,0	3500,0	4...	4700,0	9950,0	10490,0	1...	1...	1...	13440,0	13440,0	17650,0

abs costs % costs % complete show increments + - toCSV

Java Applet Window

Figure 12. History of costs mapped onto the time scale

Figure 12 shows an example; the history of costs is mapped onto the time scale. The presented modeling technique results therefore in all basic information that is necessary to be known at the early beginning of a construction project, quality, costs, and deadlines, can be generated and derived from the logic of construction processes.

6 CONCLUSIONS AND OUTLOOK

The presented modeling technique is a first step in modifying the use of information technology in the area of preparing construction processes. At present time, information technology is used to document target values for construction processes that have been generated on human experience only. Of course, algorithms are available, for instance to determine critical paths, however, the use of information processing needs specified processes and does not support the development of these processes. This usual way of using information technology is prone to errors, and it is inefficient.

The presented modeling technique supports the development of processes. It distinguishes between the logic of a process and the weighting. In a first step, the development of a correct and consistent logic of the sequence of tasks and the history of the components is supported. In a second step, the process is weighted with deadlines and costs. The results are target values that cover the three most important information for an efficient project management: target values for quality, deadlines, and costs.

An equivalent modeling technique has been developed for engineering planning processes. This technique has been successfully tested in real engineering projects (cp. Huhnt & Lawrence (2004)). Practical tests of the presented technique for construction processes are in progress.

The use of the presented modeling technique results in further questions and tasks.

The distinction between the logic of a construction process and its weights requires efficient techniques to guarantee for complete and consistent weightings. For instance, costs need to be assigned to all components of a building. Interdependencies between disciplines need to be considered. Cost information need to be checked, and consistency has to be reviewed.

Complete weightings open the way to optimization problems. Several solutions are valid for a sequence of tasks. Overall optimization techniques need to be investigated to select “the best” sequence of tasks.

The presented modeling technique makes use of specific relations only. For instance, restrictions in the use of personal or equipment are not considered. Expanding the presented technique to consider further restrictions and constraints is a challenge and has to be investigated in future.

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Linking up versus Breaking down: Demands on Cost Estimating for Turn-key Construction Projects

P. Racky
Institute of Construction Management, University of Kassel, Gemany

ABSTRACT: The complete monetary valuation of interfaces between the various building elements or work packages is a substantial success factor for a correct estimate that takes account of all costs of turn-key construction projects. The estimating processes employed by construction contractors often neglect systematic interface analysis what leads to incorrect results. This paper sketches out an interface-oriented estimating approach. This approach will lead to a procedure in which the building elements to be costed are structured in a way that corresponds to their functional logic. As result a linked-up procedure, such as is necessary to cope with complex systems, will be achieved and a complete costing made easier.

1 INTRODUCTION

Turn-key construction projects show increasing complexity. There are several reasons for this. Firstly, the high interaction of the various work packages in planning and execution. Other reasons for this increasing complexity are the accelerated pace of the business processes as a result of increasingly shorter project durations, the rising number of project participants due to increasing specialization, the progressive individualization of construction designs and the extension of project-specific objective systems established by owners and users.

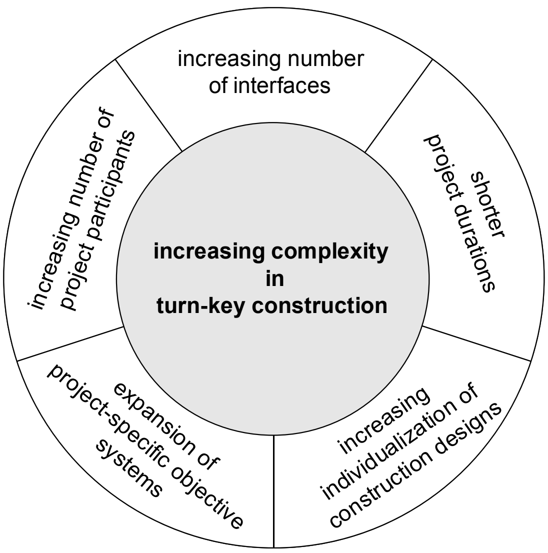

Figure 1. Reasons for the increase of complexity in turn-key construction

The increasing complexity of the product "building" in turn generates increasing complexity in the various processes in construction management, such as cost estimating, scheduling or planning coordination (cd. Gidado 1996). In this respect estimating is a process of particular importance for the contractor. The further development from classical contractor of structural works to contractor of turn-key building projects thus leads to sometimes drastically high requirements in terms of the handling of operational business processes in the construction companies. In recent years this has affected an increasing number of German companies, because the proportion of turn-key projects in the construction volume as a whole, especially in building construction, has increased continuously.

This paper describes an approach to modeling the interface valuation in estimating. This approach will be formulated from a construction management perspective with a focus on the organization of estimating in construction companies. These considerations will give rise to approaches for the future support of the estimating process by construction informatics. The aim is a process model strictly constructed on the functional logic of the turn-key construction work.

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2 CURRENT PRACTICE IN ESTIMATING

A strong characteristic of current practice in estimating involves breaking down the entire system "building" into smaller elements or packages, for example structure, envelope, M&E, interior and analysing them. On the basis of this analysis, the bid price for the project is put together. The systematic synthesis of these elements, i.e. the recording and pricing of the interaction between them and the resulting consequences for the bid price is much less intensive. Without adequate synthesis, however, it is impossible to make an adequate estimate of production costs.

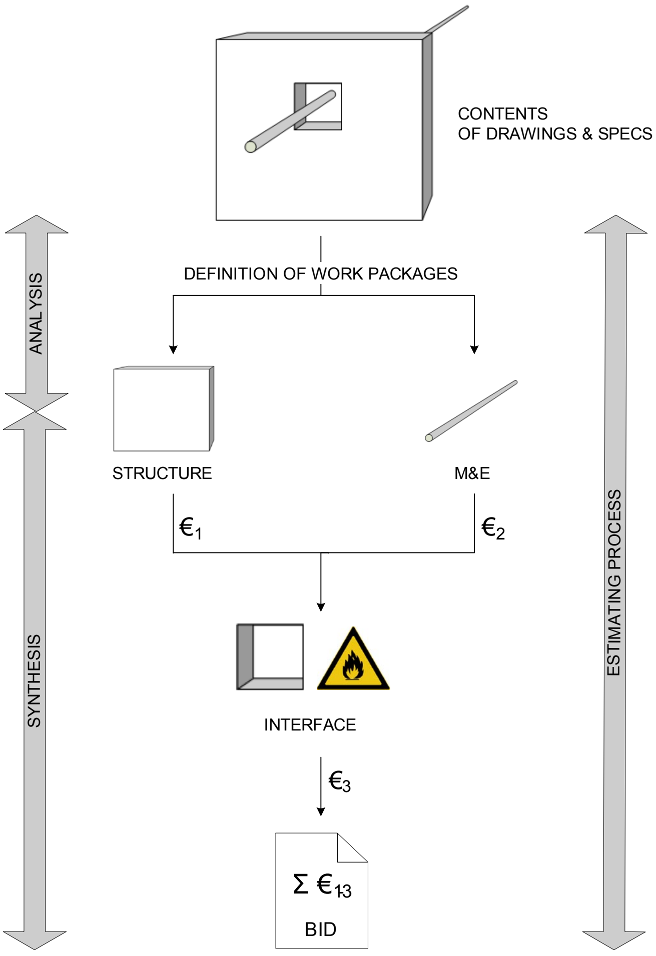

Figure 2. Analysis and synthesis of work packages in the estimating process

The reason for fragmenting the estimating process has largely to do with the historical development of construction companies from structural builders to turn-key builders. Existing expertise and resources in the area of estimating structural works have been supplemented by specialists for the other trades for which there was and still is no existing know-how in the company. These specialists are often from sub-contracting project-related external engineering companies which, spatially, organizationally and hierarchically discrete, contribute their share to costing. The networking of these various units is certainly a critical factor for the success of the process, but is often in practice, in our experience, underestimated. Thus, for example, a structural works expert calculates the wall openings required for the M&E pipings, and his colleague responsible for calculating the M&E trade itself calculates the appropriate pipings, but the costs for fire barriers that may be necessary at the intersection of structural and M&E works are often not systematically considered.

Without adequate synthesis, i.e. interface management, no satisfactory definition of the construction costs is possible. This is especially true in the case of functional technical specifications with completeness clauses. This sort of specification has become standard in turn-key construction. Unlike the specification with detailed bill of quantities it may be the case here that individual work packages belong to the works as a whole, although they are not explicitly specified, but are contractually required to deliver a building ready for occupation and use (cd. Kapellmann & Schiffers 2000). It is then that the complete linking of work packages for a correct costing becomes indispensable. Against this background and the current market-dependent influence factors on estimating depicted in Fig. 3, it becomes clear that optimizing estimating processes and methods is a fundamental success factor in construction management (cd. Seefeldt 2001).

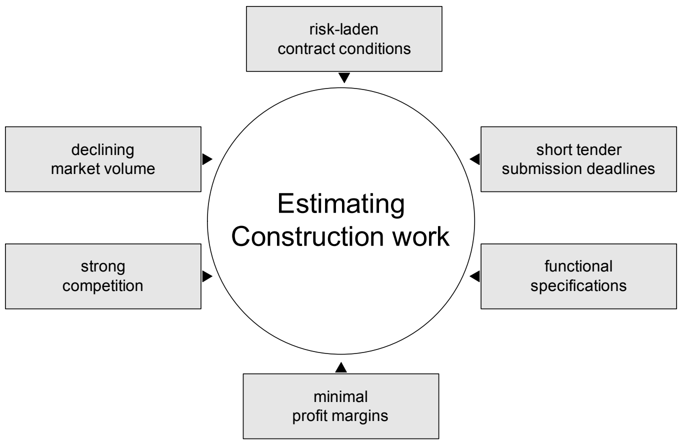

Figure 3. Current market-dependent influence factors on estimating

3 EXISTING SYSTEMS FOR STRUCTURING CONSTRUCTION WORKS AND COSTS

The hitherto normal systems for work and cost structures, e.g. the Standard Construction Work Code (Standardleistungsbuch =StLB) or German Industrial Standard (DIN) 276 – Costs in Building Construction are inadequate in taking into account the estimate-related needs of a general contractor. The

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StLB, in its structuring system, assumes a unit-price single trade based bid procedure. This form does not correspond to practice in turn-key construction. DIN 276 considers the building costs from the point of view of the owner and the architect and not from that of the contractor. Identification systems such as, for example, DIN EN 61346-1 have so far played no part in estimating for turn-key projects. The existing systems all break down the building works into elements independent of each other - in the systems theoretical sense of analysis - or into single trade work packages. In practice, however, a strictly single trade consideration contributes to an incomplete understanding of mutually dependent interfaces, with all of the resulting discrepancies that emerge in the course of the project.

4 INTERFACE MANAGEMENT

The importance of interface management has grown in recent years as the importance of turn-key building has grown (cp. Buysch 2002). Essentially, there is an interface when co-ordination between two elements of a system is necessary. Applied to the calculation of turn-key buildings, the interfaces are cost-relevant points of contact between two or more work packages. These may involve spatial, chronological or technological interfaces. A spatial interface, for example, is the opening in a wall for a sprinkler pipe. Chronological interfaces are the result of mutual dependence of work packages during the execution phase. An example for this is the time needed for the screed to dry before the interior works can be started. Technological interfaces may for example be between the sun protection function of the facade and the efficiency required of the ventilation system. Furthermore, interfaces also occur as result of the division of work made in the course of the estimating process. These are organizational interfaces between various people.

It is the task of the interface management to guarantee the complete cost valuation of all interfaces. This is a co-ordinating function within the estimating organization. Among the principal tools that support and document this co-ordination are interface matrices, interface co-ordination plans and interface specifications.

These tools however are usually discrete isolated applications. Lists or specifications of interfaces are, so far, not generated automatically from the CAD data during the planning process. Similarly, the usual estimating software has no functions that provide automatic indications of possible specific interfaces when processing individual work packages. These are possible starting points for common research projects in co-operation between construction management and construction informatics.

5 INTERFACE-ORIENTED ESTIMATING

The building elements represented in Fig. 2 are intended to clarify the approach of interface-oriented estimating. The three building elements are a reinforced concrete wall, a M&E piping that passes through this wall and a fire barrier in the wall opening. These three elements are dependent of each other in terms of location and measurements. In abstract terms, there are three objects (wall, piping, barrier) whose respective versions are interrelated. In terms of interface definition this a spatial interface.

In the course of a trade-oriented estimating process the building elements are divided between the work packages structural works and M&E works. The wall, including the opening, is allocated to the reinforced concrete works, the piping to a one of the M&E trades, e.g. sprinkler installation, and the fire barrier usually to a separate work package. In practice our experience is that at least two people from the estimating department of a construction company are involved in calculating these building elements – the structural works estimator and the M&E works estimator. The complexity of this planning detail then becomes clear if one takes into account that, in the planning phase, three parties are involved (the architect, the structural engineer and the M&E engineer), in the estimating process the two estimators previously mentioned, and in the execution phase altogether three specialist firms for structural works, M&E works and fire protection works. Because planning details often change in the course of a project and these changes have to be co-ordinated with each other, the result is an even more intensive need for co-ordination among all parties involved.

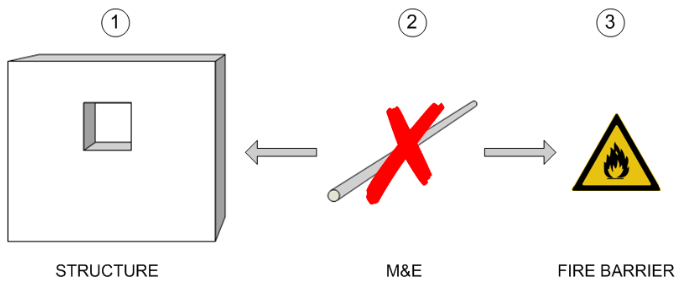

Figure 4. Trade-oriented structure of work packages

In the trade oriented calculation process the procedure is as follows: in estimating the costs for the construction of the wall, the costs of the opening are included and spread among the m² of wall surface. The costs of the piping and fire barrier are estimated separately. If in the course of a planning change the piping becomes unnecessary, there is no further need

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to build a wall opening and a fire barrier. In this case all three packages would be affected by changes in costs and would have to be re-estimated. In the case of reinforced concrete works this leads, because of the previous cost spreading, to a change of the costs per m² of wall surface.

In the case of an interface-oriented estimating process another procedure is used. This approach leads to a separate estimate of the interface costs. In the example considered, these are the costs for the wall opening and the fire barrier. The costs of the opening are consequently are not spread among the m² of wall surface. If the piping is not necessary, the estimate of the wall does not have to be revised. In comparison with the trade-oriented procedure, one co-ordination point less is necessary.

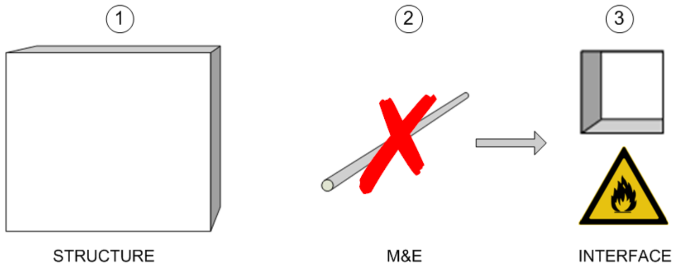

Figure 5. Interface-oriented structure of work packages.

This procedure is logical inasmuch as the opening and the barrier are necessary only because of the cross-over point between wall and piping and are otherwise dispensable. The interface-oriented approach is based strictly on the functional logic of building elements. This means that estimating and cost structuring basically follow the cost-relevant links between the work packages and not necessarily the traditional cost structuring systems and company-specific organizational structures. As a result, a estimating process that follows the inherent logic of the construction process becomes the model. This process model helps to prevent interface costs - as can be observed very often in practice - from being incompletely calculated.

The reduction of the co-ordination points required leads to reduction in complexity. Consequently the interface-oriented calculation approach helps to cope with the complexity of turn-key building projects. In the opinion of the author it is worthwhile pursuing this approach in construction management and economics research.

In the construction phase of the building the interface-oriented approach does not mean any alteration in the allocation of the building elements to the subcontracting single trade contractors. In the example cited the wall opening would still be part of the work package of the structural works contractor. The difference is, that the allocation of building elements to the work packages takes place after the calculation of the interface costs and not before.

6 APPROACHES TO RESEARCH CO-OPERATION BETWEEN CONSTRUCTION MANAGEMENT AND CONSTRUCTION INFORMATICS

A necessary basis for implementing the interface-oriented approach in estimating is the existence of a complete interface model for the construction project. Fig. 6 shows an extract from the design of a corresponding model, in which the possible spatial, chronological and technological interfaces have to be represented. The drawings and technical specifications can then be examined at the appropriate interfaces. Thus, from a general model a project-specific one can be generated. The project-specific model can then be used to make a correct allocation of the costs to the building elements and interfaces. The cost structure here has to be so flexible that both interface and trade cost allocation is possible by means of a sort function. The trade allocation for the general contractor is necessary, among other things,

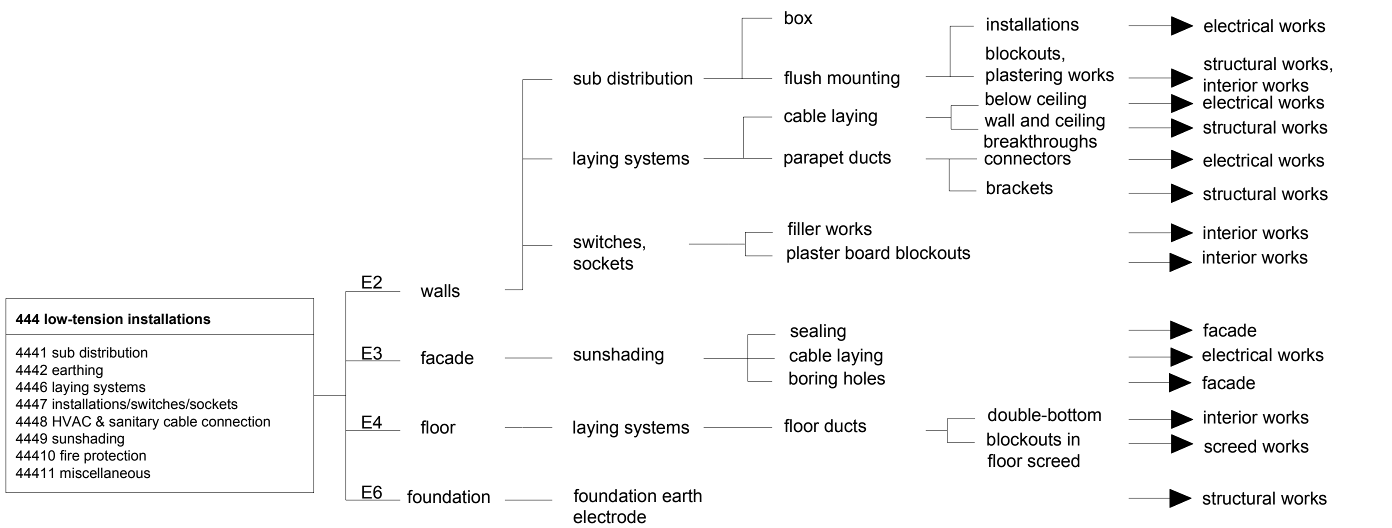

Figure 6: Interfaces of low-tension installations with other compound units and trades

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to prepare the contract awards to the subcontractors. The interface allocation is, in turn, the basis for change order management in the further course of the project.

From the point of view of construction management research it is necessary to examine, in co-operation with construction informatics, to what extent project-specific interface models can be generated directly from the CAD documents of the architect and specialist planners and engineers. The aim of concrete research co-operation in this area could be to link tools for interface management with existing CAD tools. It is conceivable that the contributions of the individual planners (architect, structural planner, M&E planner, facade planner and others) could be integrated in one CAD model of the building and that spatial interfaces then ca be detected by means of clash detection. A further field of investigation must also deal with the extent to which general interface models can automatically be updated and extended with project-specific new knowledge. The interface model would thus be a tool of knowledge management in the company that would contribute to the transformation of person-related implicit knowledge into generally accessible explicit knowledge. It supports individual and organizational learning processes and provides, besides estimating, additional approaches to optimizing further management processes in turn-key construction.

7 CONCLUSIONS AND OUTLOOK

Estimating processes for turn-key projects have to be adjusted to the complexity of the building project. The individual building elements have to be considered in their functional context. For this reason the linking-up of individual partial processes and those people working on them is of major importance for a correct estimate. The interface-oriented approach leads to the necessary linking-up of the process structures.

The approach presented could be a starting point of future joint research projects involving construction management and construction informatics. It sketches demands for the further development of IT estimating tools. Construction management practice urgently needs innovations in this area.

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Resources, Time & Money: Why project schedules simply don't work

S.M. Holzer & F. Geyer
Institute of Mathematics and Construction Informatics, University of the Federal Armed Forces Munich, Germany

ABSTRACT: Construction of buildings is a very special kind of production because each product is generally produced only once, as an individual. Therefore, there is no means of an empirical assessment of cost as a function of resource deployment, time, and sequence of tasks, by way of *experimentation* as in the case of industrial mass production. On the other hand, buildings are very expensive, so that there is a great need for reliable cost estimation, estimate updates during construction, and cost analysis. Due to the lack of known, reliable functional relations between the key cost-relevant quantities, very coarse simplifications of the system need to be introduced. The contribution discusses ways to develop such simplified cost models, without rendering valueless the results obtained by such a model. We assume that the whole cost estimation process will be implemented into an overall schedule planning system, without introducing insurmountable overhead.

1 INTRODUCTION

Commercial software tools are available for the problem of temporal *scheduling* of tasks in a production process. Such tools are based on graph theory and determine the longest path through the graph of processes and the sequence rules between them. The longest path corresponds to the minimum production time required. Input data required for the construction of a time schedule include any two of the following three: *time* required for each individual task, *efficiency* of the resources allocated to the task, *size* of the task.

Typical post-processing options included in a scheduling tool are presentation of the computation in the form of a bar chart (Gantt chart), as well as resource-versus-time charts. Adjusting the schedule to possibly limited resource availability is usually not well supported by commercial scheduling tools.

However, the time schedule is not really what one wants first when considering a construction process. Rather, what one needs first is a good estimate of the final *cost*. Often, the total duration of the construction is given as a constraint rather than sought for, and it is therefore the prime concern how to allocate resources in such a way that one meets the deadline at minimum cost.

More important still, it may happen that, during the actual execution of the project, we encounter unexpected delays or problems. In such a case, we will want to know as soon as possible what financial risk is entailed by the delay or change in the schedule.

In other words, at the beginning of a new construction project, we do not really want to plan a project schedule, but what we need is a *financial plan and model*. One of the reasons why this is particularly difficult in the construction business is that buildings are individual, unique products. As opposed to stationary mass production, it is not a feasible way to perform a test and determine the relations between task size, resource allocation, time, and cost experimentally.

The link between the size of a task, the time required, and, ultimately, the cost estimation is provided by the resources employed (human and machinery) for accomplishing the task.

Resource assessment has a long tradition in stationary mass production. For example, the *Reichsausschuß für Arbeitszeitermittlung* (REFA, committee for the investigation of working time) was founded as early as 1924 in Berlin, Germany. It continues to this day to work in rationalization of production processes in mass production.

Unfortunately, these ideas cannot be directly transferred to construction industry because the working conditions play a key role in the net efficiency which will be attained by the resources; however, the working conditions are a priori unknown in construction industry. In construction industry, the working conditions depend strongly on the process itself, and also on incontrollable and even unforseeable outer influences (e.g., weather,

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just to begin with). This is the main reason why even the initally computed time schedules usually fail to coincide with the actual construction sequence. In fact, what one would need is a feed-back iterative planning of the construction schedule itself, starting from some assumed working conditions and then performing an update of the assumed conditions, based on an analysis of the computed schedule. Once we have computed a "trial" schedule, we can detect collisions and problems of any kind which will deteriorate working conditions.

There is no hope of really overcoming the problem of indetermined resource efficiencies in construction processes in a deterministic way. Therefore, there is also probably no way to foretell construction cost and financial risk precisely. However, there is some hope at least to *bracket* both temporal and financial efforts connected to a specific construction project by employing some fuzzified model.

2 RELATION BETWEEN RESOURCES AND COST

Construction cost can be associated with three types of cost generators:

– cost of material
– cost of human and machine resources
– cost of financing

The first kind of cost is rather straightforward to determine once one knows *what* to build. However, the other two depend mainly on *how and when* one builds.

In the following, we start from the (simplified) assumption that *what* we want to build is fixed.

Time and resource cost are strongly related. Resource cost is determined by resource allocation to individual tasks. Once we have allocated a certain number of a certain type of resource to a task in the construction process, we can compute the time required to complete the task. The time required, multiplied by the unit cost of the resource per unit time, gives the actual cost of the resource.

However, such a computation holds only under strongly idealized conditions. In reality, the *efficiency* (output of a unit resource per unit time) of a resource depends in some non-linear way on the number of resources assigned ("if two masons need four days to build a wall, four masons will *not* accomplish the same task in two days"). Therefore, the time schedule itself depends non-linearly on resource allocation.

Similarly, the unit *cost* per resource may depend non-linearly on the number of resources assigned ("buy one get one free").

Both these two non-linearities are, of course, also present in stationary mass production. However, there they can be assessed at least empirically by the way of tests on a reasonably big number of prototypes. Building unique constructions, this is not a feasible way of resource assessment.

It is therefore probably a hopeless endeavour to determine functional expressions relating task size, time required, and cost in the construction business. Even if they were available, it would probably be vain hope that someone would take the trouble to input all these data into a scheduling tool.

In addition, tasks cannot be considered independent of each other. One of the main sources of financial trouble in the construction business is related to mutual hindering occuring between different tasks. E.g., assume that a painter A paints the wall in a room. Simultaneously, a floor layer B creates the floor in some other room. So far no problem. However, the efficiency of both will drop radically if both work in the same room at the same time. Also, painter A will work less efficiently if floor layer B has already done his job in the room to get painted because he will have to protect the new floor from the paint. However, before we have computed the construction schedule, we cannot foretell whether any of these cases will happen or not. We can only guess and adjust the efficiencies which we can expect for A and B in a trial-and-error procedure, perhaps guided by some automatic optimization tool.

However, the project schedule usually does not contain the data which we would need to update the efficiency defects resulting from mutual hindering. Such constraints are typically of a *geometric* type (the painter need to pass through room 1 in order to reach his working place, while the floorlayer may just be working in room 1) and are completely outside the scope of the scheduling tool.

Efficiency and cost of resources may even, in some cases, depend directly on absolute date/time: It is more costly to excavate a foundation in winter than in summer.

Finally, resources may be limited from above and below: We may need a certain number of workers to be technically able to accomplish a certain task, and, on the other hand, it may be impossible to acquire or accommodate more than some fixed maximum number of workers. These constraints may get active under some conditions which again depend on the time schedule. In order to simplify the problem of cost modeling, however, we will assume in the following that resources have unlimited availability, so that it only becomes a matter of money to buy or rent whatever we need in order to complete the construction. We do not lose much by this simplifying assumption because limits on resources can still be handled in a penalty approach by making them very costly outside the permissible interval.

Cost of *financing* depends on both material cost and resource cost. We need the functional relation

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between the sum of material and resource cost, as well as the customer's payment plan, in order to be able to compute the resulting cost of financing.

3 RESOURCE MODELING

Anyone who plans a construction project has some rough idea about "reasonable" resources attributable to a certain task. Essentially, this is what he has to do even in case he just wants to compute the tentative construction time schedule.

Furthermore, the project planner has some idea of the output achieved, under "normal" conditions, per unit resource.

However, the project planner has also some rough idea about how the resource efficiency decays if resource deployment is less than optimal, or if working conditions deviate from "normal" conditions.

Let us, for the time being, assume that all tasks may be grouped qualitatively into three classes, A="quite insensitive to influences", B="very sensitive", C="not particularly sensitive". The quality "sensitivity" describes the effect which changes in resource allocation and in the general working condition have on the output. Qualitatively, the three sensitivity classes of resources might be represented in a graph similar to figure 1:

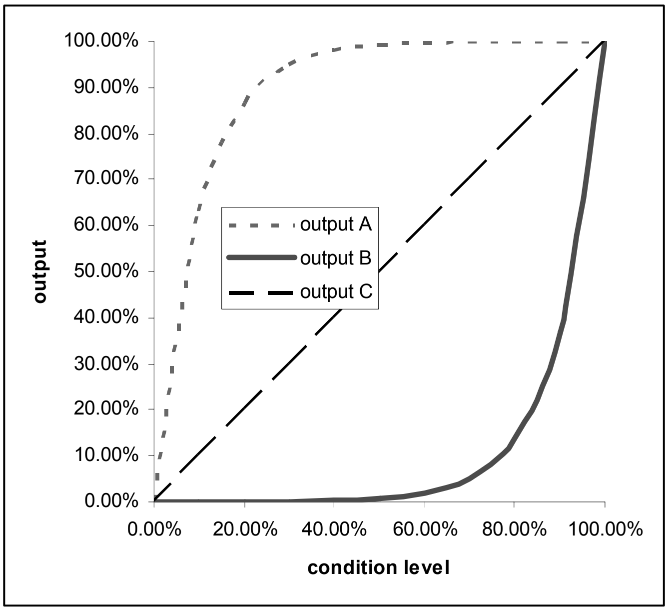

Figure 1. Three sensitivity classes of resources

In fact, the figure shows (quite arbitrarily) a mathematical formulation of the three sensitivity classes. We might as well have quantified the three classes by some number, running from class A corresponding to 0, to 1 corresponding to class B. One could use some parametrized function $f(x,a)$ with parameter a which fulfils the following conditions:

$$f(x,a)\begin{cases} \to 1 \text{ on } 0 < x \le 1 \text{ for } a \to 0 \\ = x \text{ for } a = \tfrac{1}{2} \\ \to 0 \text{ on } 0 \le x < 1 \text{ for } a \to 1 \end{cases}$$

and $0 \le f(x,a) \le 1$ for $0 \le x \le 1$.

Let us now agree to use the parameter a with $0 \le a \le 1$ as a measure of sensitivity.

"Sensitivity" makes sense only if we also define sensitivity with respect to what. Here, we have introduced another very simplifying assumption.

The quantity x on the abscissa reads "condition level", once again assuming values between 0 and 1. This rather imprecise quantity is assumed to describe, in some *overall* measure, *all* kinds of effects that we may encounter when actually carrying out the task: too few or too many workers assigned to the task, too many others around which hinder the process, effects of foul weather, and so on. x is a completely *abstract* quantity, so to speak dimensionless. How a specific task depends precisely on changes in the working conditions is described by parameter a, not by x. In other words, x=0.5 is only an abstract measure of "conflict" inflicted upon a specific task. That task, on the other hand, may in turn be quite insensitive to "conflict", which will be expressed by a close to zero, rather than using a different scale for x for each task individually. x is a scale-independent quantity. The reason for introducing this quantity is that, later on, we would wish to select x for each task automatically in a rather coarse way, without asking the user for any input on that. All experience and external knowledge of the user will be represented solely by specifying a.

Assume, for the moment, that someone is able to provide concrete numbers for x and a. Then, we have a computable functional relation between working conditions and resource output.

The presentation in the preceding paragraphs has been such as to suggest an application of *fuzzy algebra* in a next step. Using, e.g., simple triangle fuzzy numbers, we might be able to model the sensitivity a assigned to a specific resource by a simple bi-linear membership grade function on the set [0;1].

The figure 2 shows a model for a resource which is "not quite sensitive", the maximum of the membership grade function being at a=0.4, corresponding to a curve slightly above the diagonal in the preceding figure. Using this fuzzified value of a relieves us of fixing a definite number for it, but burdens us by using fuzzy algebra for the evaluation of the output function.

The next question is whether it makes any sense to handle the working conditions x as a fuzzy quality as well. This question is actually posed the wrong way. The working conditions are not a primal quantity, but rather a dependent variable. What we

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need to do is to fix some deterministic default number (typically x=1) for the working conditions (i.e., "normal conditions") initially. Subsequently, we enter into a fuzzified computation of the project schedule with this value.

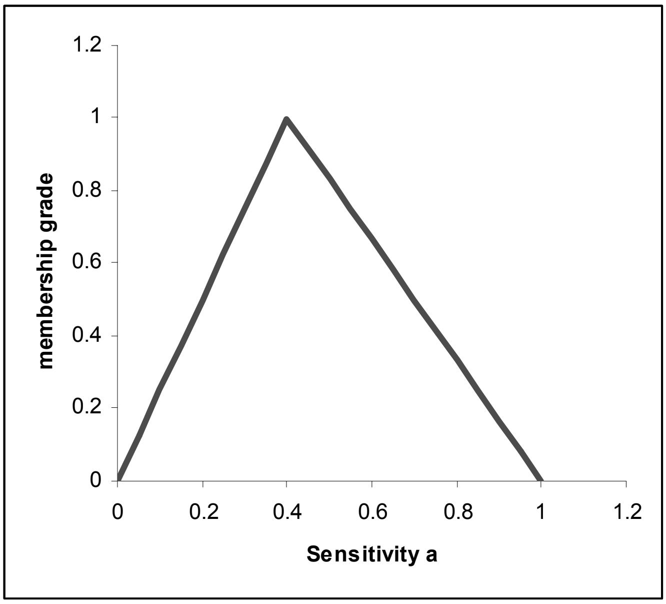

Figure 2. Bi-linear membership grade function of sensitivity

To this end, we can use the normal graph-theoretical longest path solver. We require nothing but the standard input, namely, some resource assignment for every task, and the "normal" output for the resources assigned.

We will arrive at a fuzzyfied schedule in a similar way as it has been done, e.g. in Freundt (2004). However, as opposed to Freundt 2004, we are not mainly interested in that specific schedule, but rather in its effects on the yet to be fixed parameter x, and, ultimately,on predicted construction cost.

To achieve this, we need to extend the data present in the process model. At least, we need some model on how typically some constellations influence working conditions of some sub-set of our tasks.

Many tasks in the schedule are linked to geometrical information. Each part of the building that needs to be erected has some location in space. This data is typically available in a CAD program. We require some link between the scheduling and the CAD code.

Next, we can introduce some measure of the influence of proximity in space and time on the quality x of the working conditions. This need not be a very detailed model, rather some rough estimate (e.g., we might assume that any two tasks having to be carried out within a distance of less than 5 m from each other during "roughly the same time" will deteriorate each other's working conditions to 0.6 or by a factor of 0.6). If we use this deterioration function to compute the quality measure x from our fuzzy output of the scheduling problem, we will essentially obtain a fuzzy parameter x. This holds even if the deterioration function itself does not introduce any new fuzzy parameters. In order to keep fuzziness limited, it is probably best to de-fuzzify x at this instant.

Of course, it is sensible to reset the condition number x to 1 in case there are no conflicts left for a specific task, due to shifts caused elsewhere in the project schedule.

We are next going to feed back the working conditions x into the schedule, and we obtain a new, hopefully more realistic, schedule.

Note that, so far, adjusting of the condition number can only have one effect, namely, extending the duration of a specific task.

4 STRUCTURE OF A BASIC COST MODEL

Until now, we have dealt only with resources, and, indirectly, with time, but not with money. However, it is straightforward to obtain monetary assessments of the project once we have a somewhat realistic temporal schedule. The same question as before arises when we want to associate money with resource employment: Should there be a deterministic function relating resource usage to money, or is it better to model that in a fuzzy way? We are following the guideline of keeping fuzziness to an absolute minimum in order to obtain meaningful results in the end. Therefore, we suggest that we use a *fixed* unit price for the resources, rather than any fuzzified relation. The unit price does not depend on the quantity of the resource used.

This amounts to saying that we put *all* fuzziness *exclusively* into the parameter a. In other words, the indeterminateness of the "output" of a resource comprises also the indeterminateness of cost. All effects related to quantity discounts and the like are considered as properties of the condition to output map described by x and a.

After this daring straightforward modeling decision, we have a working model which, after some iterations, will hopefully converge to a stationary solution for the scheduling problem. If we encounter conflicts, this will delay our project progress; delays may occasionally lead to resolving conflicts elsewhere, which we can also handle by resetting the condition number to 1, However, it is by no means sure that we may not find ourselves locked in an infinite repetition of useless iteration cycles. Convergence is not guaranteed at all, or rather, frankly speaking, quite unlikely. However, the effects of lack of convergence on our main goal, money, may be less dramatic. Therefore, we may altogether dispense with convergence!

Assuming (still quite naively) that there exists at least a locally optimal solution with respect to some objective function, we can, however, "force" such a

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problem to converge towards the solution if we employ some suitable optimization technique.

We are not at a loss to formulate a suitable objective function which we want to minimize. One such function would be, of course, total cost.

However, what are our design parameters? Of course, the amount of resources assigned to each task. It is important to note that the problem has changed a great deal now with respect to the classical scheduling problem: The scheduling is now turned into a mere side calculation required in order to determine the trial cost of the project. The governing, driving problem is the cost estimation problem. We do not really care for a "converged" solution to the scheduling problem. Some rough idea of the process schedule will be fine enough for our ultimate goal of cost estimation provided the prediction of the active deterioration functions is not too far from reality.

If a certain task is hampered by suboptimal conditions, it will be delayed by reduced output in our model. This may not be realistic in all cases because we may rather opt for paying more for that task, but get it completed in time. However, such an expedient is still available in our model, precisely by increasing the resources allotted to the task. This will increase cost while possibly keeping the duration constant. In other words, our model is complete in this respect. Remember that we are going to use fixed unit prices for everything, putting all fuzziness into a and all design parameters into resource allocation.

5 SCOPE OF THE MODEL

The model presented looks pretty simple. It remains to give an outline how such a model can be implemented and used. Let us first consider the problem of input. We require:

1 assigning the peak value of the task-specific sensitivity a on the scale 0 to 1 to each kind of a resource
2 input of at least some "deterioration functions".

The first requirement is probably easy to fulfill. The second is more complicated. At this point, we have to look for the other contributions of the present workshop. Referring to Huhnt, we find that tasks are derived from task classes. Of course, it suffices to define "deterioration functions" between *classes* of tasks rather than individual tasks. The evaluation of the deterioration function for each member of the set of one task class to all members of the other class involved can be carried out automatically. Rules such as "floor layers and painters are likely to hamper each other when working close to each other at the same time" can be implemented once and for all. The functional representation of such rules might even recur to *fuzzy logic* (rather than fuzzy algebra) because the input data are fuzzy anyhow. Details have to be fixed during the actual implementation phase of the research project outlined here.

Huhnt's contribution offers the direct access to the longest-path problem once we have performed resource assignment to tasks. Whereas "generating sequences of construction tasks" is based on mere topological sorting of the tasks, the longest path problem can be solved on an edge-weighted graph by Dijkstra's algorithm. Implementation of that is straightforward on a graph-centered code like Huhnt's.

6 CONLUSIONS AND OUTLOOK

In the present contribution, we have outlined a method to incorporate cost estimation into project scheduling under the specific constraints posed by the construction industry. We have resorted to a mildly fuzzified representation of the operating resources employed, and we have put all indeterminateness associated with the project exclusively into the resources. All other relations have been kept strictly deterministic, with the single exception of possibly modeling the mutual influence of spatial or temporal proximity of possibly conflicting tasks also in a fuzzy approach.

We have also demonstrated that such a model can be incorporated within the scope of a classical graph-based scheduling tool, or, alternatively, within Huhnt's graph-based sequencing tool.

The model developed is such that the input which needs to be provided by the user is in fact limited to earmarking each resource used in a class by some "sensitivity class", specifying the peak value of the parameter a in the range 0 to 1. Furthermore, some super-user has to implement at least a few very important "deterioration functions" for task classes, rather than individual tasks. In order to obtain geometrical information, the scheduling needs to be linked up to a geometric design tool (CAD).

Our approach differs from the one presented by Freundt (2004) essentially in the following points:

1 Our main goal is not a fuzzy representation of the schedule problem; rather, for us, the fuzzy scheduling serves only as an input for the *cost assessment*.
2 We require only *one single* input value for the fuzzification because the parameter a is supposed to occupy the interval [0;1], so that only the peak location of a is free. Freundt, by contrast, needs input of three values.
3 Our approach is oriented towards a more strictly causal and more fine-grain modeling than Freundt's: Rather than modeling execution times

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as a primal fuzzy quantity, we identify loss of efficiency in the resources as a cause for delays (which means, by the way, that we do not suppose that tasks can be completed ahead of time at all). Therefore, we obtain execution times by a fuzzy algebra computation as fuzzy numbers, but we do not have to ask the user to estimate them directly.

4 Scheduling is achieved in an iterative fashion in our general approach.

5 We have opened an approach towards *cost minimization* by the causal approach because *resource allocation* remains a free, deterministic design parameter in our model.

The next steps required are incorporation of the model into existing code frameworks, as well as embedding the scheduling task into an outer optimization loop.

What remains to be done is to explore the precise nature of the cost minimization problem and select suitable optimization strategies. We hesitate to assume that simple strategies would suffice to solve this kind of problem.

Finally, the whole model needs to be embedded into a cost control tool which will be used to supervise the actual construction process. During construction, details on the actual performance of the resource become available, which will help us to adjust the model by replacing the $x \to a$ map by observed data. At the same time, the number of design variables is continually decreasing, so that it becomes increasingly easy to find out what has to be done or what can be done in order to prevent the worst financial disaster of a project running less than perfectly.

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Integration of Multiple Product Models

A. Kiviniemi
VTT Building and Transport, Technical Research Centre of Finland, Espoo, Finland

J. Haymaker
Center for Integrated Facility Engineering, Department of Civil and Environmental Engineering, Stanford University, Stanford, USA.

1 INTRODUCTION TO WORKSHOP

The development of the Industry Foundation Classes (IFC) started from the vision that an integrated building product model would cover all necessary information for a buildings' entire lifecycle: from requirements management, through different design processes to construction and maintenance processes. Although the IFC model specification covers a substantial part of the required information, AEC projects still have encountered many problems putting this model into practice. AEC professionals still find it difficult to have dynamic, lossless, truly effective data flow amongst the different participants and applications. It is obvious that file based data exchange alone is not a feasible solution; some other solution for integrating project information is necessary.

This workshop discusses some viewpoints and potential solutions to the above issues and problems.

- Kiviniemi et al (2005) suggest we break the project into 4 main types of models: requirements models, design models, construction models, and maintenance models. They suggest we then use model servers with standardized interfaces (SABLE 2003) to simplify access to these models. They also call for a standard way to link objects in different models to each other. They call for an international research effort to define the framework and proof of concept that incorporates several applications in a multi-model
- Haymaker (2005) suggests an interaction metaphor called Narratives that AEC teams adopt as a way to enable dynamic communication and control of many models. With Narratives, AEC professionals formalize and control the dependencies of their models on other models. The straightforward graph based formalization is designed to enable AEC professionals to easily, visually, and formally construct and control many models and their interrelationships.

In this workshop, we propose to design a multiple model server environment using the Sable API, IFC data formats, and any number of User Applications and interaction metaphors such as the 4 Model, and Narrative. This platform would first be developed as a proof of concept and test bed for international project model research. Ultimately, AEC project teams can use it to easily and dynamically define, construct, and manage their many models.

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Kiviniemi, A., Fischer, M., Bazjanac, V., 2005. Integration of Multiple Product Models: IFC Model Servers as a Potential Solution. In: present publication, *Proceedings of 22nd W78 Conference on Information Technology in Construction*, Dresden, Germany, July 2005.

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Integration of Multiple Product Models: IFC Model Servers as a Potential Solution

A. Kiviniemi
VTT Building and Transport, Technical Research Centre of Finland, Espoo, Finland

M. Fischer
CIFE, Civil and Environmental Engineering, Stanford University, Palo Alto, USA

V. Bazjanac
Lawrence Berkeley National Laboratory, University of California, Berkeley, USA

ABSTRACT: The development of the Industry Foundation Classes (IFC) started from the vision of an integrated building product model which would cover all necessary information for buildings' whole lifecycle: requirements management, different design activities and construction and maintenance processes. Although the IFC model specification covers a substantial part of the required information its implementations into practical applications have shown several serious problems. One of the main problems is that the internal structures of the different software products do not support the information needs for the whole process. Thus, the idea of lossless, incremental data flow through the different applications used by the project participants has not come true. It is obvious that file based data exchange is not feasible solution, and some other solution for integrated project data model is necessary for the AEC industry. This paper discusses some viewpoints and potential solutions to the above problem.

1 INTRODUCTION

The development of the Industry Foundation Classes (IFC) started in International Alliance for Interoperability (IAI) from the vision of a shared building product model which would cover all necessary information for buildings' whole lifecycle: requirements management, different design activities and construction and maintenance processes (Figure 1).

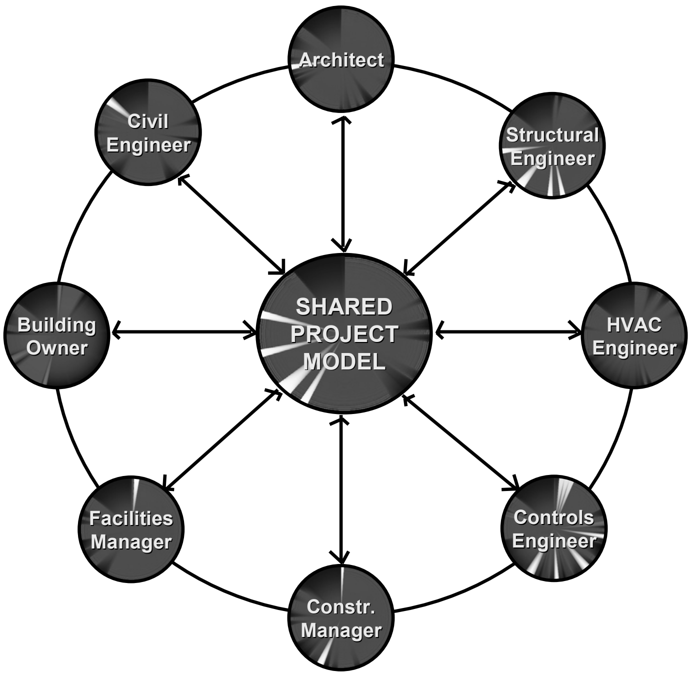

Figure 1: Shared Project Model, IAI 1997

Although the IFC model specification now covers a substantial part of the information required in the design, construction and maintenance processes, its implementations into practical applications have shown several serious problems. One of the main problems is that the internal structure of the different software products does not support the information needs for the whole process. Thus, the idea of lossless, incremental data flow through the different applications, which IAI has presented since 1996, has not yet come true (Figure 2).

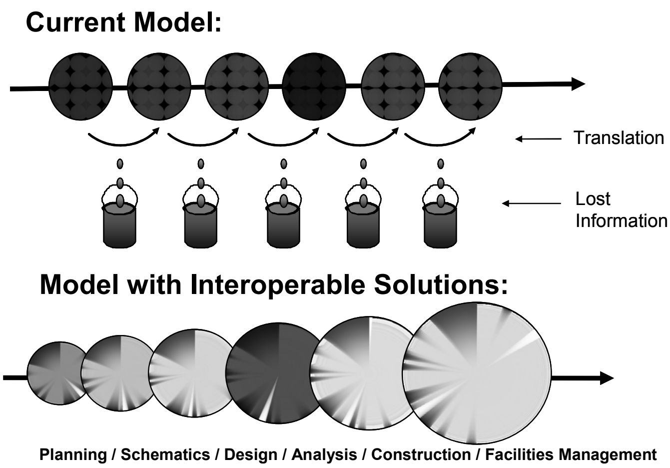

Figure 2: Incremental data flow in the AEC process, IAI 1997

The problems of one building product model and data exchange have been addressed in some earlier research projects. For example, the key problems addressed in the "PM4D Final Report" (Kam &

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Fischer 2002) were that 1) the different information content in different software products makes impossible to maintain all the data when transferring a building product model between different software applications, 2) the instantiated models are large, which makes the file exchange of the model time-consuming although usually only a small part of the model has changed and transferring the whole model would not be needed, if partial exchange was available, and 3) versioning and controlling user rights in file exchange are practically impossible.

Also, John Haymaker recognized the need for several models and the linkage between these models in his Ph.D. research (Haymaker et al 2003).

It is obvious that file based data exchange is not feasible solution, and some other solution for integrated project data model is necessary for the AEC industry.

2 INTEGRATED MODEL SPECIFICATION

The complexity of an integrated model specification has lead to criticism against the development of an integrated building product model specification (Behrman, 2002).

Behrman strongly criticizes top-down data exchange standardization efforts, such as IFC. Many of his arguments are valid, such as the difficulty and slow speed of the development and complexity of the implementation of the standard. As Behrman writes, the lack of high-level commitment of a critical mass of key players is a fundamental problem in data standardization efforts in the AEC industry.

However, the bottom-up development - independent minimalist standardization based on each use-case, which Behrman recommends - has not been more successful in the AEC industry or replaced IFC development since the publication of Behrman's report. On the contrary, aecXML, which tried to use the bottom-up approach, has not progressed since 2002, while IAI has published two new versions of the IFC specifications. Both bottom-up examples discussed in Behrman's report - landXML and gbXML - are still the only aecXML schemas and in draft stage almost three years later. Although the development and implementation of the IFC specification has been slow, it has progressed and strengthened its position as a de-facto standard since 2002.

In addition, Behrman's report does not include the latest technologies in IFC implementation: IFC model servers and standardization of their APIs (SABLE 2003). The development of model servers started in 2001 and as of June 2005 at least three products exist (IMSvr 2002, WebSTEP 2002, and EPM 2003). This development would not have been possible without a comprehensive model specification, such as the IFCs. The model servers and their standardized APIs can hide the complexity of the underlying model specification and enable the use of standard protocols in data exchange, such as XML and SOAP in the software implementation, which is one of Behrman's main critiques of the IFC Specifications.

In our opinion, there is no reason why the development of the model specification should not be based on one integrated schema. On the contrary, regardless of the problems caused by the inevitable complexity of such a schema, one integrated model specification helps to build common understanding of the appropriate structure and relations between the objects in a building product model.

The problems are on the level of instantiated models. The data content in any existing software tool used by the AEC industry covers only a small part of the necessary information. Thus, data exchange between different types of applications contains almost always objects which cannot be stored in both applications. This leads to the same data loss scenario which IAI has been trying to fix by the IFC development (Figure 2).

3 SEPARATION OF INSTANTIATED MODELS

These problems can be addressed by dividing the instantiated model of a project, i.e., project's data set, into four separate main models: 1) Requirements Model, 2) Design Model(s), 3) Production Model(s), and 4) Maintenance Model. These linked sub-models form the integrated project information model (Figure 3).

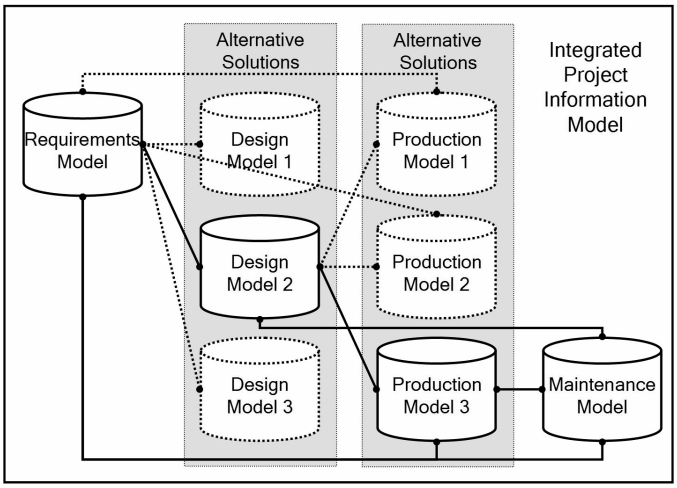

Figure 3: Integrated Project Information Model consisting of the four main models

A crucial issue in the use of separated instantiated model is the ability to link objects in different models to each other. This issue is documented more in detail in the first author's doctoral dissertation (Kiviniemi 2005) and also in a CIB W78 conference paper (Kiviniemi 2005b).

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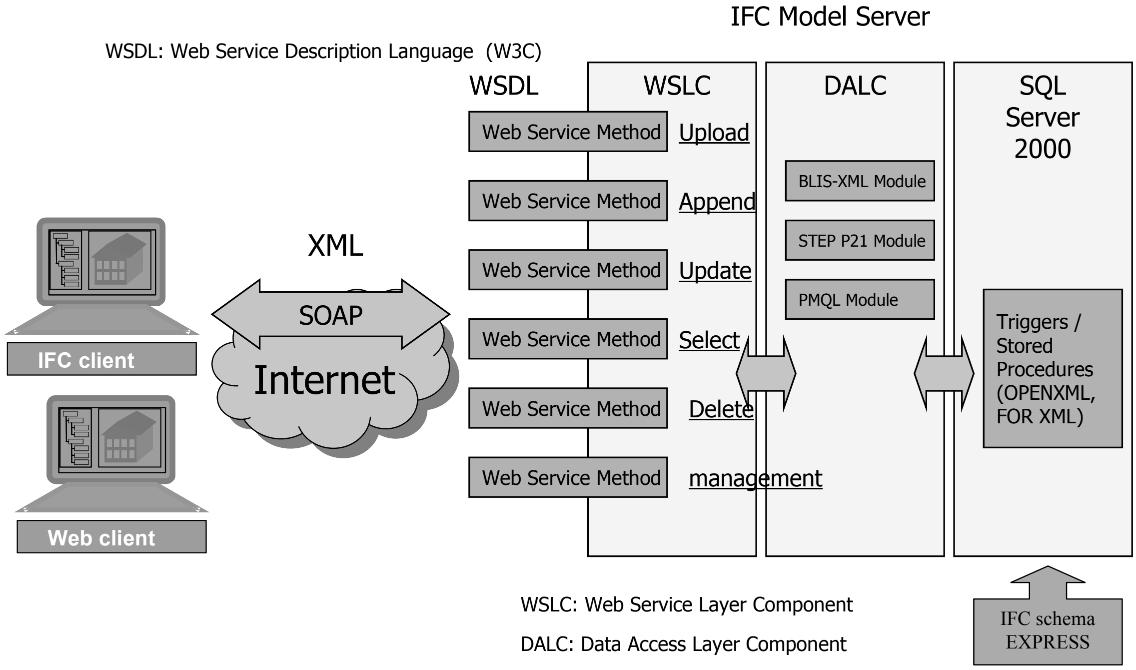

Figure 4: IFC model server architecture © Yoshinobu Adachi 2002

4 MODEL SERVERS

As mentioned earlier, the file based exchange is not a feasible solution for shared building product models, and partial model exchange is also a necessity. In addition, the complexity of the IFC specifications has been one of the bottlenecks for implementation, and easier access to the model data using simple queries would improve the usability of the IFC specifications. To solve these problems, several projects have been developing IFC model servers since 2001: IMSvr (Figure 4), WebSTEP and EPM 2003. All these model servers provide partial model exchange and simple query access to the model using standard technologies such as XML (Extensible Markup Language), SOAP (Simple Object Access Protocol), and STEP (STandard for the Exchange of Product model data) (Adachi, 2002). As mentioned in Section 2, at least three IFC compliant model servers exist as of June 2005.

However, from the implementation viewpoint, the different application interfaces to different model servers are a problem, because they either limit the use to one model server or require implementation of several application interfaces for each domain (Figure 5)

5 STANDARDIZED MODEL SERVER API

A standardized application interface for each domain can solve the problems mentioned above. The SABLE project is developing such interfaces based on SOAP (SABLE 2003, Figure 5). Each domain-specific API handles the information exchange needed by the client applications for each domain, which logically corresponds with the BLIS views (BLIS 2001). The SABLE project is ending in summer 2005 after which its results can be taken into wider use.

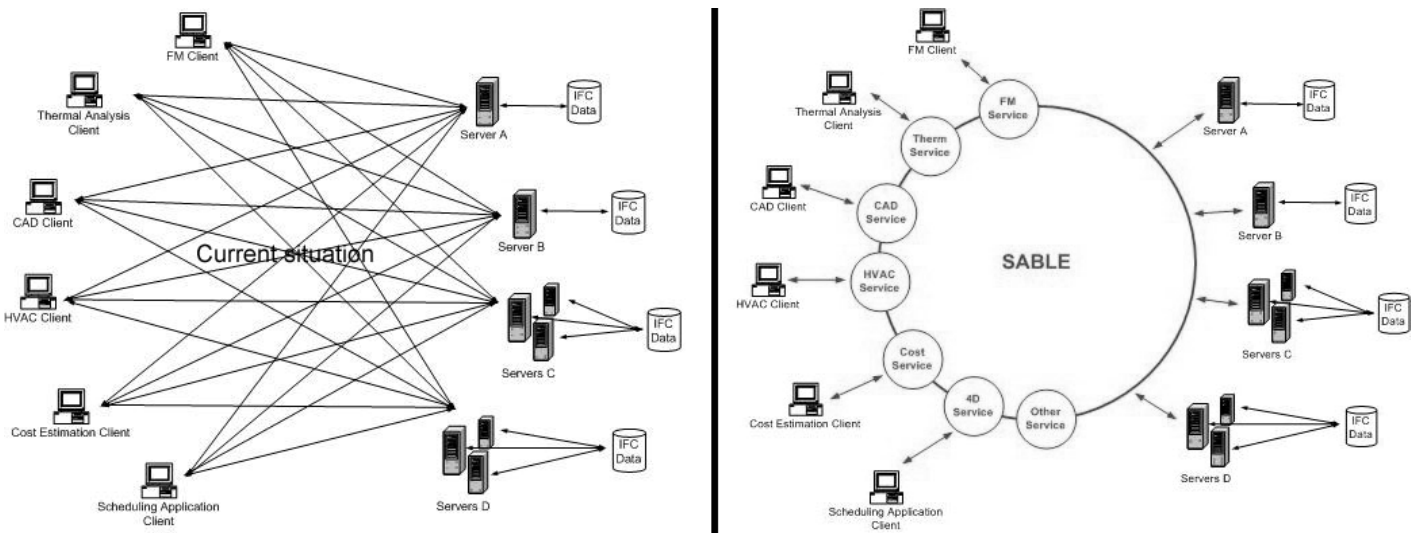

Figure 5: Advantage of the standardized interface approach © BLIS & SABLE 2003

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6 FURTHER DEVELOPMENT: A PROOF-OF-CONCEPT

Although some IFC compliant model servers exist and SABLE API is at the finalizing stage, the interfaces for end-user applications are still missing. Thus, the concept of a multi-model environment has not been tested in real projects.

VTT, CIFE and LBNL formed the Virtual Building Environment (VBE) consortium in 2002. The aim of the VBE consortium is to develop and facilitate the use of building product model technologies in the AEC industry.

One of the efforts starting in the VBE II project in summer 2005 will be the development of some interfaces for end-user applications and testing them in a multi-model environment using real project data, SABLE API and existing model servers (Figure 6). One potential partner in this development will be TNO where Peter Bonsma has developed a 3D component as a part of his IFC Engine Series (Bonsma 2005).

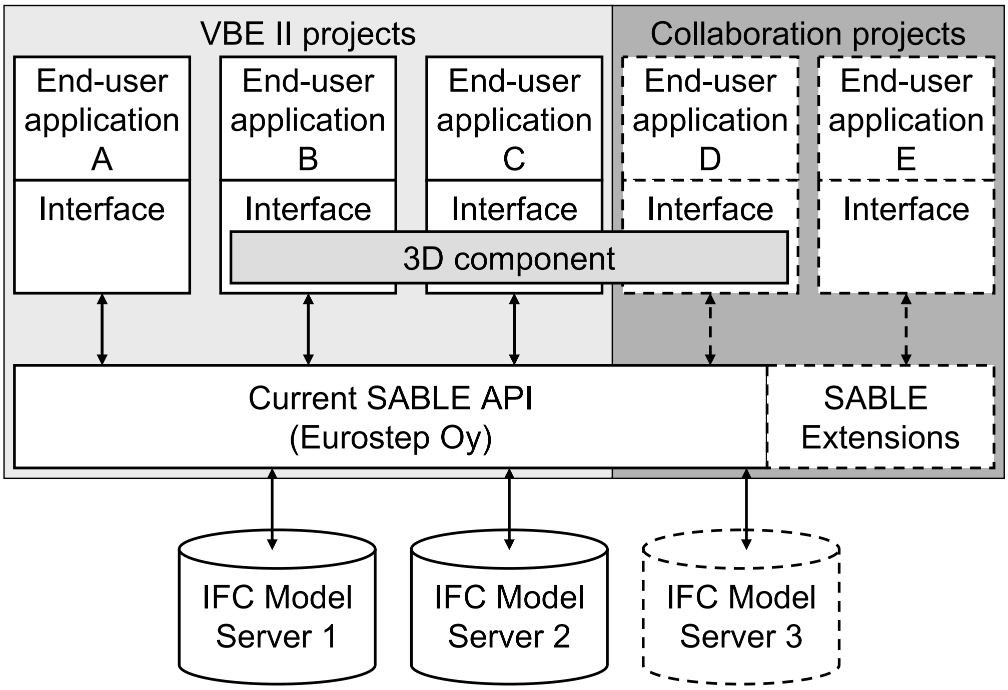

Figure 6: Planned interface development within the VBE II project

An additional potential in the concept presented in Figure 6 would be the possibility to "standardize" an international platform for multi-model environment research. This platform would enable efficient collaboration between different universities and research institutes and efficient use of resources, because a standardized API and underlying model server would simplify the implementation efforts, and the use of software modules developed in other projects would enable simultaneous testing of several features of a shared model without the need to program all necessary functionalities in each project.

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Formalizing and managing the dependencies between models

J. Haymaker
Center for Integrated Facility Engineering, Department of Civil and Environmental Engineering, Stanford University, Stanford, CA, USA

ABSTRACT: AEC professionals need information models that are structured for their specific tasks. They also need to be able to control the integration of these models with the models of other professionals. In this paper I propose methods for formalizing and managing the dependencies between information models. Using these methods, an AEC professional constructs an information model, called a Perspective, and specifies the sources and nature of its dependency on other Perspectives. He specifies the nature of the dependency using a reasoning algorithm called a Perspector that describes the automated or manual reasoning needed to construct the dependent Perspective from its source Perspectives. He uses Management Processes to control the integration of the dependent Perspective as its source Perspectives are iteratively modified. AEC professionals apply this method repeatedly and collaboratively to compose and control directed acyclic graphs of Perspectives and their dependencies, called Narratives. Narratives provide a simple, formal, visual, flexible, distributed, yet collaborative way to construct and control the integration of multiple task-specific Perspectives. They are intended to help AEC professionals communicate, integrate, and automate multidisciplinary design processes and the information models used in these processes.

1 INTRODUCTION

Architecture, Engineering, and Construction (AEC) projects must address many criteria, such as sustainability, function, structural stability, constructability, security, and cost. To do this work, AEC professionals produce a lot of information to describe everything from existing conditions, to project requirements, to design options, to design analyses, to construction documentation, to fabrication, to installation and as-built information. They usually construct this information from other information, which is often produced by other professionals, in other project phases, disciplines, and industries, and they need to maintain the integrity of their information as the project progresses.

That is, AEC professionals implicitly develop what I call narratives for their own work and interweave them with narratives of other engineers. The Oxford English Dictionary defines a narrative as "An account of a series of events, facts, etc., with the establishing of connections between them." In AEC practice, narratives help professionals expose cross-disciplinary impacts and integrate their work with the work of other project stakeholders; however, currently these narratives are not formally represented or managed. Surprisingly, the connections between information from different disciplines, in this case the dependencies, are not generically represented but rather stored in the heads of the professionals. This way of constructing, organizing, and communicating project information is proving to be time-consuming, error-prone, and expensive.

In this workshop we are exploring how to expand the IFC specification to "support links between objects in two different instantiated models." In this position paper, I propose that as part of this specification, we formalize the sources, status and nature of the dependencies between the models that contain these objects. I also propose we formalize Management Processes to help control the integration of these models. First, I introduce our current formalization for Narratives. Next, I'll show their application to two test cases from different parts of the building lifecycle. Finally I'll discuss some of the benefits and limitations of Narratives.

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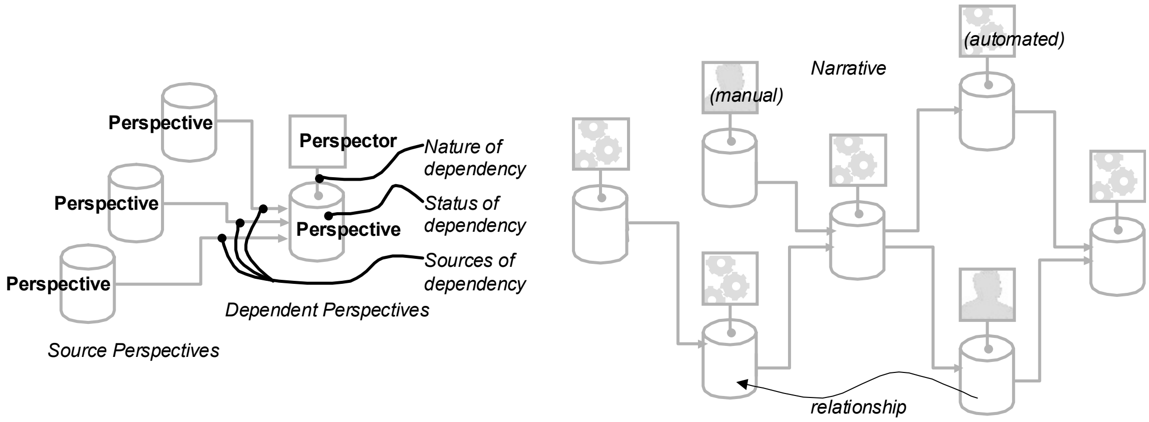

Figure 1: Formalizing the dependency between task-specific information. **A.** Formalizing the sources, nature, and status of the dependency of a dependent view on source views. **B.** A Narrative emerges from the repeated application of the formalism described in A.

2 NARRATIVES: PERSPECTIVES AND THEIR DEPENDENCIES.

In Haymaker et al 2004 a, we proposed that AEC professionals could have addressed the difficulties they are currently having constructing and integrating their task-specific information by formalizing Narratives. Specifically, we propose that design and construction processes could be augmented by, if not founded on, simple formal, generic, expressive methods to construct information by formalizing its dependency on other disciplines' information and by controlling the integration of this information as the project progresses. A formal Narrative could emerge as AEC professionals iteratively apply such methods.

We proposed formalization for Narratives. Using what we call the Perspective Approach AEC professionals specify the sources, status and nature of the dependency of their information model, called a Perspective, on other Perspectives.

Sources: The source Perspectives on which a dependent Perspective depends.

Status: Integration status of a Perspective with respect to its source Perspectives.

Nature: The reasoning method (automated or manual) that constructs the information in the dependent Perspective from information in the source Perspectives. We call this reasoning method a Perspector.

Fig. 1A diagrams this formalization of the dependency of dependent information on source Perspectives(s). Fig. 1B shows that a formal Narrative can emerge form the iterative application of this representation method. It also shows that the Perspectors are generic, and can therefore specify either human or automated, off-the-shelf or user defined reasoning.

Because a Perspector analyzes information in source Perspectives to produce information in dependent Perspectives, any Perspector can itself be decomposed into a sub-Narrative. Such decomposition aids in the thought process when constructing a Narrative, as well as the readability of a composed Narrative. I provide examples of this decomposition in Figures 2 & 3.

The Perspective Approach also formalizes Management Processes to help AEC professionals control the integration of these Narratives. The first Management Process assures that the dependencies between Perspectives are properly constructed:

Management Process 1: When constructing a new dependent Perspective, construct a reference to the source Perspective in the dependent Perspective's Source Perspectives list, and place a reference to the dependent Perspective in each source Perspective's Dependent Perspectives list.

The second Management Process assures that the integration status of all Perspectives is up to date with respect to the iteratively modified source Perspectives on which they depend:

Management Process 2: Before (re)constructing a Perspective, check that each source Perspective's Integration Status is set to Integrated. While (re)constructing a Perspective, set that Perspective's Integration Status to Being_Integrated. After (re)constructing a Perspective, set that Perspective's Integration Status to Integrated, and recursively set all dependent Perspectives' Integration Status to Not_Integrated.

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3 EXAMPLES OF NARRATIVES

In this section, I describe two Narratives that I composed to address problems I observed on real AEC projects. The first Narrative (see Figure 2) formalizes a multidisciplinary cost benefit analysis for different design strategies, such as an atrium and a green roof. The second Narrative (see Figure 3) formalizes an automated design process to detail the metal deck attachments that connect the project's concrete slabs (designed by the architect) , and the projects steel beams (designed by the steel detailer).

I also briefly describe an implementation of the second Narrative in the computer.

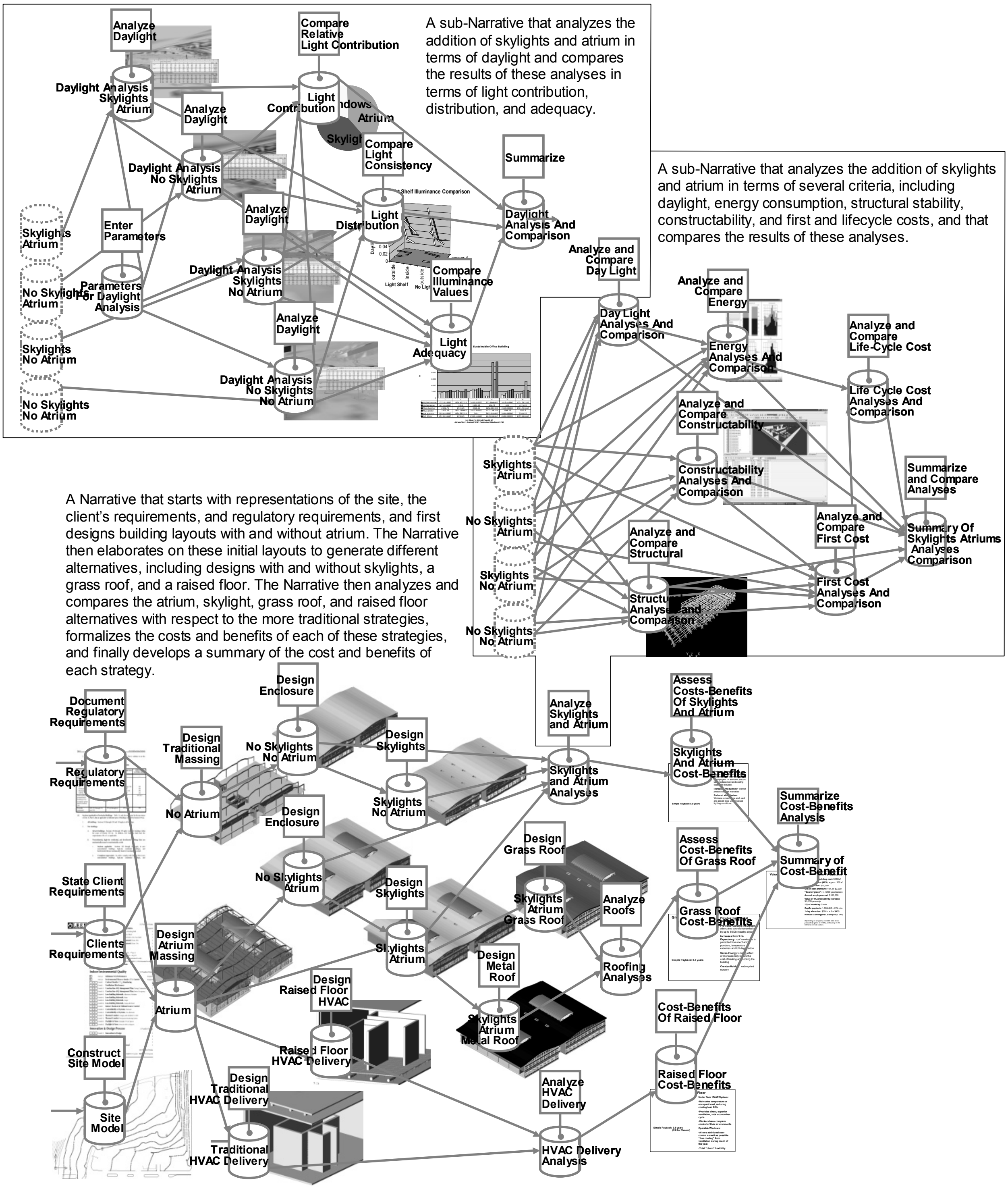

Figure 2: A conceptual Narrative to formalize a cost-benefit analysis during schematic design. The figure shows that the "Analyze Skylights and Atrium" Perspector decomposes into a Narrative that performs this analysis. The figure also shows that within this sub-Narrative, the "Analyze and Compare Daylight" Perspector decomposes into a sub-Narrative that performs this analysis.

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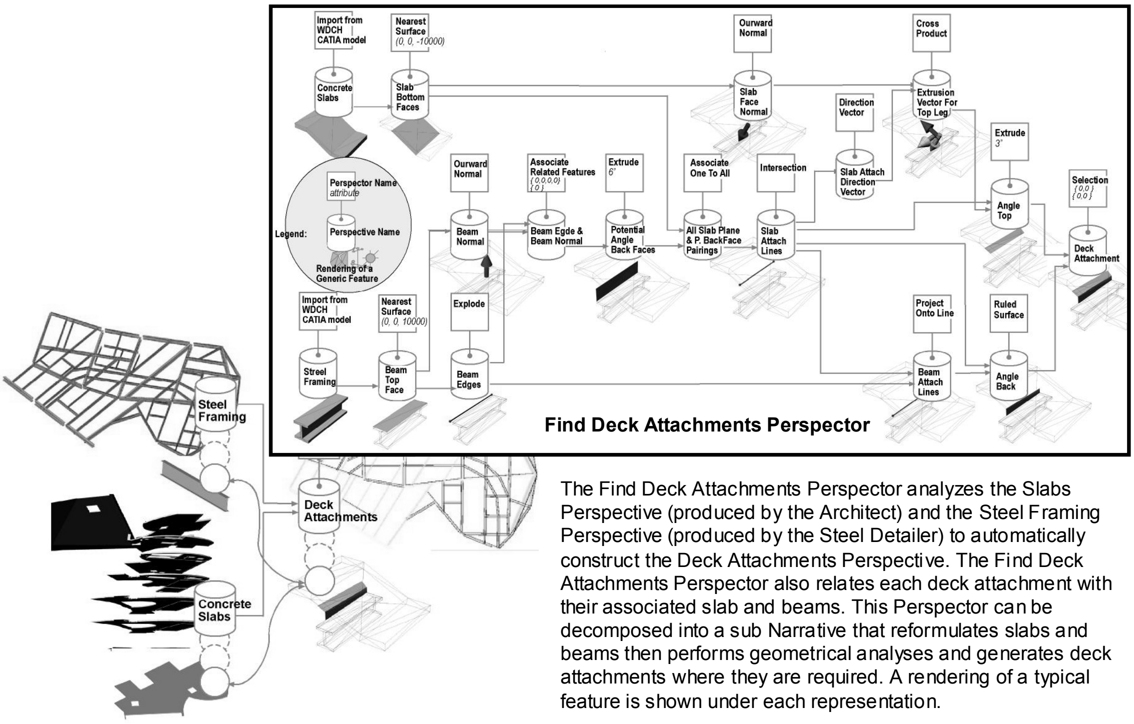
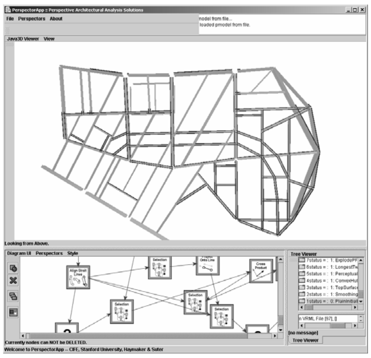


Figure 3: A Narrative to automatically design deck attachments. The figure shows that the "Find Deck Attachments" Perspector decomposes into a sub-Narrative that automatically identifies where these conditions are required, and then designs each required deck attachment.



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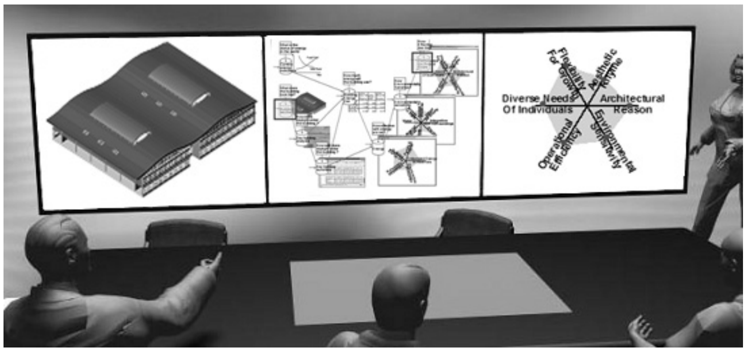

B

Figure 4: Implementations of a *Narrator* that enables engineers to quickly connect reasoning and representations into MDA Narratives. **A.** Our initial software, which constructs and controls geometric Narratives, with the implemented deck attachment Narrative. **B.** A future implementation of the Narrator mocked-up for the I-Room. In this scenario, the team is iteratively modifying a design of the building (the left screen) as they work to achieve their project goals (right screen). The Narrative is on the center screen.

We implemented a computer program, called PerspectorApp (See Figure 4A), that allows an AEC professional to compose Narratives of geometric Perspectives and Perspectors like the one described in Figure 3, and control their integration. Future work will explore computer programs that allow AEC professionals to construct and control Narratives with Perspectives containing arbitrary datatypes, allow AEC teams to construct and control NArratives in collaborative environments like the Information Workspace (Johanson et al 2002), and allow distributed project teams to constrcut and control Narratives over the web.

Using PerspectorApp, we found that Perspectors could be reused in different Narratives. Figure 5 shows that several of the Perspectors used in the deck attachment Narrative were also used in the Find Cantilever Conditions Narrative, that analyzed the ceiling system and it's structural supports for cantilever conditions. Given a set of representational primitives (such as those proposed in the IFC) a finite set of Perspectors might be defined that can be composed into Narratives and subsumed to define arbitrarily complex Perspectors, minimizing or eliminating the need to program.

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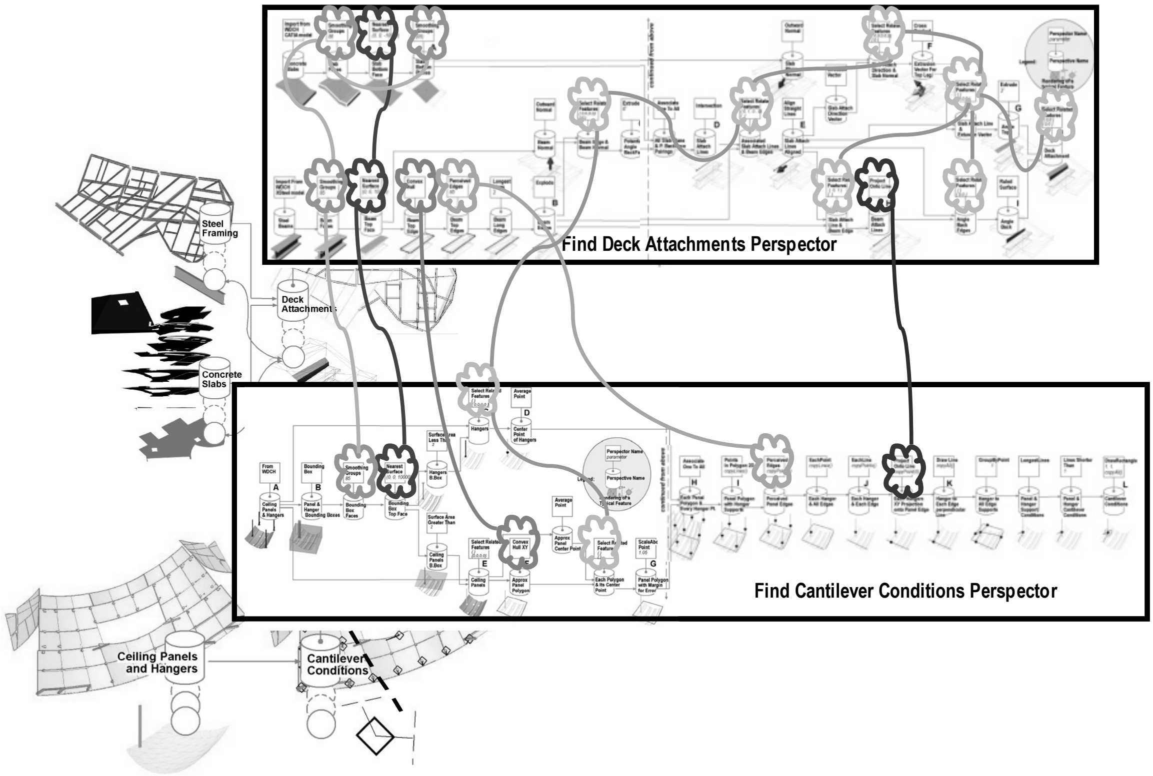

Figure 5: Many of the same low-level Perspectors employed to design deck attachments were reused to analyze for cantilever conditions. I hypothesize that a finite language of low-level generic representation and reasoning can be developed that AEC professionals can compose to construct discipline-specific Narratives.

4 LIMITATIONS AND BENEFITS OF NARRATIVES

In this section I conclude with a discussion of the benefits and limitations that I have observed so far with Narratives.

4.1 *Limitations of Narratives*

– Limited Representation: In PerspectorApp, geometric Perspectives contain Features that contain Surfaces, Lines, and Points. Other geometric data types, such as NURBS, Solid Models, other non-geometric data types, and more complex view structures than a collection of Features can increase the expressive power of Perspectives, however potentially at the expense of greater complexity for AEC professionals who need to understand the Perspectives and the Perspectors that transform them. Formalizing Perspectives that contain IFC data types, and Perspectors that are programmed to expect these data types are future work.
– Limited Reasoning: While they perform well on the test cases, the individual geometric Perspectors and Narratives we've implemented were chosen in a somewhat ad-hoc manner to address our test cases. They are an initial investigation into the power and generality of the Perspective Approach. New test cases will require some new Perspectors.
– Limited Management: Due to the acyclic nature of the formalism, the Perspective Approach does not support cycles in dependencies. While acknowledging that the dependencies between information models can often be cyclical (for example the architect may revise the location of slabs or beams based on the number and size of deck attachments) the conceptual simplicity of formalizing a project model as a directed acyclic graph of views and their dependencies provides an appropriate level of computational support for multidisciplinary, constructive, iterative, and unique AEC projects. AEC professionals can manually manage the cycles in the dependencies by modifying source Perspectives in response to the information in dependent Perspectives.
– Limited Implementation: We did not address issues of version management, access control, computational performance, UI tools to enable manual Perspectors, or distribution of Perspectors and Perspectives across a network.
– Limited Validation: We have shown the Perspective Approach to be adequately generic, expressive, formal, and simple to address certain test cases described in this paper. However, more explicit formalization of these criteria, testing for these criteria on more test cases, and more explicit comparisons of the Perspective Approach against other approaches with respect to these criteria are required.

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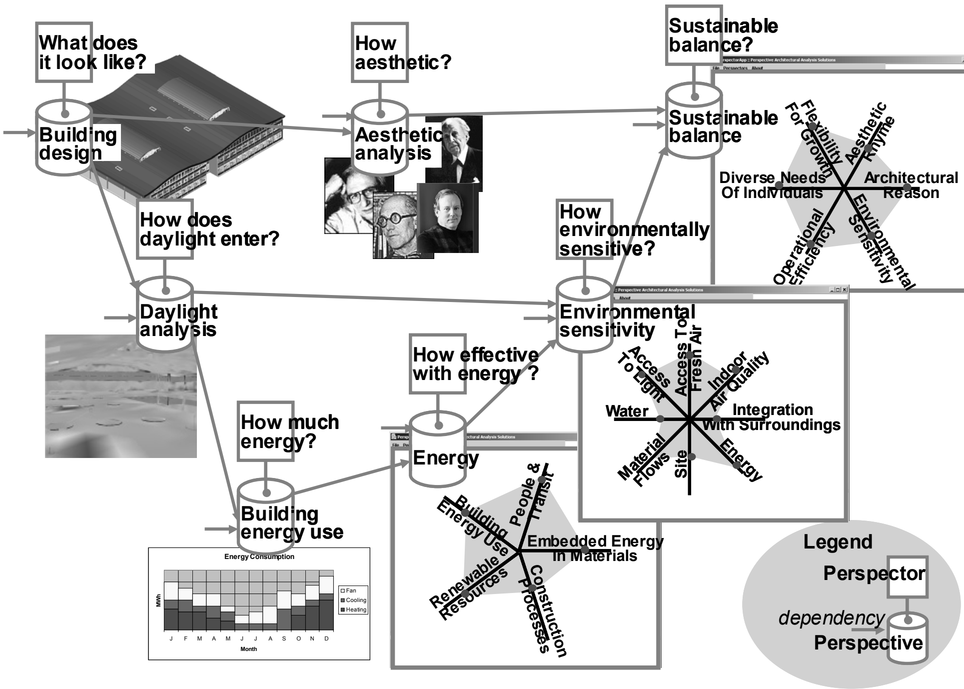

Figure 6: A partial conceptual Narrative to explicitly measure a project in terms of its goals. Starting with representations describing the current energy context, the building geometry, day lighting analysis, and other representations (not shown), the Narrative constructs a representation of Projected energy performance of the building. From the Building Energy Use representation and from other representations (not shown) the Narrative constructs a representation describing the Energy performance for the entire project. From the Energy representation and from other representations (not shown), the Narrative constructs a representation of the Environmental Sensitivity of the project. From the Environmental Sensitivity Representation, and from other representations (not shown), the Narrative constructs a representation describing the overall Performance in terms of the project's core goals. The project team can iteratively modify the Building Design Perspective while they search for a design that optimally satisfies all their goals.

4.2 *Advantages of Narratives*

While there are limitations in our current implementation of Narratives, I see many benefits to the formalization of Narratives. Among the benefits, Narratives are:

- *General*: The representation generically describes the sources, status, and nature of dependencies between Perspectives and provides generic Management Processes to enable engineers to easily control the integration of these Perspectives. In addition, I have shown that once a representational schema for the data in Perspectives is chosen, individual Perspectors can be reused for different test cases.
- *Simple*: To construct a new Perspective, all an AEC professional needs to do is specify its source Perspectives (currently done in PerspectorApp by drawing arrows), and specify it's Perspector (from a drop down list).
- *Flexible*: New Perspectives can be added to a Narrative at any time, making it possible for the project model to emerge over time as the issues of the project are discovered and refined.
- *Distributed*: While the initial implementation is on a single computer, the formalism lends itself to a distributed implementation, where AEC professionals can connect their task specific Perspectives over the internet.
- *Formal*: As shown with the implementations, Narratives can be implemented in the computer.

A general, flexible, simple, formal, and distributed formalism like Narratives can provide the basis for a language that can help AEC professionals better communicate, integrate, and automate and thus improve their multidisciplinary design processes:

- *Communication*: Narratives contain the graphical view of the dependencies between information models, providing a common way to communicate the task inter-dependencies and their status. These diagrams make it possible to collaboratively design and execute the design process.
- *Integration*: Each Perspective contains a formalization of it's status, and the Management Processes help control the status, enabling AEC professionals to explicitly control the integration of their Perspectives.
- *Automation*: As shown in the test cases, Perspectors and entire Narratives can be automated to provide fast and accurate dependent Perspectives. As more and more design tasks can be formalized and automated they can replace manual Perspectors. Therefore Narratives provide an incremental framework in which to continuously incorporate best of breed software.
- *Better Design Processes*: Enabling AEC professionals to explicitly define their Perspectives and their dependencies, and to control and automate these processes, is expected to lead to better de-

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signs. Figure 6 shows a conceptual Narrative to explicitly track a project with an architect's stated goals for the project: To design a project that "combines aesthetic rhyme with architectural reason, environmental sensitivity with operational efficiency, the diverse needs of individual employees with the scale and flexibility required by a growing company (Bay Area Council, 2000)."

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Processes Modelling in Civil Engineering based on Hierarchical Petri Nets

V. Berkhahn & A. Klinger
Institute of Computer Science in Civil Engineering, Universität Hannover, Germany

U. Rueppel, U. F. Meissner, S. Greb & A. Wagenknecht
Institute for Numerical Methods and Informatics in Civil Engineering, Technische Universität Darmstadt, Germany

ABSTRACT: Process modeling is a central aspect for the support of the network-based coordination of planning processes in civil engineering. Hereby, the planning processes are characterized by some significant aspects, especially the great complexity and the dynamical behavior. To master both, the complexity and the refinement of planning processes, appropriate hierarchical structured process models are necessary. This contribution provides a Petri Net based approach for hierarchical process modelling. The focus is on the formalism to ensure the structural and behavioural correctness of the hierarchical process models and a prototypic software implementation for hierarchical process modelling in civil engineering.

1 INTRODUCTION

In building engineering every state of design, planning, construction and usage is characterized by specific processes. These processes can be organized very efficiently with the support of modern information and communication technology. Within the research projects " Coordination of Planning Processes in Geotechnical Engineering" (Darmstadt) and "Relational Process Modelling in Co-operative Building Planning" (Hannover), that are both part of the priority program "Network-based Co-operative Planning Processes in Structural Engineering" from the German Research Foundation (DFG), relational process models based on hierarchical Petri Nets have been defined and implemented.

2 PROCESS MODELLING WITH PETRI NETS

Petri Nets provide a mathematical formalism and a graphical representation based on the graph theory in order to model the concurrent and asynchronous behavior of a discrete system. The Petri Net theory origins from the PhD thesis of Carl Adam Petri (1962). Since then, various researches, extensions and improvements have been applied to the original Petri Net theory. The application of Petri Nets to process modeling and workflow management has been introduced by, e.g., van der Aalst (1998) and Oberweis (1996). Especially, the application of Petri Nets on civil engineering processes is explained in, e.g., (Rueppel et al. 2003) and (König 2004). The main reasons for modeling Civil Engineering processes with Petri Nets are:

- the graphical representation of the structure an marking
- the bipartite structure with places and transitions for modeling both planning states and planning activities,
- the token concept for modeling logical firing conditions and the flow of planning information within an engineering workflow
- the mathematical formalism for structural, behavioral and simulation analysis of engineering process models.

For a short introduction to Petri Nets see, e.g., (Aalst 1998), for a comprehensive introduction, e.g., (Reisig 1985) or (Baumgarten 1990) are recommend. As illustrated in Figure 1 Petri Net consists of places, transitions and arcs, with each arc connecting either a transition and a place or a place and a transition. The tokens reside on the places. Based on well defined rules the transitions can "fire" and thus let the tokens "flow" through the net.

3 HIERARCHICAL PROCESS MODELING

3.1 Basic Idea of hierarchical process modeling

The process structure covers all planning activities. Activities represent work packages carried out by planning participants within a prescribed time period. They are specified on the basis of planning schedules for components and connections.

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3.2 Structure

The entire planning process of a project is decomposed into basic activities which are also called phases. Typical basic activities are the feasibility phase, design phase and construction phase. The directed relationships from one activity to a successive activity are specified by planning states. Activities and states form a bipartite directed graph which is called workflow graph.

The following rules are introduced to realize parallel or alternative execution of activities and states. These rules, illustrated in Figure 1, form the basis for checking the structural correctness of workflow graphs.

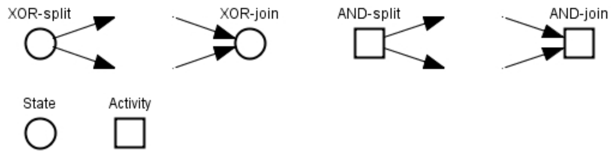

Figure 1. Rules for activities and states

A decision (xor-split) is modelled if a state has more than one successor. In this case only one of the following activities can be chosen and will be executed. A contact (xor-join) is modelled if a state has more than one predecessor. In this case the execution of exactly one of the predecessors must be guaranteed. An asynchronization (and-split) is modelled if an activity has more than one successor. In this case all following states will be executed. A synchronization (and-join) is modelled if an activity has more than one predecessor. In this case it must be guaranteed that all predecessors are executable.

Activities and states that are defined during the planning process can be specified in more detail. This recursive decomposition process leads to a process structure which is represented mathematically by a hierarchical bipartite directed graph.

$$P := (A, S; R, Q, f_{AT}) \qquad (1)$$

with $f_{AT} : (A \cup S) \rightarrow (A \cup S)$

- A Set of activities
- S Set of states
- R Relations between activities and states
- Q Relations between states and activities
- f_{AT} Mapping for the composition of activities and states

The hierarchical bipartite directed graph is consistent, if a directed relationship on a higher level is associated with a directed relationship on a lower level and vice versa. For the correct execution of the activities the structural correctness of the process structure must be guaranteed. The process structure is correct, if there are no deadlocks and no lacks of synchronization.

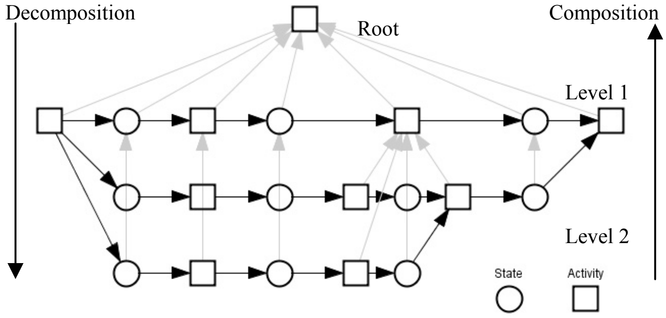

Figure 2. Hierarchical process structure

A deadlock as shown in Figure 3 arises, if after a decision alternative activities are merged by a synchronization. In this case the synchronization activity can not be executed.

A lack of synchronization as shown in Figure 3 arises, if asynchrony activities are merged by a contact. In this case the following activities would be executed more than once.

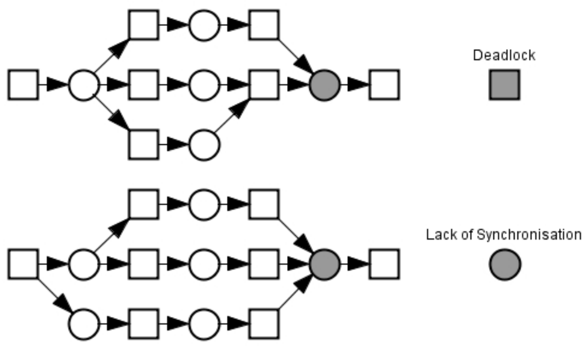

Figure 3. Deadlock and lack of synchronization

Deadlocks and lacks of synchronization are detected by hierarchical instance sub graphs which were introduced by van der Aalst (2002b). Every hierarchical instance sub graph describes one possible workflow without decisions. An algorithm for building hierarchical instance graphs is presented in (König 2004).

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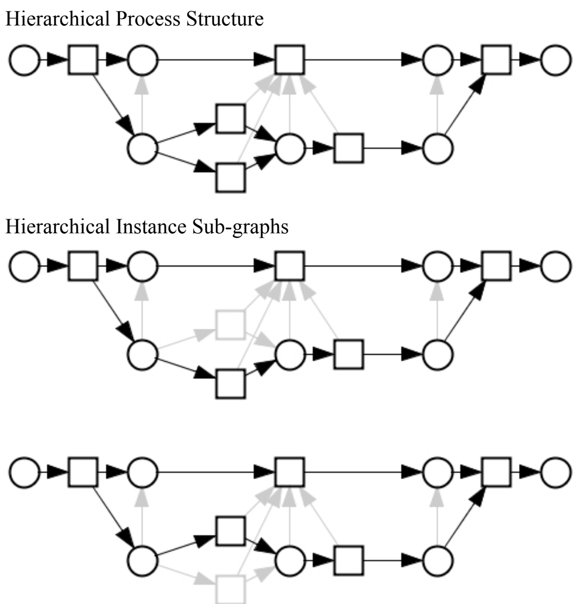

Figure 4. Hierarchical instance sub-graphs

3.3 *Critical Path Method*

The observance of time schedule for the planning process is very important. If an activity is not completed by a certain time the whole planning process could get delayed. The planning and observance of a time schedule is one important task for process modelling. For time scheduling the critical path methods can be used. They can be transferred in generalized form to bipartite graphs. The consideration of the hierarchy requires additional consistency conditions.

For each activity a participant needs a certain time to finish. Therefore each activity is labelled with a positive real time value.

A state specifies a relationship between activities. For time scheduling different types of relationships are defined. For a planning process it is sufficient to describe a state with a minimal time lag between predecessor and successor activities. If the time lag is negative these two activities can be handled parallel. If the time lag is positive a waiting time between these activities exists. Each state is labelled with a real time value.

For critical path methods the hierarchical directed bipartite graph is extended by a label mapping for activities and states.

$$P := (A, S; R, Q, f_{AT}, w) \qquad (2)$$

with $w:(A \cup S) \to \Re$ and $w(A) \subseteq \Re_0^+$

P Labelled process structure
w Labelling of activities and transitions

The critical path for each level of the hierarchy of a labelled hierarchical bipartite graph can be calculated with the well-known critical path methods. If the hierarchical graph is consistently labelled, the length of a critical path on an upper level is an upper bound for the length of a critical path on a lower level.

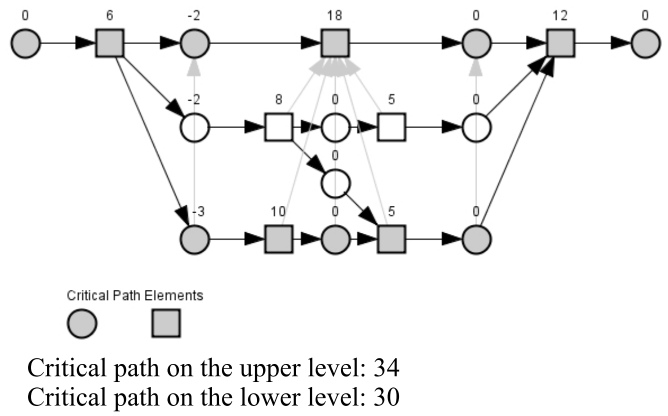

Figure 5. Consistent labelling of a hierarchical process structure

The consistency of the labelling has to be verified. For each decomposed sub-process of an activity on a lower level there is a labelled bipartite partial graph. The labelling is consistent if the critical path length of the partial graph is not greater than the labelling of corresponding activity.

$$w(x) \geq P(x) \qquad (3)$$

w(x) Label of *x*
P(x) Length of critical path in partial graph

3.4 *Petri Nets*

For the process structure the methods of simple Petri nets are used to realize an event oriented communication. The hierarchy leads to additional conditions for the consistent marking of the process structure.

Each activity is in a certain state at any time. For an event oriented communication two different states of an activity are defined: not completed and completed. Each activity is marked by 0 (not completed) or by 1 (completed).

A state is active if all predecessor activities are completed and all successor activities are not completed. Each state is marked by 0 (not active) or by 1 (active).

For the application of simple Petri nets the hierarchical process structure is extended by a mapping for the marking of the activities and states.

$$P := (A, S; R, Q, f_{AT}, m) \qquad (4)$$

with $m:(A \cup S) \to \{0,1\}$

m Marking of activities and states

The marked process structure is extended by exactly one start state and exactly one end state. The initial condition of the marked process structure is defined as: each state without predecessors is

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marked with 1 and each state with predecessors and each activity is marked with 0.

The consistency of the marking of a hierarchical process structure has to be checked. Each decomposed activity is completed, when all activities of the decomposition are completed.

The consistency conditions for states are based on the firing rules of transitions in Petri nets. These conditions can be described in vector and matrix form. With the initial marking of states and the actual marking of activities the actual marking of states can be checked.

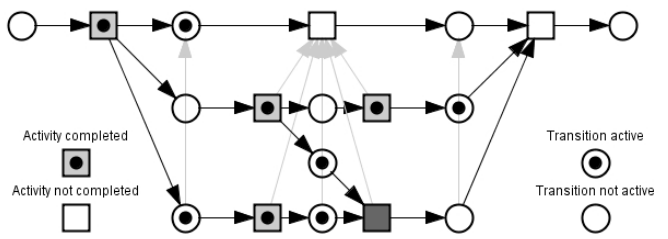

Figure 6. Consistent marking of a hierarchical process structure

An event oriented communication for planning processes is supported by a marked hierarchical process structure and Petri net methods. An activity can start if all predecessor states are active. Thereupon the planning participant is notified. If the participant reports the completion of an activity, the activity is marked with 1. The marked hierarchical process structure has to be updated.

Planning decisions obstruct the automation of an event oriented communication system. If a decision state (xor-split) is active the automatic process flow has to be stopped. The obstruction of the process has to be solved interactively by a participant with an appropriate role. If one of the successor activities is selected to be executed the associated participant can be notified.

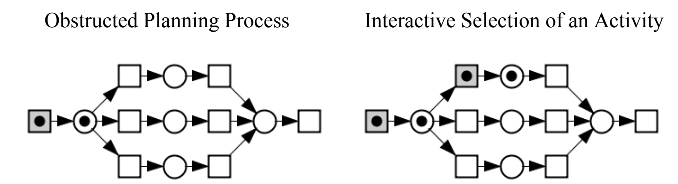

Figure 7. Marked process structure with a decision situation

4 PROMISE

Hierarchical process models are important for the computer aided support of engineering planning processes. This hierarchical concept facilitates the handling of large process models which are typical in engineering. Based on hierarchical process models the complex processes (e.g. planning processes, construction processes, maintenance processes) can be modeled by using a distinct number of detailed but small process models which are related to each other by a superior coarse process model. Depending on the level of detail, these process models can be generated independently by distributed technical engineers (Rueppel et al. 2004). Moreover, predefined process models, so-called process patterns (Katzenbach/Giere 2004), which have been applied during preceding projects can be used and adapted to the conditions of the current project.

ProMiSE is a software tool to support process modeling, process analysis and process control based on Petri nets. In the following, the focus is on the process modeling phase, i.e. the construction of a computer enabled hierarchical model of the real word processes. The theoretical background for the generation of hierarchical Petri net based process models - as implemented in ProMiSE - is presented by Kurt Jensen (Jensen 1996). Generally, it is possible to refine planning states and/or planning transitions. However, a refinement of transitions is recommended and reflects a more intuitive way of hierarchical process modeling.

When adding a sub-process to a planning activity in ProMiSE, the input and output states of the corresponding transitions are copied to the sub-process model. Figure 8 illustrates how to add a sub process to a planning activity

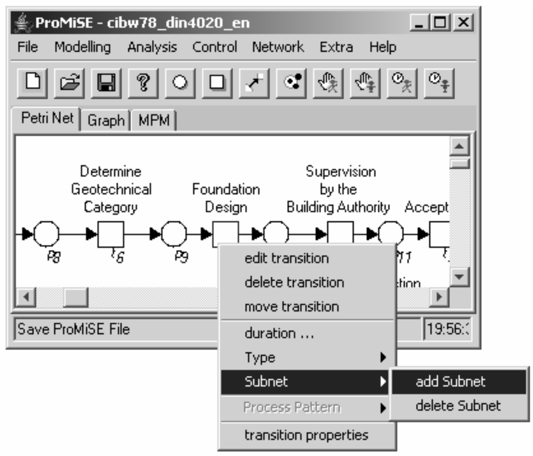

Figure 8. Refinement of a transition modeling a planning activity.

Figure 9 illustrates the initial state for modeling a sup-process. Hereby, the places (p_{25} and p_{26} in figure 9) are reference to the input and output places of the transition to be refined. These places define the interface between the superior process and the sub process. They declare the input information/condition as well as the output information, i.e. the result of the sub process. Having a precise definition of input and output information, is especially of great importance, if the hierarchical process models are generated by different and distributed planning participants. Furthermore these input and output place are necessary if a sub-process is realized by a pre-defined process model.

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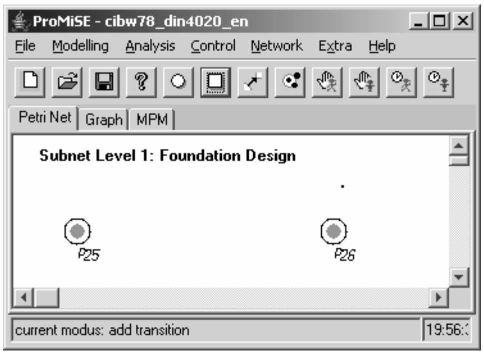

Figure 9. Initial state for modeling a sub-process.

5 PLANNING SCENARIO FROM GEOTECHNICAL ENGINEERING

To illustrate the hierarchical process modelling with ProMiSE by example, a typical design task in geotechnical engineering, namely the design a foundation for a building and the corresponding retaining wall for the excavation, will be modeled.

The top level process net within this example is a process according to the German standard DIN 4020 shown in Figure 10. This process model describes planning activities and planning states in order to design a foundation for a building and the corresponding retaining wall for the excavation. Therefore the focus of the process model is on geotechnical engineering with interactions to other technical domains, e.g., architecture, structural engineering or environmental approval authority or the building owner. At this level of detail, the process model provides an overview of activities without going into the technical details of each activity. The activity being refined is the transition t_7 "Foundation Design".

The associated sub-process net provides the design process for a distinct foundation technology, e.g. a shallow foundation or a pile-raft foundation. The process model illustrated in Figure 11 is a part of the design process for a pile-raft foundation.

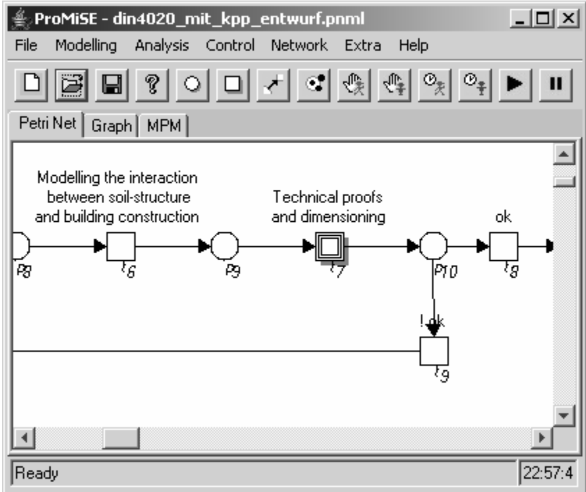

Figure 11. Design process for a pile-raft foundation (excerpt)

Depending on the result of the planning activity t_7 "Technical proof and dimensioning" the design process proceeds or an iterative planning process has to be initiated. Basically, this sub-process model contains parallel, sequential or conditional planning activities without going into detail of each planning activity. This is realized by further sub-process models.

Figure 12 illustrates the sub-process model of the transition "Technical proof and dimensioning" mentioned above. It provides detailed technical planning tasks in order to dimension a pile-raft-foundation. At this level of detail the sub-process model describes planning and dimensioning activities for a specific

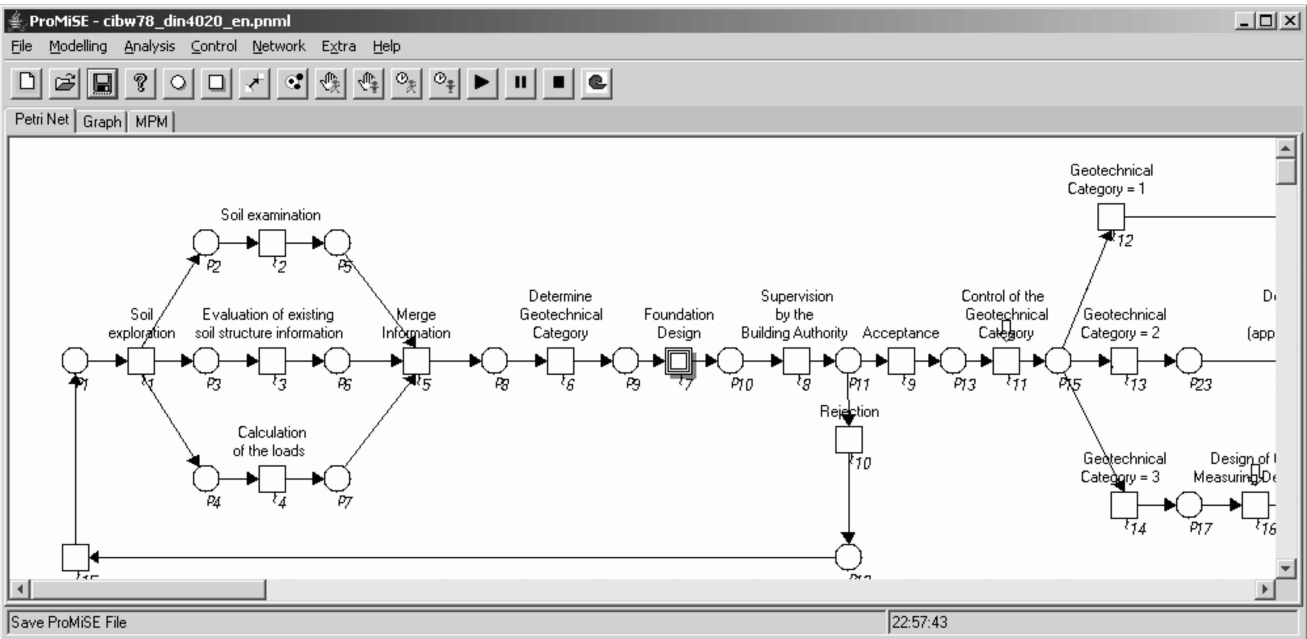

Figure 10. Geotechnical planning process according to DIN 4020

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foundation technology. Whereas the top level process model comprises different planning participants in this sub-process model it is only the geotechnical engineer who executes the modeled activities.

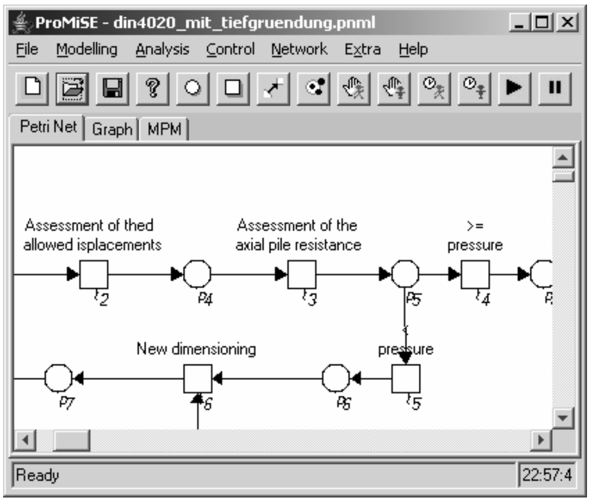

Figure 12. Technical proof and dimensioning process for a pile-raft foundation (excerpt)

6 SUMMARY

This paper presents a concept for a hierarchical Petri-net based process model for planning processes in building engineering as well as an implementation of this concept. The hierarchical structure of this model supports the dynamical aspects of cooperated planning processes in building engineering. The consistent and correct composition of the relational process model is very important. To ensure consistency and correctness of the compositions, conditions as well as methods for coordination and controlling of the planning process are formally defined.

The structures, conditions and methods have been implemented prototypically and were used in extracts for example projects.

The software tool ProMiSE supports process modelling, process analysis and process control based on Petri Nets. Within this paper the focus was on the definition of hierarchical process models and an exemplary scenario from geotechnical engineering modelled with ProMiSE.

7 ACKNOWLEDGEMENT

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Supporting Geotechnical Design with Petri-Net-Based Process Patterns

R. Katzenbach & J. Giere
Institute and Laboratory of Geotechnics · Technische Universität Darmstadt · Germany

ABSTRACT: The paper deals with process patterns based on Coloured Petri-Nets as a process model to coordinate planning in structural engineering, e.g. geotechnical engineering. Coloured Petri-Nets are mathematically well-founded, and are often used to solve problems concerning concurrency in processes in other engineering domains. The paper introduces a new method to represent geotechnical information in Coloured Petri-Nets, thus enabling a content-based control over design process. Elementary process patterns are introduced, which serve as smallest modules in a bottom-up approach to the more complex process models.

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1 INTRODUCTION

Design and construction-processes in civil engineering and especially in construction engineering require close cooperation of many planning participants who work in separate domains. The activities of architects, engineers, building owners, authorities and construction companies amongst others have to be coordinated in order to achieve cost and time effective solutions of high quality. The globalization of engineering services even increases the demands of coordination. The developments in internet technology have led to a widespread use of net-based communication systems in the construction industry. They often lack however adequate methods to coordinate planning processes as they do not use formal process models.

In order to overcome the shortcomings of contemporary net-based solutions for project communication and cooperation such as web-portals and cooperation-systems, various research activities in the last years have focused on processes and process-models. With respect to the character of planning processes in civil engineering the following aspects have to be considered:

- In contradiction to production processes in the industry, the design process in civil engineering is a priori only partly known. With the proceeding design, various design activities and planning participants have to be involved in the design process.
- As to have control of the actual planning state connected to costs, time etc. the process model requires the distinction between activities and states.
- Activities in the design process produce information, which is exchanged between the planning participants. Based on this information (plans, expertises, calculations, …) following activities may have to be carried out. The process model should be able to take into account this information.

Colored Petri-Nets have all the necessary properties for a suitable process-model. In this paper a process-model will be presented, which is based on the Petri-nets is steering the process based on information from the

2 PETRI-NETS

For a good introduction to the Petri-nets the reader is referred to [Reisig 1985]; a very good comprehensive report can be found in [Murata 1989].

Petri-nets consist of the disjoint finite set of places P and transitions T as nodes of the graph, which are connected with directed arcs as a flow relation F. The marking M, which is represented by tokens in places represents the actual state of the system. By firing a transition, the token is subtracted from the input place of the transition and added to the output place. Thus firing a transition transforms the state of the system to the subsequent state.

The basic form of a Petri-Net is defined as a tuple PN = (P, T, F, M_0), where

P is a finite set of places

$$P = \{p_1, p_2, \ldots, p_m\}$$

T is a finite set of transitions

$$T = \{t_1, t_2, \ldots, t_n\}$$

$$(P \cup T) = \varnothing \text{ and } (P \cap T) \neq 0$$

F is a set of arcs as flow relations

$$F \subseteq (P \times T) \cap (T \times P)$$

M_0 is the initial marking

$$M_0: P \rightarrow \{0, 1, 2, 3, \ldots \}$$

Petri-nets have a graphical representation as is shown in figure 1. The figure also depicts the connection between Petri-nets and the corresponding elements of the planning process.

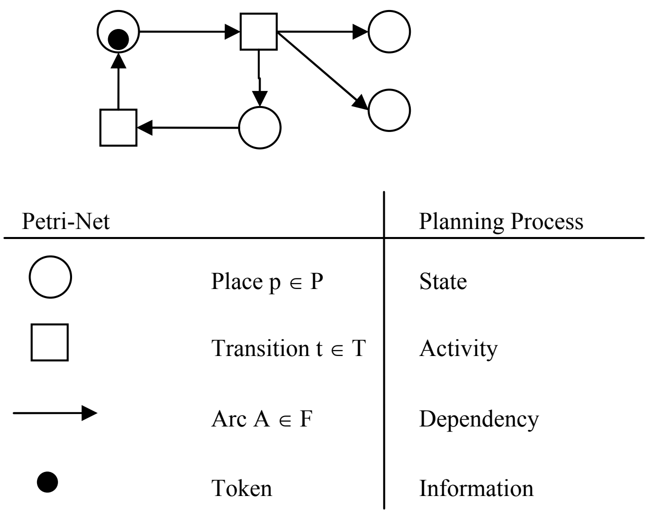

Fig. 1: Graphical representation of Petri-nets and

2.1 *Formal requirements*

As Petri-nets provide a formal framework, they also provide the possibility to analyze them and to define properties of the net, which are appropriate to the given problem.

With respect to the requirements of process modelling of business processes, v.d. Aalst gives a formal definition of Petri-nets as workflow nets [v.d. Aalst 1996, 1997, 1998, 2002], defining as well a soundness criterion. According to it, a workflow net (wf-net) has one single input place *I* and one single output place *O*. When the wf-net is short-circuited by a transition t*, it is strongly connected. When the output place *O* is marked with a token, all other places in the wf-net must be empty, so no other activities can be carried out (no transitions are enabled to fire). This prevents, that a task has erroneously not been carried out, although the process should already be terminated. In this case the process has not been modelled correctly. Figure 2 shows basic routing primitives in Petri-nets.

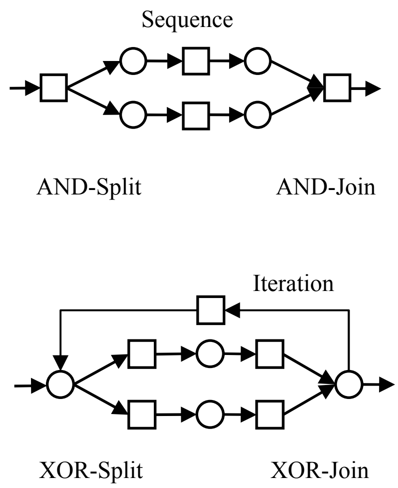

Fig. 2: Basic routing primitives in Petri-nets

In civil engineering the design process is partly unknown at the beginning but evolves with the proceeding planning. It is necessary to adapt the underlying process-model. This is achieved by the hierarchical substitution of transitions in the net as shown in figure 3.

In the coarse net the transition with the adjacent socket-places is substituted by an underlying, finer net with the port places.

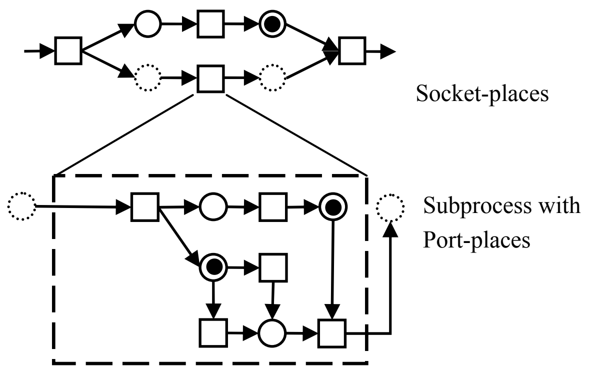

Fig. 3: Hierarchy by substitution

2.2 *Petri-nets with individual tokens*

For the representation of information in the Petri-nets it is necessary to introduce Coloured Petri-nets, where different tokens are distinguishable.

Within the activities the planning information is generated or modified. Depending on the actual planning state the further planning activities have to

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be carried out. For example the number of basement floors which are designed by the architect imply the required construction for the retaining walls. In order to be able to take into account the exchanged information and the results of each planning activity in the planning process and its effects on the process-model, the Petri-Nets are extended with a formal semantic to individualize the tokens.

The theory of Coloured Petri-Nets [Jensen 1996] expands the formal semantics of the Petri-nets by adding colours to the tokens and a formal semantic to perform operations on the individual tokens. Thus it is possible to transport information through the Petri-Net and define operations based on this information. Guard functions on the transitions can be arbitrarily complex to formulate conditions to fire the transition, i.e. carry out the activity.

3 METAINFORMATION

The information exchange in the design process today is mainly document-based. Product-models exist only for specific domains, such as steel-constructions. In order to access the information which is necessary e.g. for decisions in the process-model, a metainformation is introduced. The idea is, to abstract only the necessary information to control the design-process from the abundance of information, which is generated in the planning process. Of course the difficulty lies in the definition of the adequate amount of information. One approach from the technical basis is to abstract the information from technical standards and regulations [Katzenbach et al. 2004].

The metainformation has to be accessible for the process model, which was programmed using Standard ML (SML, [Milner et al. 1997]). As a first approach, a very simple approach using tuples of labels (identifiers), values and index is used. One tuple carries one construction specific piece of information, coded in string, integer or real. The tuples are listed in one indexed list called the information container.

Table 1 shows the identified requirements from process-modeling in the left column and the developed implementation in the right column, an example is given in fig. 4.

Table 1: Requirements to the metainformation

Requirements deriving from Process-Modelling	**Implementation in Petri-Nets with individual Tokens**
Metainformation Single, construction specific information • label (string) • value (integer/real/string) • version (integer)	Tuple (label, value, index) Example („foundation_type“, S(„shallow“), 1) („excavation_depth“, R(6.5), 1)
Information container All metainformation necessary for the control of the process	List of tuples (Tuple 1, Tuple 2, …, Tuple n)

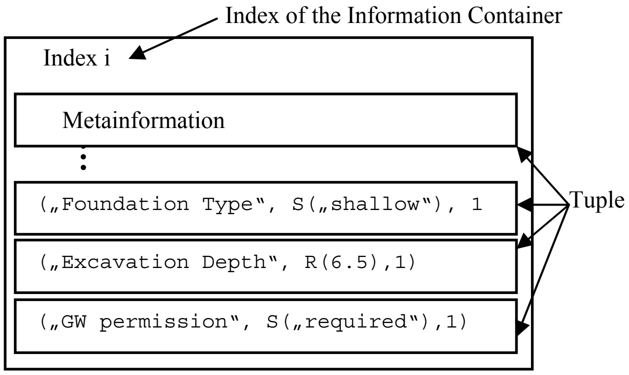

Figure 4: Information Container in SML (Example)

4 DESIGN PATTERNS

On the basis of the introduced metainformation the routing primitives shown in fig. 1 can be extended towards the use of semantics. The work was done using CPNtools [Ratzer et. al 2003] and Standard ML.

The aim of the use of design patterns is to build up the whole complex process-model from small parts in a bottom-up approach. Each design pattern has to meet the formal requirements.

The six routing primitives (Sequence, Iteration, XOR-Split, XOR-Join, AND-Split, AND-Join) are arranged into elementary design patterns, taking into consideration the kind of dependency between two activities in the design process. The possible dependencies of two activities A and B and the corresponding arrangements are given in table 2. For a better overview not all inscriptions of the net are shown in the figures of the table.

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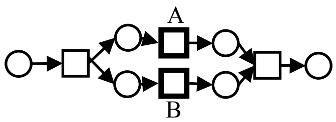
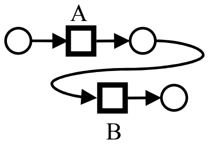
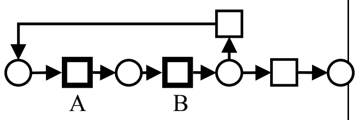
Table 2: Design patterns in Petri-nets

dependency	primitives	Design patterns in Petri-nets
no dependency	concurrency	
unilateral dependency	sequence	
mutual dependency	sequence + iteration	

For the mutual dependency of activities A and B it is necessary to carry out both activities until the result of the activity B has no effect on A. An example for such a mutual dependency is the design of a combined piled-raft foundation, where the load-settlement behaviour of the whole foundation interacts with the rising structure. Structural engineer and Geotechnical Engineer have to cooperate iteratively to optimize the construction. Both planning domains have to approve the design before the next steps can be taken. In the design pattern this is symbolized by the XOR-split following activity B.

```
color Int_Real_String = union I:Int + R:Real + S:String;
color Meta = Product String * Int_Real_String * Int;
color Info = list Meta;
...
var info, info1, info2: Info;
var b, b1, b2: Int;
...
(* list_union unifies two lists of Metainformation *)
fun list_union ([], list2) = list2
|list_union (hd::tl, list2) = exists_l hd (list_union(tl,list2)) ;
```

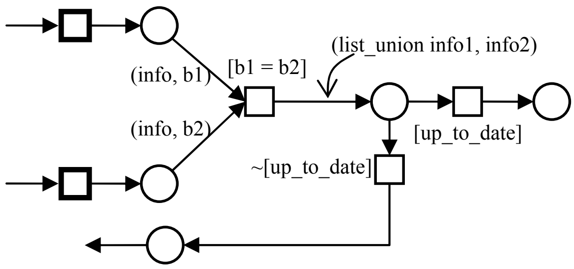


Figure 5: Detail of Petri-net

A library of functions has been installed in SML to carry out the necessary operations on the meta-information in the information container (token). These operations include splitting, unifying and versioning of the information.

Figure 5 shows a detail of an example of a design pattern including some net inscriptions. The arc inscriptions are in brackets, the guards of the transitions are shown in angular brackets. There are two concurrent design activities, marked with the thick line. In both activities information is generated and the list of metainformation in the tuples is modified. After finishing the information is merged under the condition, that the index of the information container is identical (b1=b2). It is then checked, whether the information is up to date. If applicable the design process is to be checked again, indicated by the iteration.

5 DESIGN PROCESSES AND CONCLUSION

The given process-model has been implemented in a new cooperation platform called ProMiSE (Process Model in Structural Engineering) [Rueppel et al. 2004, Katzenbach et al. 2002] and has been tested for design scenarios with several planning participants. For the domain of Geotechnical Engineering the design processes for the geotechnical constructions such as retaining walls, foundations, slopes etc. have been transferred to the process model. The model comprises all design activities in the domain from the technical point of view. It showed, that the hierarchical approach is well suited to integrate processes from the granularity of single proofs up to the very coarse process of the whole scenario. The standard processes of Geotechnical Engineering can be provided by a library and be integrated during runtime into the process model, thus enabling the change and adaptation to the proceeding design process.

Design patterns including the function library to operate on the metainformation are a universal approach to design processes. Although the information is kept in a rather simple way, the functionality of the model is sufficient. With a process model of the design process taking into consideration the actual design via the metainformation and a formal framework, cooperation between the planning participants is easier to achieve and to control.

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Application of Coloured Petri-Nets for the Business Process Modelling in Construction Companies

A. Khneisseh & R. Schach
Institute of Construction Management, Technische Universität Dresden, D-01062 Dresden, Germany

ABSTRACT: Business processes represent a series of added value activities which lead flow-oriented with one or more measurable inputs to a defined, measurable output. The modelling of business process is very complex because of the large number of modelling purposes, modelling subjects and modelling methods and it therefore requires a systematic preparation. The modelling of business processes by means of CPN represents an excellent opportunity to carry out both qualitative and quantitative evaluation of the business processes in construction companies.

1 INTRODUCTION

Business processes represent a series of added value activities which lead flow-oriented with one or more measurable inputs to a defined, measurable output. In the financial field of the construction company, areas which can be mentioned include for example audit, procurement and payroll accounting. In the technical field there are, for example, design, construction site controlling or supplement processing.

2 THE SPECIAL SITUATION OF THE BUILDING INDUSTRY AND SPECIAL FEATURES OF THE BUSINESS PROCESSES IN CONSTRUCTION COMPANIES

The building industry can be distinguished basically from the industries with permanent sites by the uniqueness of the building projects. The delivery of the service occurs almost exclusively as a local production on the premises of the building owner. As a result of influences such as ground conditions, traffic conditions or weather, identical buildings types can result in completely different building projects with costs differing from each other greatly under the circumstances. On the one hand the costs of transportation and communication being two of the most important parts of the business process costs, increase as the distanceof the construction site to the corresponding administration and the suppliers increases. On the other hand, due to increasing project complexity, particularly concerning technical problems between the project participants, there arises the requirement for improved communication.

Building projects distinguish decisive from industrial production processes. The production can include anything from a detached house right up to a complex multi-story building or from the construction of a tunnel right up to a bridge project. This variety has differing results. Thus the personnel and device intensity differ by the entire projects quite considerably. The business processes are influenced in a project-specific way by varying contract and organizational structures.

The construction companies themselves can be distinguished from many viewpoints. For example, only a small number of large-scale enterprises compete with a very large number of companies with only a few employees. Hardware and software equipment varies greatly. Therefore the business processes can be accurately compared in different construction companies only with great difficulty. This hinders the training of open, universal and transparent business processes. There must be a high degree of flexibility of business processes in the building industry in order that it is able to adapt itself to the customer preferences. As a result of that the number of procedures can be reduced.

As a conclusion it must be shown that the business processes are on the one hand heavily dependent on the projects to be dealt with, but also on the enterprise itself, that means, its flow organisation, structure and size. The long and nonuniform process chains and the specific problems and orders within individual subprocesses in the construction company place a high demand for experienced and qualified specialists.

An automation of processes that leads to improvements in procedures in the industrial enter-

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prises, due to the same or at least similar business processes which can be considered as an optimization potential of the business processes, can be implemented only with great difficulty in construction companies. This often leads to a manual processing of the processes and complicates the application of IT-tools.

The error rate can also increase with the ascending extent of the documentation to be adapted to the individual employees, which reduces the quality of the business processes. Furthermore only insufficient project information is often available to the project participants as a result of poor communication. Further deficiencies frequently result from that in the processing.

A data exchange between the project participants applies in this case to all specialist fields (figure 1). At the heart of building projects are a great number of persons and companies, who have a variety of different tasks to fulfill and to exchange and use data. Below is a list of data that is continuously exchanged:

- Drawings and technical data;
- Contract documents;
- Tenders as well as
- Caveats, protocols and hindrance advertisements.

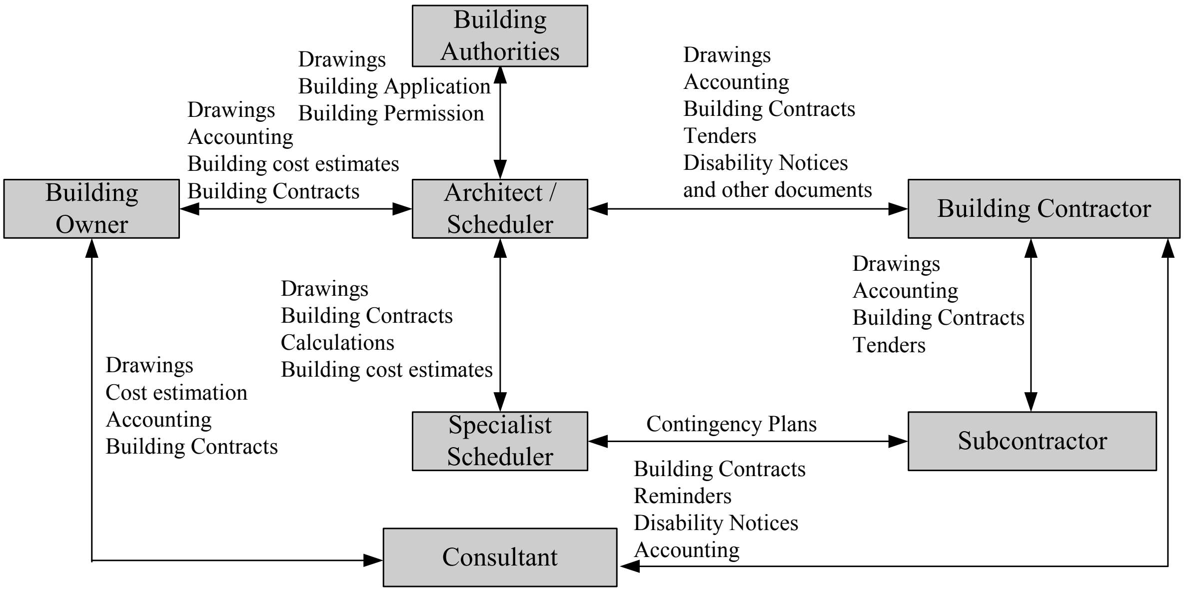

Figure 1: Data exchange during a building project (rough structure, exemplary in extracts representation)

An exchange of information is also necessary within a construction company, conditional through spatially separate buildings, such as the headquarters, the responsible departments and the construction site offices.

Since the place of the service delivery – the construction site – and the main office of the enterprise will in most cases not be the same, a communicative data exchange is indispensable for a common information base and for the avoidance of redundant data. Therefore the means of communication and the technology used play an important role in the construction company. A wide range of dispersion of process costs and the connected running times can result from this given situation.

In addition there is a high demand on the flow of information and communication, as a result of the large number of personnel that participate in the building project.

Furthermore, business processes in the construction company show a series of special features which are very different to the processes of manufacture in the fixed base industry.

In order to be able to assess the quality of the highly complex and dynamic business processes in a construction company it is necessary to model and to evaluate these through simulations.

3 MODELLING OF BUSINESS PROCESSES

The modelling of business process is very complex because of the large number of modelling purposes, modelling subjects and modelling methods and it therefore requires a systematic preparation. In this case the selection of the modelling language has special importance.

In the center of the business process modelling poses the question what, for which and how the process can be modelled.

Over a period of time many methods for the business process modelling were developed based on the available software technology.

The business process models represent a simplified illustration of the real activities in the enterprises. They are used, above all, as a basis for the process analysis, for documentation purposes, for

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taking decisions for the optimization of the business processes, for the planning of the resources and also in the enterprises depending on the modelling method for the computer-aided simulation of business processes. This is particularly dependent on hich viewpoints the business processes are modelled. The methods for the modelling of business processes can be distinguished from each other, as can be shown in chart 1.

Methods \ Viewpoints	Function viewpoint	Data viewpoint	Object viewpoint	Process viewpoint
Data Flow Diagram (DFD)	X			
Structur Analysis (SA)	X			
Structur Analysis and Design Technique (SADT)	X	X		
Data Dictionary (DD)		X		
Jackson Diagram (JD)		X		
Entity Relationship Model (ERM)		X		
Vorgangskettendiagramm (VKD)				X
Wertschöpfungskettendiagramm (WSK)				X
Funktionszuordnungsdiagramm (FZD)	X	X		X
Semantic Object Model (SOM)			X	
Object Behavior Analysis (OBA)			X	
Classes Diagram (CD)			X	
Integrierte Unternehmensmodellierung (IUM)			X	
Objekt-Oriented Software Engineering (OOSE)			X	
Objekt-Oriented System analysis (OOSA)			X	
Object-oriented Modelling and Design (OMT)			X	
Vierdimensionale Prozessdarstellung (VPD)				X
Prozesskettenmodell (PKM)				X
Ereignisgesteuerte Prozesskette (EPK)	X	X		X
erweiterte Ereignisgesteuerte Prozesskette (eEPK)	X	X	X	X
Architektur integrierter Informationssysteme (ARIS)	X	X	X	X
Petri Nets (PN)	X	X	X	X

Chart 1: Modelling methods of business processes

The modelling according to the functional viewpoint covers the description of the activity, the flow of information or the work flow of a business process, which consists of several connected tasks. It transforms input data into output data.

The visualization of the data view includes both paper based documents and electronic documents of the business process under consideration.

By modelling according to the object viewpoint which is characterized also as a structure-oriented and/or organization-oriented modelling, the information and/or utilization systems in an integrated model formation must be described.

The above mentioned approaches for the modelling of business processes which are necessary in order to carry out a process analysis and to suggest improvements of the work flow, do not form any basis for the integrated description of the process viewpoint in enterprises. For this purpose many approaches were developed in the last few years, within which activities and work flow, data structures, states and structural units and dynamic properties of business processes are integrated.

In chart 2 the most important methods for the modelling of business processes for certain viewpoints are compared. The aim is to find out a suitable method upon which the business processes can be modelled and evaluated in building enterprises taking into account the observation of the most important requirements of the business process management.

	Modelling Methods					
	DFD	SADT	SOM	ARIS	EPK	PN
Data flow	+	+	o	+	+	+
Data structur	-	+	+	+	-	o
Parallelism	+	+	+	+	+	+
Hierarchy	+	+	+	+	o	+
Learnability	o	o	o	o	+	+
Prospects	-	o	-	o	-	+
Clearness	+	+	o	o	o	o
Flexibility	o	o	o	-	-	+
Structur variance	+	o	o	o	o	+
Time modelling	-	-	-	o	o	+

Chart 2: Comparison of the modelling methods of the business processes ((-) not possible, (o) hardly possible and (+) possible)

By means of the comparison which can be carried out and the important requirements of the modelling of business processes, the Petri Nets (PN), due to thei exceptional advantages and their specific characteristics, present a very suitable method for the modelling and description of business processes.

It can be proved, that Coloured Petri Nets (CPN) with its programming language SML, is most suitable as a tool for the modelling and evaluation of business processes because all states and cases can be represented and can be modelled with CPN.

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4 EXAMPLE OF A PROCESS MODELLING BY MEANS OF CPN

The process modelling is clarified by the examples of the "audit" and "Supplements processing" in construction companies.

The audit is divided, depending on the company size, for example, into the following subprocesses, as is represented in figure 2:

- invoice receipt;
- price checking of the invoices;
- factual check;
- possible treatment of supplements, which is divided into the negotiation stage, processing and confirmation of supplements;
- arithmetic check;
- allocation and posting;
- payment releasing.

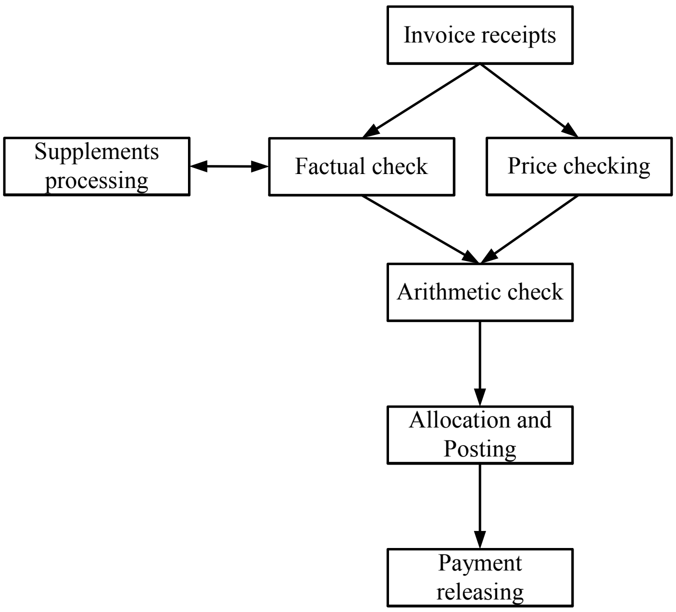

Figure 2: Subprocesses of the audit in a construction company

These subprocesses can be divided furthermore into several single activities.

For the process modelling it is important that their destinations are known at the beginning so that the model does not supply any false results. The elements and characteristics of the modelled processes and their level of detail reflect the destinations of the modelling The basic pattern of the process modelling consists of elements which are joined to each other by means of directed arrows or flow lines. Thus, all important elements of the business processes can be represented, as activities, resources and other process objects together with their relationships to each other. Every project should include information which is necessary for the later analysis and evaluation of the described business process. First of all, an informal model must be created which represents all elements of the examined processes with initial data. After that all parameters, which are relevant for the evaluation of the business processes, must be conceptually modified. They give an indication of how a business process is to be estimated from the viewpoint of the costs, time and quality.

In addition, the variables of the informal model are classified as follows:

- Structure-dependent variables,
- Time-dependent variables,
- Cost-dependent variables,
- Quality-dependent variables.

In chart 3 the structure-dependent variables introduced in the model are summarized, for example, as resources, employees, technology and invoice type. Thus the available structure of the audit can be easily adapted to changes.

Structure-dependent variables	Symbol
• invoice number	n_{rech}
• invoice type	a_{rech}
• position number	n_{pos}
• supplement number	n_{nach}
• page number of invoice	n_s
• copy number of invoice	n_k
• employee number	n_{ma}
• involved employee	b_{ma}
• resource number	n_{res}
• resource type	a_{res}
• contract type	a_{ver}
• transport type	a_{trans}

Chart 3: Abstract of the introduced structure-dependent variables

The informal model must be then converted into a CPN-model. For this purpose all determined and modelled data of the running time, costs, quality and resources with corresponding variables of the influencing variables must be integrated in the CPN-model.

The CPN-model is displayed by a hierarchy tree (see figure 3).

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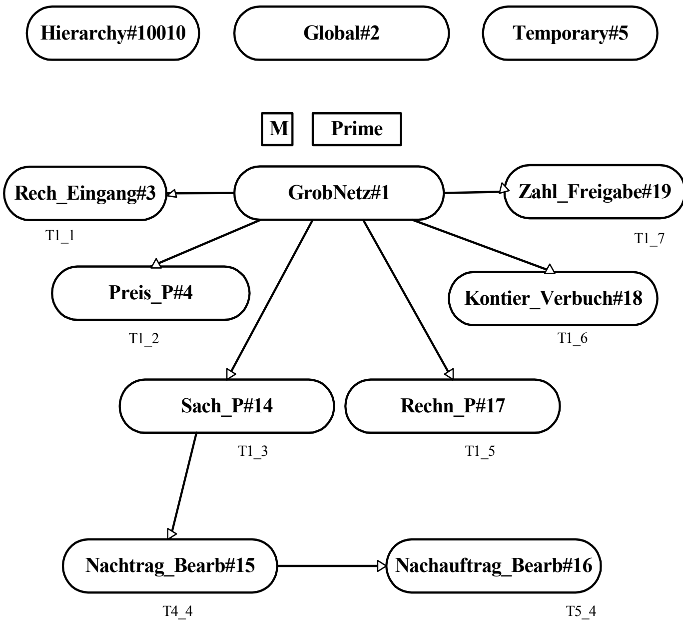

Figure 3: Hierarchy tree of CPN-Models

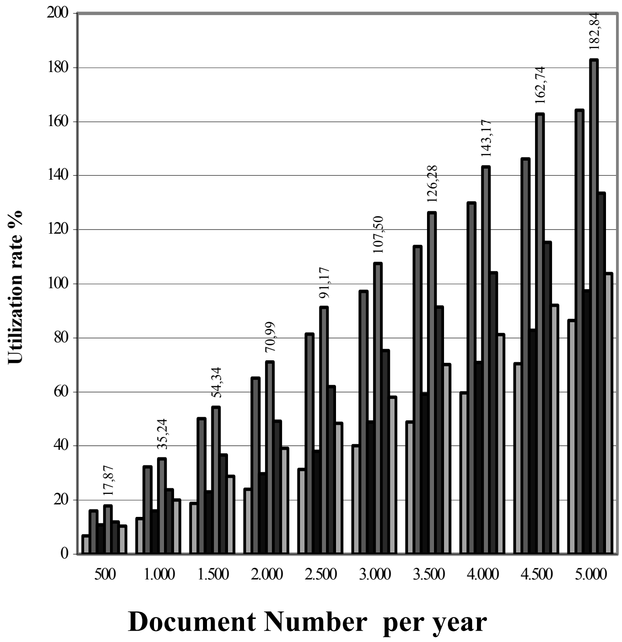

Figure 4: Calculation of the employee utilization

5 PROCESS ASSESSMENT AND RESULTS

The following cases can be examined on the basis of modeling with CPN:

- What is rate of utilization of every employee. Thus it can be evaluated, which employee in the construction company is overloaded, fully or partly loaded for a specific extent of the documentation received in one year.
- How much time and cost the business process takes, depending on the annual number of documents on the one hand and on the other hand depending on the technology used.
- How high is the quality of the business processes in relation to the cost and time for specific technology and for a specific extent of documentation.

For the evaluation of the utilization rate of every employee the percentage utilization degree of every employee can be calculated through the simulation which can be related to the document number per year (see figure 4 - columns show different functions).

In the same way the running time of the process can be evaluated from the simulation results with varying numbers of documents per year and for a determined personnel structure in a construction company (see figure 5).

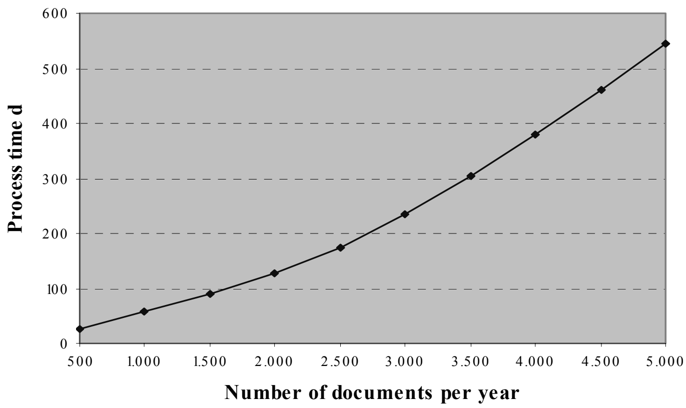

Figure 5: Calculation of running time of process

With increasing numbers of documents per year, the complexity of the processing increases considerable due to the variety and the expenditure of the processing options. The errors and the resulting error correction costs therefore increase exponentially and it can be determined through the simulation (see chart 4).

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Document number per year	Error costs (€)	Part from total costs (%)
500	70,11	0,39
1.000	164,07	0,44
1.500	255,28	0,46
2.000	372,30	0,57
2.500	502,60	0,68
3.000	657,03	0,85
3.500	821,27	1,01
4.000	1.105,73	1,31
4.500	1.335,60	1,51
5.000	1.682,99	1,83

Chart 4: Part of the error correction costs from the total costs

A qualitative evaluation for the modelled business processes can also be carried out. By means of a detailed analysis of the modelled business processes, a concrete investigation of the quality criteria can be carried out. The values of the process quality can be determined from the simulation for different document numbers per year (see figure 6).

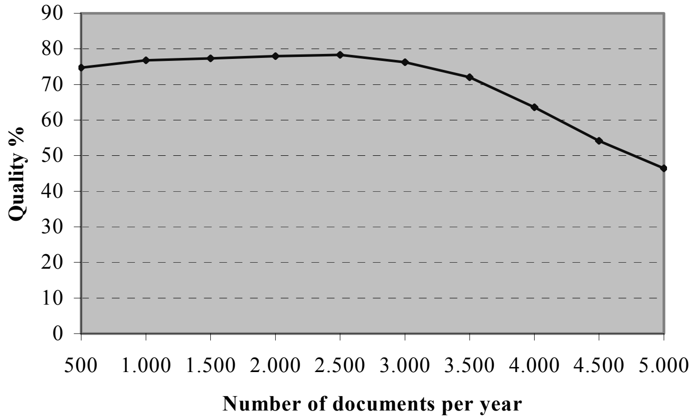

Figure 6: Process quality for different numbers of documents per year

6 SUMMARY AND OUTLOOK

Business processes in construction companies are evaluated up to now mainly qualitatively. However the quantitative evaluation factors also have exceptional importance, for example, for the definition of the business process costs The modelling of business processes by means of CPN represents an excellent opportunity to carry out both qualitative and quantitative evaluation of the business processes in construction companies. The evaluation of the either existing or restructured business processes in construction companies is seen as a basis for the fulfillment of the requirements, which increase with the evolution in the building industry. Thus, on the basis of the evaluation of different work flows of business processes the improvement potentials of the company structure can be examined.

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WEB-Services as a Technology to Support Construction Processes

N. Riediger, K. Laube, W. Huhnt & B. Kochendörfer
Institute of Civil Engineering, Berlin University of Technology, Berlin, Germany

ABSTRACT: Construction projects are characterised by specific peculiarities so that the processes for the execution of construction projects need to be prepared and setup individually for each project. However, a lot of tasks are executed in similar ways in different projects. The knowledge of executing these tasks can be transferred from project to project whereas the context and the interaction between tasks may differ. The approach presented in this paper reflects the situation in dealing with construction processes and discusses WEB-services as a suitable technology to support the processes. The idea is to support specific tasks by WEB-services. These services are implemented once. The tasks that are supported by these WEB-services may occur in different projects. This is expressed in an individual process model for each project. Based on the relationships between tasks and WEB-services, an individual information system for each project can be customised on the basis of the process model.

1 INTRODUCTION

Construction projects need to be prepared individually. This is well known in practice and it is state of the art to develop work plans where rules for the project execution phases are documented. The work plan covers the specification of tasks and their sequence. Software systems are necessary to support the execution of tasks in distributed environments because project participants work at different locations.

This paper discusses an approach to support construction projects by an information system that considers the requirements of civil engineering projects. These requirements result from the specific peculiarities of construction processes. As an example, tasks in the area of managing defects are chosen to illustrate the use of the concept presented.

2 CONSTRUCTION PROCESSES

2.1 *Definition*

The term "process" has been defined in different disciplines. In business administration, a business process is defined as a sequence of performances belonging together for the purpose of goods and services (Scheer 1998).

Construction processes can be defined similar to business processes. Tasks are subdivided into subtasks. The sequence of tasks has to be developed. Additional elements like persons or technical equipment can be assigned to tasks so that different modelling techniques can be used to specify constructions processes.

2.2 *Complexity*

By this definition, "construction processes" are characterised not that precise accept of the fact that in these processes the influence of participants or different phases of the lifecycle respectively cause a high level of complexity. Therefore, the construction process has to be enlarged by these influences.

The physical life of a construction- or real estate project can be subdivided into different phases. It starts with the idea of the project and results in the deconstruction or demolition. Especially development, execution and utilisation are phases containing various principle tasks in the areas of project development, project management and facility management (Kochendörfer et al. 2004). Proceeding in these various phases does not differ eminently according to varying industrial sectors. However, the existence of diverse formalities such as HOAI (the German law on calculating fees for architects and engineers) or DVP (German Organisation of Project Management) leads to diverse variants of how to classify the phases.

The management of interfaces between the process phases in particular causes difficulties. The com-

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plexity of construction processes additionally increases by the high number of participants and the interdependence of the process phases. That makes the demonstration of all details within a process model exceedingly difficult.

Beside the owner and the architect, many other participants take part in construction projects. The bigger the project the higher the number of people involved. The management is responsible for the coordination. A main task is to find the right organisational structure in order to define the contract management. The most common constellations are individual enterprises, master planers, general contractors or main contractors and total contractors. The contract interfaces, the effort of coordination and the risk often decrease from high in individual enterprises to low in total contractors.

2.3 *Characteristics of construction processes*

Construction projects are characterised by specific peculiarities so that the processes for the execution of construction projects need to be setup individually for each project. However, many tasks are executed similar in different projects. The knowledge of executing these tasks can be transferred from project to project. The context and the interaction between tasks may differ.

Given the fact that the construction area changes and expands constantly it is obvious that the establishment of an all-embracing process model is considered as not possible. An all-embracing process model would have to include all aspects and variants of the construction area. Even though we could install such a model at present, it would have to be upgraded permanently. Any new form of contract, any new technical solution or new construction material would have to be included. To summarise all that, an all-embracing process model would never be completed.

The approach to set up construction processes based on optimised sub-processes does not work out. This fact is well known from mathematics. It is proved that the existence of local optimums does not inevitably mean that there is a global optimum. Figure 1 shows an example from the construction area. The sub-processes shown are optimised sub-processes that are valid in its discipline. To string these processes together does not lead to a global optimum because interdependences are not regarded (Fig. 2). A possible rightly connected optimum is shown in Figure 3. The sub-processes of the main-process are partly interrupted by subtasks of other sub-processes.

An optimised partial process to be executed by an architect (extract):
A1: define design requirements
A2: create preliminary design
A3: create final design

An optimised partial process to be executed by a structural engineer (extract):
S1: create preliminary structural report
S2: create final structural report
S3: create reinforcement drawings

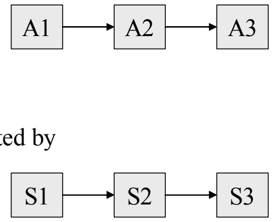

Figure 1. Optimised sub-processes (Huhnt 2004).

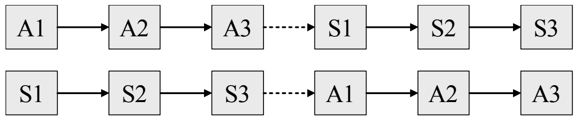

Figure 2. Non-optimal overall processes (Huhnt 2004).

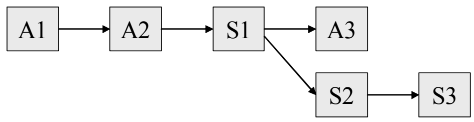

Figure 3. A possible optimal overall process (Huhnt 2004).

Another approach tries to deduce construction processes from roughly detailed and optimised processes. This approach does not provide the solution either. Figure 4 shows a roughly modelled construction process and the deduced processes in detail. Once dependencies between sub-processes are introduced a completely different structure of activities can be the result. That is shown in Figure 5. From rough to fine it is possible to bring processes in the right order but not the other way around. The result would never be explicit.

That underlines the fact that construction processes have to be set up newly from project to project. The only constants in this context are single tasks. They can be executed equally in different projects. The duration of the task has to be planned within the individual project.

An optimised process (extract) :
A: create architectural design
S: create structural report
R: create reinforcement drawings

Detailing tasks and relations:
A: A1, A2, A3
S: S1, S2, S3
R: R1, R2, R3
A-S: A1-S1, A2-S2, A3-S3
S-R: S1-R1, S2-R2, S3-R3

Definition of further relations:
A: A1-A2, A2-A3

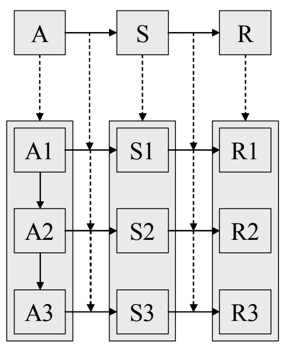

Figure 4. Introduction of dependencies within detailed processes (Huhnt 2004).

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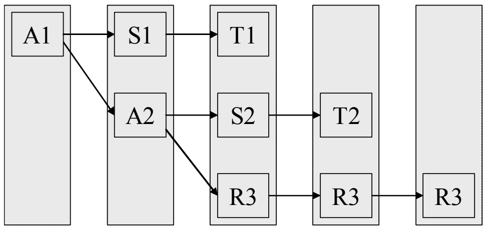

Figure 5. An optimal detailed process (Huhnt 2004).

All these approaches result in the displayed concept as follows.

3 SUPPORTING CONSTRUCTION PROCESSES IN DISTRIBUTED ENVIRONMENTS

The finding that construction processes need to be redesigned from project to project leads to the consideration that the reusability of processes is restricted. However, a lot of similar tasks need to be executed in several processes. Therefore, functionalities to support tasks can be reused. Supporting construction processes can be realised by providing one-time implemented functionality, which can be applied for each subtask calling for.

The process itself has to be modelled specifically for each project. In the process model it is now known which task has to be completed by whom. As a result of that the required functionalities of each process and person can be assembled. The principle of this concept is shown in Figure 6.

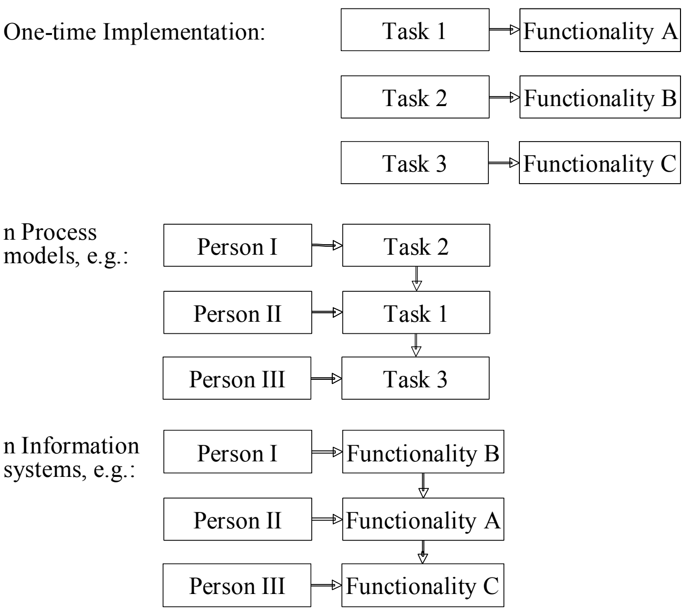

Figure 6. Concept of process support.

The development of an information system consists therefore of three steps. In the first step, the functionalities are implemented once. The second step models the process. This is individual for each project. The third step provides the function specific for a project and the persons involved. The third step acts automatically.

The functionalities are provided with WEB-services via the Internet. Therefore, a distributed system for project processing is provided in which functionalities can be used by different participants working at different locations.

4 MANAGING DEFECTS

4.1 Defects

The motivation for a systematic prevention of defects is the high cost of defects in construction processes. It is considered as a typical construction process where usually 4%-12% of the overall construction costs are spend on rectifying faults and defects (Jungwirth 1996). There is a high capability of cost reduction by using information technology based upon process modelling. The management of defects fulfils the theoretical requirements: Different processes are necessary to be supported by an information system depending on the point in time when a defect is detected.

Defect prevention in particular is very important concerning the lifecycle of structural works. Most frequently defects appear during execution. However, defect prevention is a process attending the whole lifecycle of buildings from development to utilisation. The context and the interdependencies of tasks differ depending on the fact if a defect is detected before or after the final acceptance of a specific work. Although the tasks required are almost identical in different processes. Due to the process model supported by WEB-services the users of the system should be able to create their own specific information system by choosing the tasks in the desired order only with a “click”.

4.2 Detection of defects before acceptance

As described above, the process of defect prevention is suited for exemplified realisation of the R&D-project. Same tasks are assembled to different processes. It follows a precise description of the defect prevention process as well as the fundamentals it is based on.

In the process of defect management the legal claim of the client or the owner respectively changes at this moment of time when the client accepts the asset under construction or after completion (acceptance). The VOB part B (German Construction Contract Procedures, similar to British Fidic) strictly distinguishes the legal rights of the client regarding construction defects before and after acceptance. Before acceptance the legal rights of the client results from § 4 no. 6 and § 7 VOB/B. After acceptance

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§ 13 VOB/B with a changed burden of proof to the disadvantage of the client is relevant.

Allocation of the burden of proof (before acceptance burden of proof is with the contractor, after acceptance shifting of the burden of proof to the principal), the possibility of substitutive execution and the beginning of limitation are depending on the basis for claim.

In the following the process of defect prevention will be described in more detail.

In case of defects before acceptance the construction supervision has to react as shown below.

As mentioned above before acceptance the legal rights of the client results from § 4 no. 7 VOB/B. If a defect is detected by the construction supervision it has to be taken up correctly. If the good or service is without defect after proof claims do not occur. In case of a defect the causer has to be found and the defect has to be associated with the causer. Right after declaration of a defect it has been proved beneficial to distinguish between contractor, subcontractor and assistant of the principal. As a result of that the taken up defect document can be handed out correctly.

1 If the principal or its assistant is responsible for the defect it has to be declared if concerns have been registered officially.
- If concerns have been registered claims of the principle to remove the defects are forfeited. This has to be communicated to the principle.
- If no concerns have been registered but the defect was hidden claims of the principle to remove the defects are forfeited. This has to be communicated to the principle as well.
- If the defects have been recognisable costs of defect removal are quoted based on proportion of causation. Often the contractor arranges the removal and gets paid referring to the proportion of causation.

2 If the reason of defect is on the side of the contractor it has to be declared who has caused it. However, with respect to proceeding responsibilities of the object the defect occurred, attention on potential re- or extra work of other participating groups has to be paid.
- If the defect of a good or service is due to the contractor or any other third party a notice of defect including an appointment of a date and demand for removal of defects has to be send.
- For accounting control belonging to construction supervision a notice has to be made for deduction of price in case of outstanding defect removal (up to three times of the expected cost of defect removal).
- If the defect removal took place within the appointment of date the following has to be proved.
- If the removal of defect has been successful the deduction of price has to be paid off or disregarded in the next account respectively.
- If the removal of defect is insufficient another notice of defect has to be made and send to the contractor.
- If the defect is not removed within the appointed date the construction supervision has to decide if the contractor gets another opportunity to remove or not.
- In case of providing another opportunity the contractor has to get a notice of delay including extension of time. Normally a second appointment of date should be provided.
- In case the contractor exceeds the second appointment or refuses the removal altogether the client has got the legal right of substitutive execution. That means he can order the execution some were else for the costs of the contractor. Therefore the contract with the contractor has to be cancelled in advance.

The elimination of defect by the contractor has to be communicated in written form to the client. This paper is also used as a certificate of documentation and tracing of defect. The construction supervision has to assure itself on location if the announced defect has been corrected.

4.3 *Detection of defects after acceptance*

After acceptance the legal right comply with § 13 no. 5-7 VOB/B, the contractor is responsible for the guarantee.

In case of defect it has to be proved if:
- the defect has occurred effectively.
- the defect has been known while acceptance or if known the removal has been reserved.
- the claim of guarantee is not time-barred.

If the noticed defect does not feature one of the requirements no claims can be assert. In this case the principal has to be informed with justification accordingly.

In case the defect fulfils the requirements, the causer has to be detected for the following procedure.

1 If the defect is within the area of responsibility of the principal or one of its assistants, is has to be declared if the contractor has registered concerns.
- If the contractor has registered concerns the principal does not have any legal rights on defect removal. The principal has to be informed about this.
- If no concerns have been registered, but the defects does not have to be seen the principal does not have legal rights either. He has to be informed about this as well.
- If the defects were to be seen a quoting of costs of defect removal has to be done. The quoting has to comply with proportion of causation. Often the contractor arranges the removal and gets paid referring to the proportion of causation.

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2 If the reason of defect is on the side of the contractor, it has to be declared which maintenance group has caused it and which contractor it has to be assigned to.

– It has to be analysed if a removal of defect is technically possible.
  - If removal of defects is technically impossible the contractor is allowed to refuse removal. In case of refusal reasons have to be proved. If the refusal was right the principal is allowed to reduce payment.
  - If the removal of defect is possible but out of scale, removal does not take place. The principal is allowed to reduce payment either.
– The extent of reduction has to be calculated and communicated to the principal and contractor. If no agreement of the extent of payment reduction can be done, the client or the owner respectively is allowed to employ an estimator.
  - If the removal is possible, not out of scale and the principal does not refuse it, removal of defects has to be done by the contractor.
– A notice of defect including an appointment of date has to be sent to the contractor.
– Does the removal of defects take place within the appointment of date, it has to be proved.
  - If removal has been successful the principal has to be informed.
  - If the defect has not been removed within the appointment of date or no reduction of payment has been agreed upon respectively, it has to be decided if the contractor gets another opportunity to remove defects. In case of another opportunity the contractor has to be admonished. If this is not the case, a substitutive execution at the expense of the contractor has to be suggested towards the principal. If this happens it is due to the principle to demand the costs of substitutive execution from the contractor. He also can receive the costs from the deduction for guarantees, the contractor has to make within the period of guarantee.

    The substitutive execution has to be proved after completion and to find fault if necessary.
  - If the defect has been removed the principal has to be informed. A letter should include a written confirmation of the contractor.

Basically, all detailed questions regarding conduct (judicial) should be answered by experts (jurisprudents in particular) to avoid methodological error.

5 IMPLEMENTING A DEFECT MANAGEMENT SYSTEM

5.1 *State of the implementation*

A pilot implementation is under development to demonstrate the use of the concept presented. The pilot implementation covers the development of WEB-services to support tasks in the area of managing defects. The processes are modelled using the existing modelling tool ARIS® Toolset by IDS Scheer AG. Based on an individual process model, the functionalities are available to support the execution of that process.

5.2 *Implementing functionalities*

A lot of research has been done in the area of implementing WEB-services. The WEB Services Description Language (WDSL) is available (WDSL 2001), and tools are available to generate the specifications of these services. The present pilot implementation uses the Unified Modelling Language (UML) to extract the information from the process models (Kochendörfer & Huhnt 2005). The WEB-services themselves need to be implemented.

5.3 *Modelling a sequence of tasks*

The processes are modelled as extended Event Process Chains (eEPC). Their central objects are functions that are used in this context to model the tasks to be executed. Beside the sequence of events and functions the eEPC includes additional rules and organisational units for modelling, e.g. the persons involved. Figure 7 shows the element types that are used in the present context to model construction processes. It consists of tasks (rectangle), operations (rectangle with two brackets in up right corner), application systems (rectangle with two additional lines in both sites plus the letters Ex), the entity type (simple rectangle) and the participants (oval with line in the left). The direction of arrows indicates data input or output. Figure 8 shows an extraction of a process model.

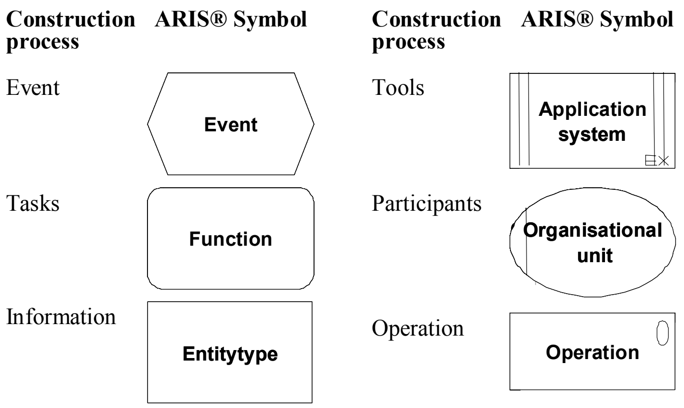

Figure 7. Methodology of modelling (IDS Scheer 2003a, b).

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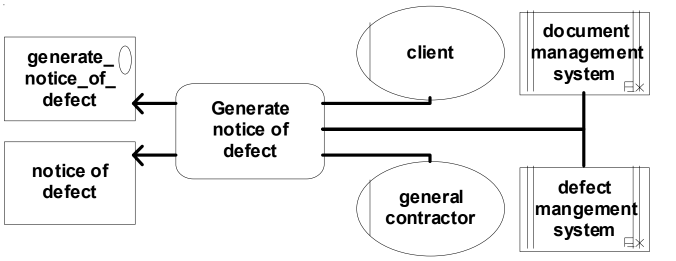

Figure 8. Extract from a process model.

5.4 *Generating an information system*

Based on the process model, all information is available to generate an information system for an individual process. The development of the functionalities required for managing defects is under progress so that for the processes described in section 4.2 and 4.3 information systems will be available in the near future.

6 CONCLUSION

This paper shows that process models can be used reasonably for specific provision of information systems in the construction area. The sequence of tasks in construction processes differ from project to project, whereas single tasks in various projects are alike. Therefore, the procedure of implementing functionalities of tasks has to be executed once whereas the functionalities can be used in different processes.

Construction processes take place in distributed environments where sometimes people work together from different continents and in different time zones. The use of the Internet is state of the art. WEB-services are a suitable technology to support construction processes. Therefore, this technology has been chosen to demonstrate the beneficial use of process models in supporting construction processes by information systems.

The research made has been shown in processes of defect removal exemplarily because they are representative for construction processes. They affect nearly all phases in construction processes and have to be operated in different phases at the same time. Defects are detected mostly at the joining of different phases. Its handling is a relevant assignment in the construction area and important for the efficient and effective processing of projects.

The tools used in the project as well as methods of information transfer are exemplary. Time will show which tools and languages are going to be appropriate in future. However, irrespective of technical progress, the analysed approach in principle is sustainable for supporting construction processes in distributed environments.

7 ACKNOWLEDGEMENTS

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A methodology to plan, communicate and control multidisciplinary design processes

J. Haymaker, C. Kam & M. Fischer
Center for Integrated Facility Engineering, Department of Civil and Environmental Engineering, Stanford University, Stanford, CA, USA.

ABSTRACT: Architecture, Engineering, and Construction (AEC) projects require multidisciplinary solutions. To develop these solutions, AEC professionals need to construct their discipline specific information, but they also need to interrelate and make trade-offs with the information of other disciplines. Today AEC professionals have formal methods to construct much of their single discipline information; however, they lack formal methodologies to plan, communicate and control their multidisciplinary processes. As a result, AEC professionals struggle to design and execute good multidisciplinary solutions. By leveraging existing industry and our own methods and technology, we are designing and implementing such a formal methodology. Using this methodology, AEC professionals will collaboratively and iteratively define their objectives using our POP (Product, Organization, Process) method. They will develop options and analyze them using our Narrative method. They will decide upon options using our Decision Dashboard method. To develop this methodology, we are gathering test cases from ongoing AEC projects, implementing our methodology in the CIFE iRoom, re-enacting these test cases and conducting live charettes with our implemented methodology, and validating the extent to which this methodology enables AEC professionals to better communicate and control their multidisciplinary design processes. The scientific purpose of this research is to better formalize and manage design processes among many AEC professionals and their information. The practical purpose of this methodology is to enable AEC professionals to improve their multidisciplinary designs.

1 INTRODUCTION

Building Information Modeling (BIM) promises to revolutionize the way AEC professionals design and execute projects. Many anticipate a future where they will collaboratively use computer-based methods to improve the multi-disciplinary performance of their designs rapidly and execute these designs effectively (Khemlani, 2004). Today, AEC professionals are currently benefiting from discipline-specific BIMs and methods that improve single discipline performance. However, iterative multidisciplinary processes are difficult due to ad hoc methods for information communication and control. It is therefore difficult to optimally execute these projects. AEC professionals tend to sub optimize for single disciplinary performance, making late, over-budget, and functionally unsatisfactory projects all too common.

Kunz and Rittel (1970) describe design as a social process in which AEC professionals simultaneously formulate statements about problems as well as statements about possible solutions to those problems. Gero (1990) and Schön (1991) similarly characterize design as a goal-oriented, decision-making, exploration and learning process. Through literature review and observation of AEC projects, we have identified four interrelated and iterative design processes that we believe AEC professionals could formalize, and therefore better communicate, and control. AEC professionals need to be able to *define* the important functions their designs need to perform. They need to *propose* design forms, and they need to *analyze* the behavior of these forms with respect to their many required functions. Finally they need to *decide* which options most effectively satisfy their many functions. We observe that today AEC professionals struggle to *communicate* their goals, proposals, analyses, and decisions among project participants. They also struggle to *control* the integration of this information with the information of other participants and throughout this iterative define, propose, analyze and decide (DPAD) design process. As a result, AEC professionals struggle to *optimize* the multidisciplinary performance of their designs.

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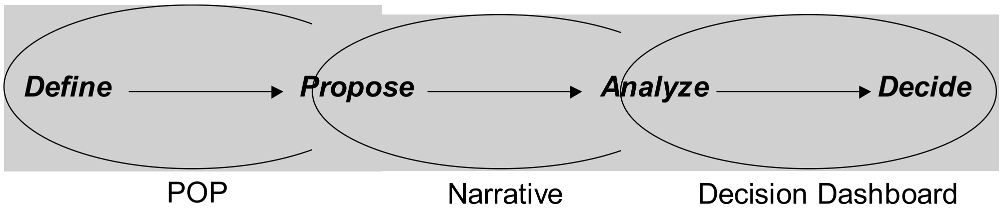

Figure 1: We are formalizing four interrelated design processes to help AEC professionals better communicate and control them: *define* design functions, *propose* design forms (these can be product, organization or process forms), *analyze* these forms, and *decide* on forms. To formalize these processes, we propose to integrate three CIFE methods: *POP* enables AEC professionals to *define* the functions, forms and behaviors of the products, organizations, and processes. *Narratives* enable AEC professionals to *propose* and develop many design forms and *analyze* these. *Decision Dashboard* enables AEC stakeholders to compare analyses, make tradeoffs, *decide*, and document their decisions.

We are therefore working to design and implement a methodology that enables AEC project teams to better communicate and control their DPAD processes. This methodology builds on three recent projects at the Center for Integrated Facility Engineering. AEC professionals will define the important functions, forms, and behaviors (FFB) of their products, organizations and processes (POP) using the POPFFB (or POP for short) method. They will rapidly propose and analyze many competing forms using the Narrative method. They will decide amongst these competing forms, making multidisciplinary tradeoffs and driving the project towards improved performance using the Decision Dashboard (DD) method. See Figure 1.

In this paper we describe a test case to motivate our methodology. We then describe our ongoing effort to formalize and implement this methodology. We are gathering test cases from current AEC projects. We are implementing this methodology in the CIFE iRoom. We will re-enact our test cases, and conduct live charettes using our implemented methodology. We will validate our methodology with respect to AEC professionals' ability to communicate and control their multidisciplinary design processes and information.

2 MOTIVATING TEST CASE

This test case describes and diagrams the design process an architecture firm went through to determine the costs and benefits of employing an atrium in an office building in Northern California. Figure 2 describes and diagrams some of the requirements they defined, some of the design options they proposed, some of the analyses they performed and a summary of the decision they made. The lines in the diagram are dashed because this process was not formalized in the computer.

The architect knows that atria can be effective ways to take advantage of natural light, reduce building energy consumption, and improve the quality of the work environment, and thus the productivity of the occupants. However, atria can cause uncomfortable glare conditions, have constructability and maintenance issues, and result in a bigger building footprint that costs money and takes longer to build. Therefore the architect wanted to know if they should employ an atrium on this project. They first defined the site description, researched the regulatory requirements, and worked with the client to define the client's requirements. Based on this functional information, they then proposed two design options, a design with an atrium, and a more traditional design with no such daylighting feature. Next, they set about to analyze these designs. They analyzed the amount of daylight in key work areas and at key times of the day, measuring the sufficiency and comfort of the lighting conditions. They used this information to estimate how much artificial lighting would be needed, factoring this amount into an analysis of the amount of energy each design would consume in a year. They then analyzed how long each design might take to construct, and how much each design might cost to construct. Using the first cost, and the energy consumption, they estimated the lifecycle cost of each design. They used all these analyses to inform their client, and themselves, as to the cost and the benefits of the atrium, from which the client could make a decision.

While the building is recognized as a highly innovative and successful example of sustainable architecture (Leventhal 2001), the architect struggled to effectively communicate and control this design process, and they did not optimize this design:

Communication: The architect provided a series of Microsoft Word™, Excel™ and other documents, containing over one hundred pages, in which they described the process they executed to determine the costs and benefits of the atrium. While the required design functions, proposed forms, analyzed behaviors, and decisions appeared in these documents, no diagram such as Figure 2 or other formal description of their DPAD design process that formally defined and interrelated these concepts existed for this project. The architect has expressed a desire to more effectively communicate their design process to the owner, to consultants on this and on subsequent projects, and to the design community as a whole in order to share a sound sustainable design process.

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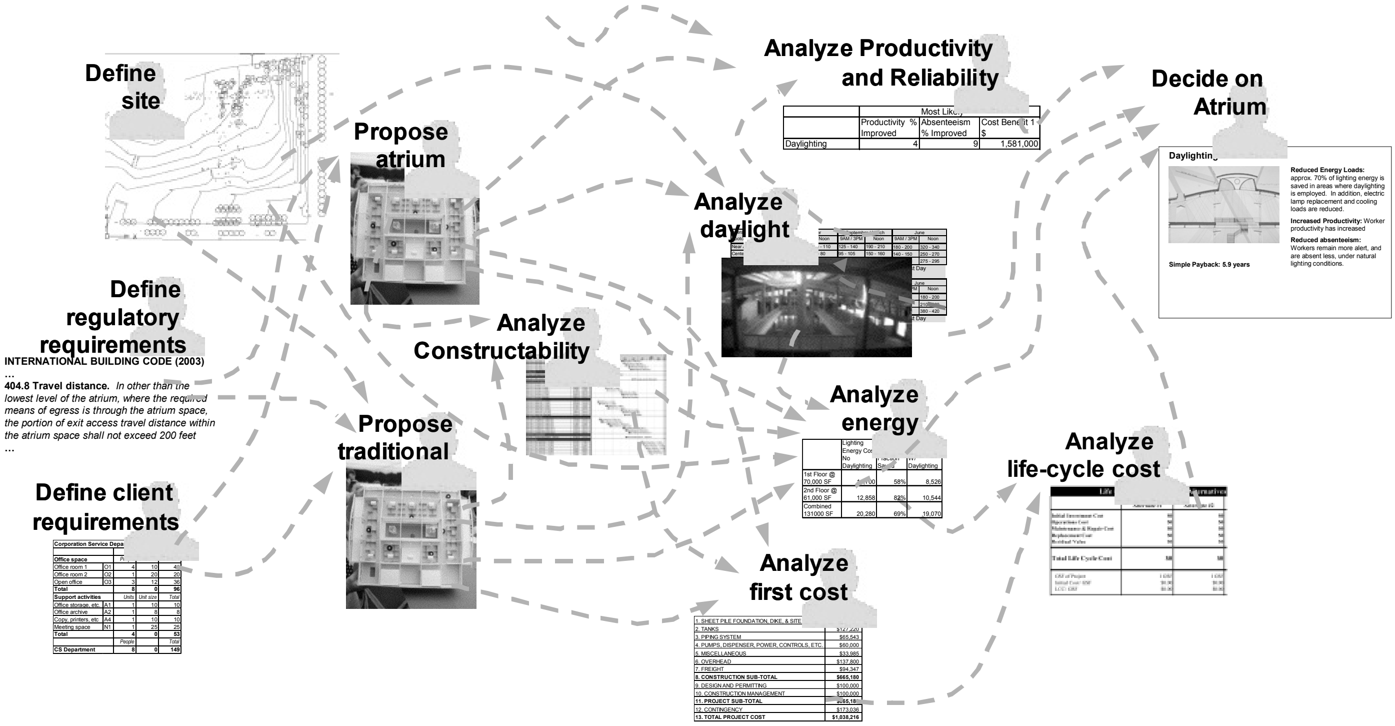

Figure 2: A portion of the design process an architect and their consultants executed to define project requirements (functions), propose design options (forms), analyze these options based on many requirements (behavior), and decide on the appropriate design options based on these analyses.

Control: The architect also struggled to control this design process. On examining their documents we found a failure to accurately integrate information from the energy analysis into the life cycle cost analysis. Integration difficulties between discipline-specific information have been well documented, for example: between requirements information and design information (Kiviniemi, 2004), between design information and analysis information (Kam and Fischer 2002), between design information and fabrication information (Haymaker et al 2004), and between analysis information and decision information (Kam, 2004).

Quality of Design Solution: Because of the difficulty communicating and controlling this design process, the design team was not able to fully explore this design. For example, they were unable to sufficiently explore many configurations of atria layout to determine the optimal layout for the energy, daylight, cost, and other criteria they determined were important. The ability to formally define and manage their information, the interdependencies between this information, and the decisions based on this information would have enabled the design team to more effectively communicate their design process to the owner and other project participants, more effectively control and automate this process for the exploration of more options, and thus improve their multidisciplinary design solutions.

3 POINT OF DEPARTURE

3.1 *Limitations of current BIM to support multidisciplinary design processes*

The concept of modeling a building project in a computer has had successes and received a lot of publicity in recent years. Despite promising progress to date, we only see ad hoc management of BIMs in support of the multidisciplinary collaboration. We review a successful multidisciplinary application of BIMs and identify some limitations from that state-of-the-art example.

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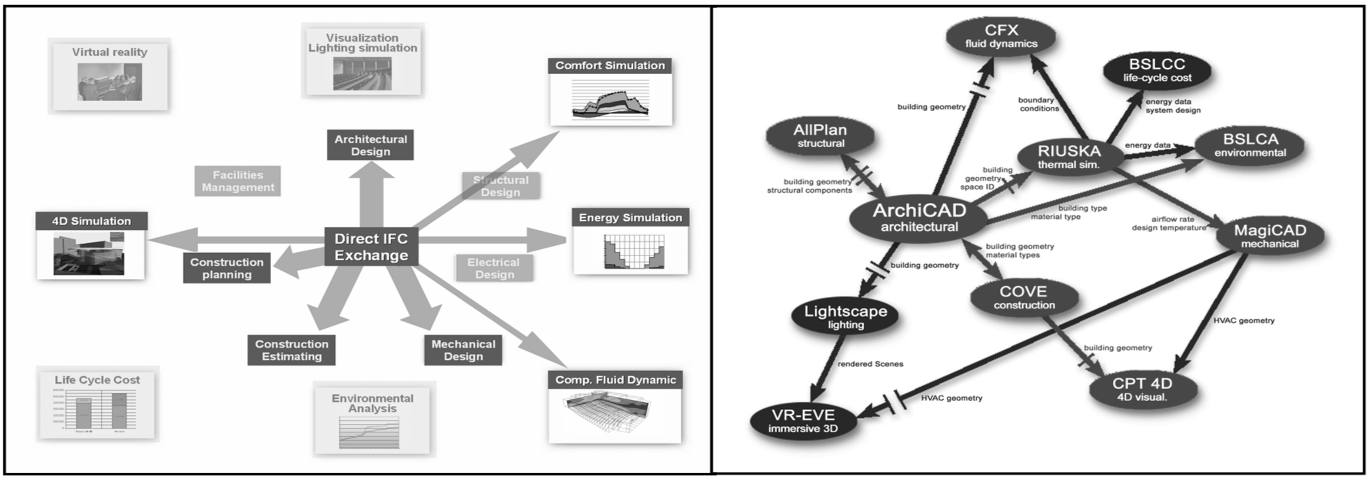

Figure 3: We captured both the theoretical concept (left) and the "chaotic" reality (right) of information exchange among the many BIMs from the HUT-600 Auditorium project in Helsinki, Finland. Although the project benefited from various domain-specific BIMs, iterative multidisciplinary proposals, analyses, and decision tradeoffs were difficult due ad hoc methods for information communication and control.

The HUT-600 auditorium project in Helsinki, Finland is one of the first industry projects to use an array of multidisciplinary BIMs in the design process (Kam and Fischer 2002). The architects, structural engineers, energy consultants, HVAC designers, and construction managers developed specific BIMs that addressed their disciplinary needs. As a result, these individual BIMs enabled the end-users to better visualize the design; the architect to improve his efficiency in producing design documents; and the energy and cost consultants to improve performance of their specialty services. However, the exchange process among the BIMs was ad-hoc and cumbersome in spite of the availability of an interoperable data exchange standard (See Figure 3). Decision-making focused on single-disciplinary proposals, such as HVAC choices (e.g., underfloor versus conventional systems) or architectural features (e.g., skylight versus windows), but not on integrated choices across multiple AEC disciplines (e.g., structural system relationships with different architectural or HVAC choices). There were no means or methods to define multidisciplinary objectives, propose and analyze multidisciplinary options, and make tradeoff decisions.

As this state-of-the-art example illustrates, AEC professionals in many disciplines are benefiting from BIM oriented computer applications, such as architectural visualization, daylight analyses, energy simulation, cost estimating, etc. Emerging data structures such as the Industry Foundation Classes (IAI 2005), CIMsteel Integration Standards (Steel Construction Institute 2003), and the Green Building XML Schema (GBXML 2005) are supporting limited data exchanges, and a number of software applications are implementing these data standards. We do not envision that a single BIM will adequately serve to communicate and control multi-disciplinary interests present in a building project. The case study illustrates that current AEC methodologies do not enable AEC professionals to easily communicate and control design processes consisting of many BIMs, such as multidisciplinary objectives, proposals, analyses, and decisions.

3.2 *Three Emerging CIFE Methods to Address These Limitations*

In our effort to address current limitations of BIM's to support multidisciplinary communication and control of design processes, we investigate three promising CIFE methods—POP, Narratives, and the Decision Dashboard as the starting points for our research.

The POP method (Kunz and Fischer 2005, Garcia et al 2003) enables AEC stakeholders to collaboratively *define* the important functions, forms, and behaviors of the products, organizations, and processes of an AEC project. For example, most BIMs are most commonly used to represent the form of the product (e.g., the architectural and structural systems and components of buildings). However, other aspects of the project design – as shown in the other cells of the POPFFB matrix – need to be made explicit and designed as well (see Figure 5). The POP method enables a broader and balanced communication and integration of these nine types of interrelated information models shown in the matrix. We suggest AEC project teams use the POP method to collaboratively define and communicate their many types of information.

The Narrative method (Haymaker et al 2004) enables AEC stakeholders from multiple disciplines to formally and iteratively construct information models from other information models and control the integration of these evolving, distributed, multi-disciplinary models. AEC professionals will use Narratives to *propose* many options, and *analyze*

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these options by formally defining the dependencies between the defined functions, proposed forms, and analyzed behaviors, and to control the integration of these models. The Narrative method provides a graphical view of these dependencies.

The Decision Dashboard method (Kam 2005) enables AEC professionals to decide amongst project options. Represented in Decision Breakdown Structures (DBS), decision information includes competing sets of criteria (functions), decision topics, options, and alternatives (aggregations of options), and their relationships. The Decision Dashboard allows stakeholders to interactively change and evaluate choices as the decision process evolves. The DD makes all relevant decision information explicit and available for stakeholders to make and document informed decisions. It facilitates, but does not replace, the analysis or negotiation processes that are vital in AEC decision-making.

4 RESEARCH METHODS

To design our methodology, we are currently gathering test cases, refining the POP, Narratives, and Dashboard theory and prototypes, integrating the prototypes in the CIFE iRoom, implementing the test case into the prototypes, holding charrettes with AEC professionals, and validating our research. The following subsections explain these research tasks in further detail.

4.1 *Gather Test Cases*

We are observing real AEC projects and formulating case studies like those described in Sections 2 and 3. We are collecting the many representations the AEC professionals construct, and we document the issues they discuss. We are developing these observations into manageable test case scenarios, and use them to motivate, and develop criteria against which to validate, our work.

4.2 *Refine and Implement Our Methodology*

We are refining existing POP, Narrative and DD modeling application prototypes, deploying them in the CIFE iRoom, and defining interfaces among these prototypes. The interface development relies on a generic Representation object, which all three methods specialize for their purpose. POP adds the POPFFB classification, Narrative adds dependency information, and DD adds Decision classification and relationships.

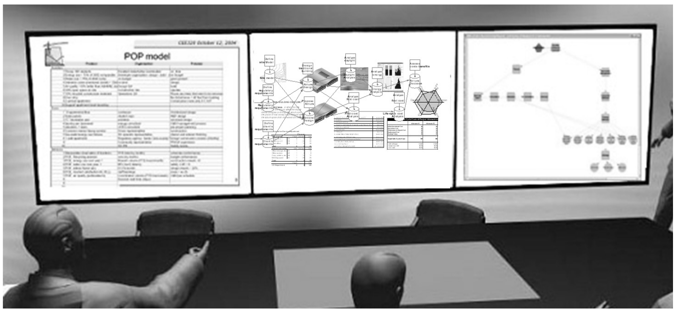

Figure 4: A mock up the integrated POP (left screen), Narratives (center screen), and Decision Dashboard (rights screen) in the CIFE iRoom.

4.2.1 *Define and Analyze with POP Modeling*

AEC professionals will use POP modeling (see figure 5) to define the key project requirements (i.e. functions), options (i.e., forms), and analyses (i.e., behaviors) of the project's Products, Organizations, and Processes (see Figure 5). Current POP models are built in Microsoft Excel; we plan to develop a simple prototype with a similar interface that will enable AEC professionals to define each of the Product-Organization-Process-Form-Function-Behavior *Representation* elements. POP modeling will promote synchronous, communication of multidisciplinary information models among the project's stakeholders.

	Product	Organization	Process
Function	Respond to Site	Energy Expertise	Sustainable
	Regulatory Requirements	Product. Expertise	On time
	Clients Requirements	Daylight Expertise	On budget
	Good Daylighting	Fast	Meet LEED Reqmts
	Low Lifecycle Cost	Inventive	
	…	…	
Form	**Atrium**	Energy Consultant	Design Sched
	No Atrium	Construction Mgr	Const. Schedule
	Green Roof	Lighting Consult-	LEED Certification
	Metal Roof	Architect	
	Raised Floor HVAC	Daylight Software	
	Overhead HVAC	…	
Behavior	**Daylight Analys.**	Many Options	Meet Finish Date
	First Cost Analys.	Good Light *Analys*	Meet Budget
	Energy Analys.	Good Prod Analys	No Change Orders
	Lifecycle CostsAnalys.	Minimal Rework	Minimal Latency
	Productivity Analys.		Many Light Analys.
	Structural Analys.	…	

Figure 5: POP models define the important Forms, Functions, and Behaviors of the project's Products Organizations and Processes. For example, this POP model defines an atrium and no atrium as two proposed form options, and defines the need for several analyses of the behavior of these forms, including Daylight, Cost, Energy and Productivity (shown bold).

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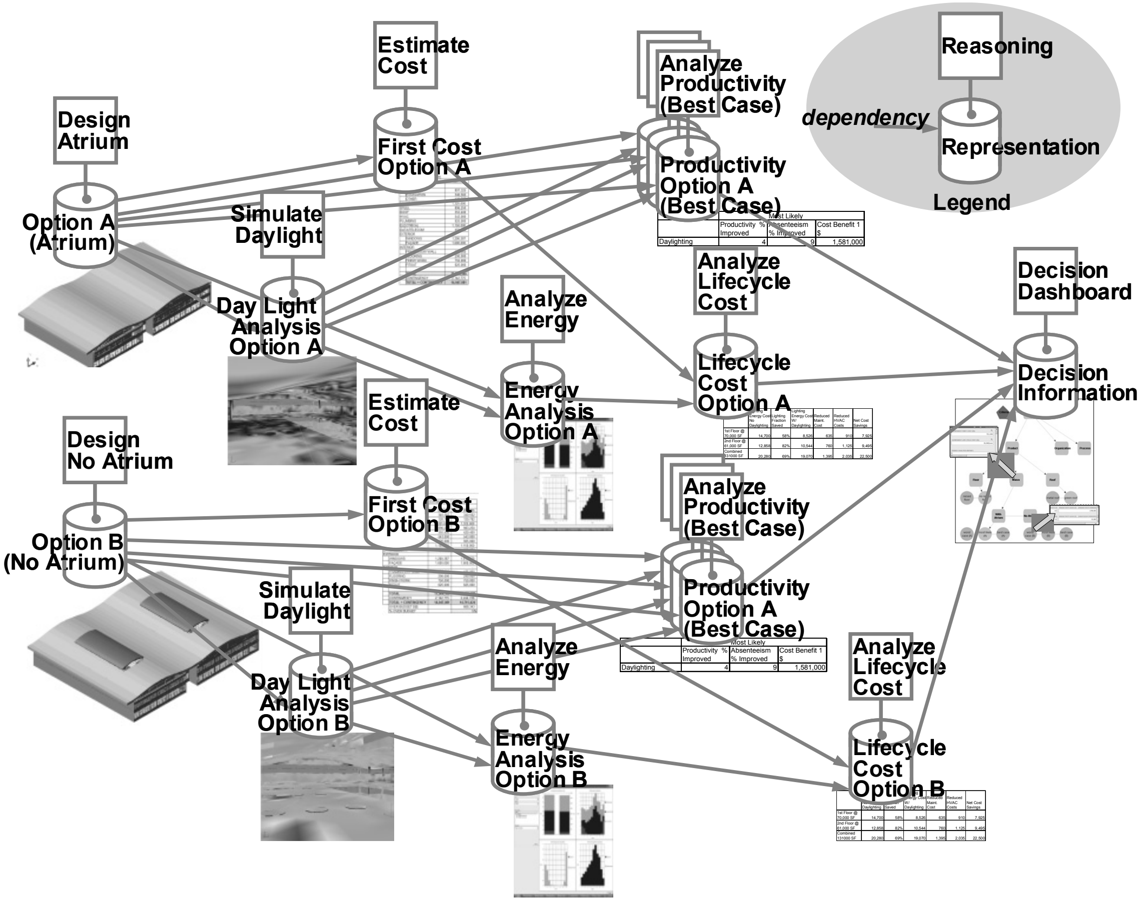

Figure 6: Narratives formalize and control the dependencies between information models. This Narrative formalizes the dependencies between the Atrium and No Atrium design options, and the many analyses of these options. The information in these Narratives serves as input to the Decision Dashboard.

While the POP model makes the main elements of a project's Function, Form, and Behavior with respect to its Product, Organization, and Process explicit, it does not make the dependencies between these elements explicit and therefore does not inform the process the project organization should carry out to design the project forms to accomplish the functions. Narratives inform this process by representing these dependencies.

4.2.2 *Propose and Analyze with the Narratives:*

Narratives (see figure 6) formalize and control the sources, nature, and status of the dependencies amongst information models. A node in a Narrative consists of Representation and Reasoning. The representation (e.g., a BIM describing the architectural design of the office building with an atrium) serves as the information repository for professionals and their software tools for a particular task (e.g., Estimate Cost). The reasoning specifies how the task (a combination of human and software activity) transforms the information from the information sources (repositories) into the information generated by the task. By relating tasks (including their representation elements and tools) to each other a network of dependencies between, for example, forms and behaviors emerges, allowing AEC professionals to design, communicate, and control the design process explicitly. AEC professionals will use Narratives to help them propose and analyze different competing options (e.g., propose atrium and other designs, and perform energy and cost analyses). Our current implementation of Narratives constructs and controls dependencies between geometric models (Haymaker et al 2004b); this research will extend the Narrative implementation to construct and control dependencies between generic representations.

4.2.3 *Analyze and Decide with the Decision Dashboard:*

Through the application of POP models and Narratives, professionals should be able to generate the right options with the best multi-disciplinary process possible. Now, AEC stakeholders need to make the appropriate trade-offs between and decisions about the generated options. To do so, they then can use the Decision Dashboard (DD, see figure 7) to make design decisions from information constructed in both the POP and Narratives applications. The form and behavior elements of the POP and Narratives inform the options from which the stakeholders need to select the best. The functions become the criteria against which the options will be evaluated. The Narratives give the decision makers the confidence that the options were analyzed in a consistent and integrated way. They also offer the potential to adjust or redo the analyses quickly and consistently should

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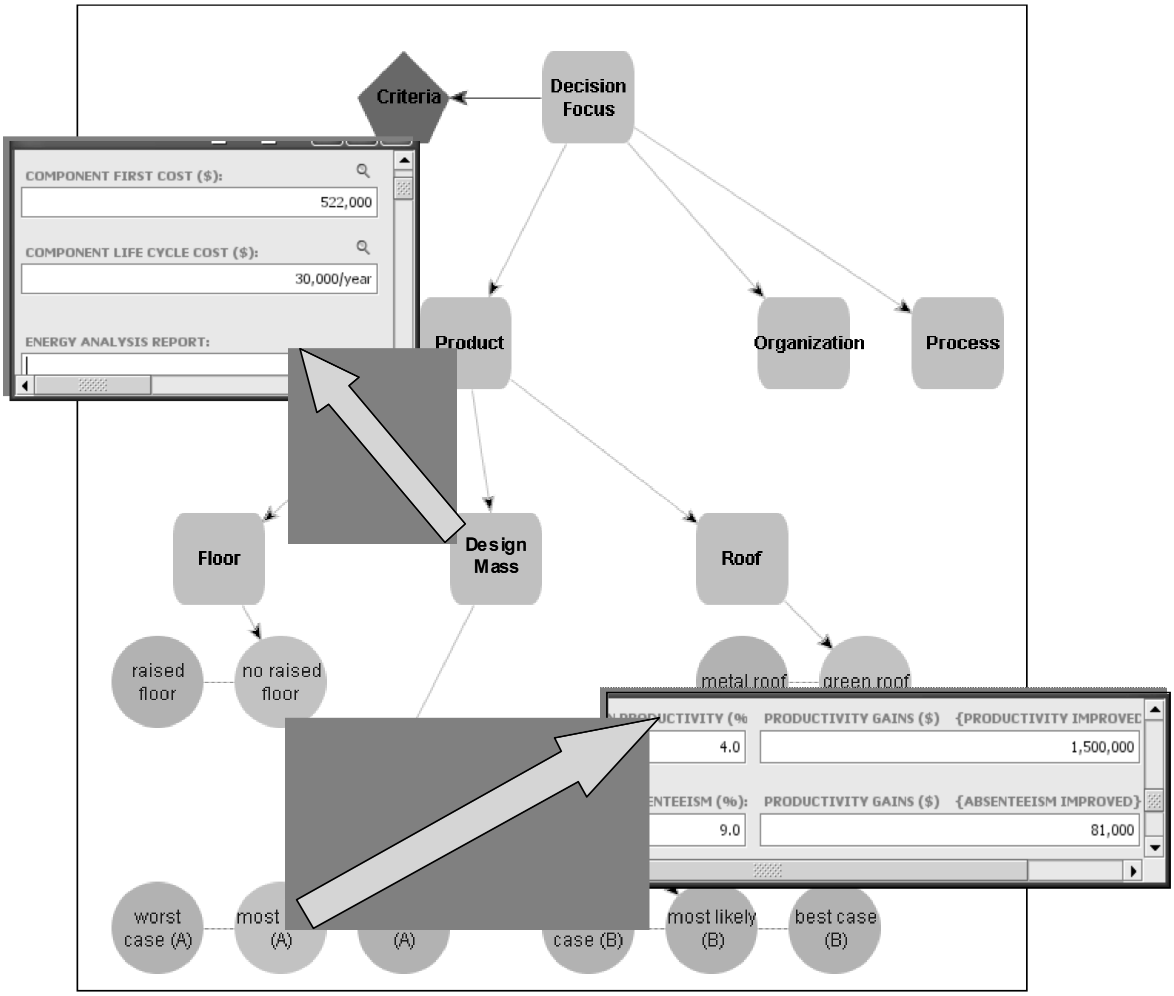

Figure 7: The Decision Dashboard enables AEC professionals to manage project options and facilitate the decision-making process. This DD organizes the atrium and no atrium design options under a decision topic called "Design Mass". Each Design Mass option has associated worst, most likely, and best-case options for the productivity analyzed in the Narrative. When a DD user switches the arrow from one option to another, the DD automatically propagates the effects of this change up this hierarchy, such that the currently selected decision topic, such as Design Mass, has productivity, lifecycle cost, and any other attributes that are defined lower in the hierarchy.

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the criteria or options change during the decision making process. Thus, the DD serves as a decision-support tool for AEC professionals to analyze integrated decision information and to document the decision-making process for other AEC stakeholders.

4.2.4 *Apply the methodology*

We will re-implement the test cases we gather using our *DPAD* methodology. We will also re-enact these test cases in charettes with students and AEC professionals. These charette participants will first use the POP approach to define the important models for the project. They will then use the Narrative framework to establish and control the interdependencies (either manually or automatically) between these models. Finally, the participants will use the Decision Dashboard to organize, enhance, and document the decision trade-off process. As the prototype matures, we will work with these participants to apply our methodology on their current multidisciplinary design and analysis problems.

4.2.5 *Validate the methodology*

The test cases will allow us to validate for the extent to which POP, Narratives, and DD help AEC professionals communicate and control their multidisciplinary projects. While gathering case studies, we are documenting the performance of the AEC teams in terms of the following communication and control metrics. We will then compare the performance of AEC teams using our methodology with this baseline data:

Communication: We will measure the number of stakeholders involved, the number of contributions made by these stakeholders. We will also measure the quality of communication by these stakeholders through a DEEP analysis (Garcia et al, 2003). DEEP measures the amounts of time AEC professionals spend in meetings Describing, Explaining, Evaluating, and Predicting. The purpose of this metric is to measure if AEC teams are communicating effectively. The idea being that if they can spend less time Describing and Explaining, and spend more time Evaluating and Predicting, they are communicating more effectively, and adding more value.

Control: We will measure the latency and rework involved in the data integration among different information models. We can measure the amount of time each information model remains not integrated with respect to the information models on which it depends. We can also measure the amount of time AEC professionals spend working on information that is not integrated. The purpose of this metric is to measure how quickly and accurately AEC teams are able to control their design processes.

5 CONCLUSION

AEC projects lag behind other industries in formalizing and controlling their processes. This is in large part due to the multidisciplinary and unique nature of AEC projects. We are working to design a collaborative design environment in which AEC teams can formalize their DPAD design processes . We are doing so through specializing three interrelated methods: POP, Narratives, and Decision Dashboard.

We expect that more formal and transparent definition, proposal, analyses, and decision processes will improve the communication between the many information models and the many stakeholders. We also expect that our refined prototype and interfaces will minimize data re-entry and shorten integration delay across multidisciplinary needs, enabling better process control. Finally, we expect that improving the communication and control of the multidisciplinary design processes will improve the quality of multidisciplinary solutions.

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Enabling dynamic networks using an architecture for collaborative scenarios

T. Theling, J. Zwicker & P. Loos
ISYM – Information Systems & Management, Johannes Gutenberg University, Mainz, Germany

O. Adam & A. Hofer
Institute for Information Systems at the German Research Center for Artificial Intelligence (DFKI), Saarbruecken, Germany

ABSTRACT: Collaborative business requires integration of involved enterprises' information systems. Characteristics of project networks like changing business partners or raising exceptions lead to dynamic structures within collaborations. This is a special challenge for a common IT infrastructure. This paper presents an architecture for dynamic cross-enterprise processes' planning, execution, and controlling on a conceptual level. In a first step, a distinction of local and global knowledge is provided in order to establish a Collaborative Business Process Management Lifecycle. Afterwards, requirements for a collaboration-supporting architecture are briefly upraised and the resulting architecture is presented. In a last step, the architecture is adopted to special requirements of AEC. Domain-specific data like placing units and specifications are introduced and the process of tender, placing and accounting is depicted within the architecture. Therefore, different parts of the architecture are involved.

1 INTRODUCTION

1.1 *Motivation and Structure*

Innovation pressure arises in interaction relations like supply chains and in networks with complementary core competence partners. The opening of organizational borders is no longer regarded as a necessary evil, but rather as a chance with strategic importance. Therefore inter-organizational applications and the transfer of business process management aims into collaborative IT systems are considered.

This paper presents an architecture for dynamic cross-enterprise processes' planning, execution, and controlling on a conceptual level. After an overview about related work, chapter 2 introduces a distinction of local and global knowledge in order to establish a business process management lifecycle in chapter 3. Chapter 4 presents an integrative architecture, which enhances appropriable concepts of workflow management and business process management to enable collaborative business integration on multiple levels. Chapter 5 shows a possible application within the domain of Architecture, Engineering & Construction (AEC), while chapter 6 gives a summary and an overview of future work.

1.2 *Related Work*

Collaborative Business is discussed from several perspectives. Many authors describe reasons for collaborations and establish several economical theories like transaction costs (Coase 1938; Williamson 1995), the market-based view proposing strategic groups to evaluate cooperations' effects on the market (Caves & Porter 1977), or the resource-based view emphasizing competencies of corporations (Hamel & Prahalad 1990). The coopetition approach integrates several aspects of these theories (Brandenburger & Nalebuff 1995).

Concepts of borderless enterprises (Picot et al. 1999) have been discussed for years and the collaborative production of goods and services has been established. Current approaches addressing solutions to specific problems of dynamically interacting organizations are summarized under the term "*Business Integration*"; the field of investigation is referred to as *"Collaborative Business (C-Business)"*. C-Business describes the Internet-based interlinked collaboration of all participants in an value added network (Zang et al. 2004). It considers organizational aspects and assimilates existing concepts of workflow management and business process management (BPM) frameworks (Eom & Lee 1999; Evaristo & Munkvold 2000; Hollingsworth 1995; Rittenbruch et al. 1998; Scheer 1999; van der Aalst 2002; Wild et al. 2003). Regarding a technical support for this topic, Web Services and Service Oriented Architecture (SOA) are discussed (Alonso et al. 2004; Patankar 2003).

Many articles and contributions discuss architectural approaches which support collaborative BPM.

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Numerous requirements concern trust within collaborations (De Santis et al. 2003; Gronau 2003; Megaache et al. 2000; Whitescarver et al. 1997), so e. g. secure transactions or role-based computing. Another aspect is flexibility which enables easy application integration, self-organization of IT-architectures or scalability of software systems (Gronau 2003; Patankar 2003). Reusability of components (Blake 2000; Patankar 2003) and integration of used business modeling languages (Gronau 2003) are further requirements. Whitescarver et al. upraise further requirements of different frameworks like socio-psychological collaboration, organization and communication, user interfaces, network infrastructure, and meta tools (Whitescarver et al. 1997).

A possible approach to fulfill some of these requirements is using portals with unique user interfaces. Portals can integrate tools for teamwork and project management or for collaborative process execution. They provide access to unstructured information like documents or charts as well as to structured information like transaction data, analyses and evaluations. Many approaches have not been accepted within AEC.

2 VIEWS ON BUSINESS PROCESS MODELS

The different views onto business process models are based on the Architecture for Integrated Information Systems (ARIS) and divide it into a vertical axis of *global knowledge* (available for all network participants) of all collaboration partners and a horizontal axis of *local knowledge* (available for two cooperating partners) of the single participants (cf. Fig. 1). The organisation view and the output view are global knowledge because a goal-oriented collaboration is impossible without them.

At the time the interaction occurs between two partners, local knowledge is shared (bilaterally) between the partners, i. e. additional information, like data structures and semantics, is exchanged. Updates of the local knowledge do not influence the network as network knowledge has to be available for all partners. This information is stored in the description of interfaces between the process modules of the partners. Changes in the global network knowledge and as a consequence changes in the output and organization view have to be accessible to all partners immediately, for example if a company leaves the network or if a product or service is no longer available within the network.

Global and local knowledge merge gradually in the step-by-step development of C-Business process engineering. Following the distinction between global and local knowledge, a language is needed for the exchange of these knowledge fragments. Because the necessary detail functions and data schemes of the respective enterprise are determined in the data and the function view, these are treated from a micro perspective. They are characterized by an intensive internal interdependence, whereas externally a standardized encapsulation has to be provided. Interfaces of the data and function views to other network participants become visible in the process view in form of attribute correlations to process modules and concern the technological field of the cooperation during the realisation much more intensely than the conceptual one.

This technique enables the generation of **public** (visible to network partners) and **private** (enterprise-internal) **views** and levels of detail for management, process owner and IT-experts out of a C-Business model.

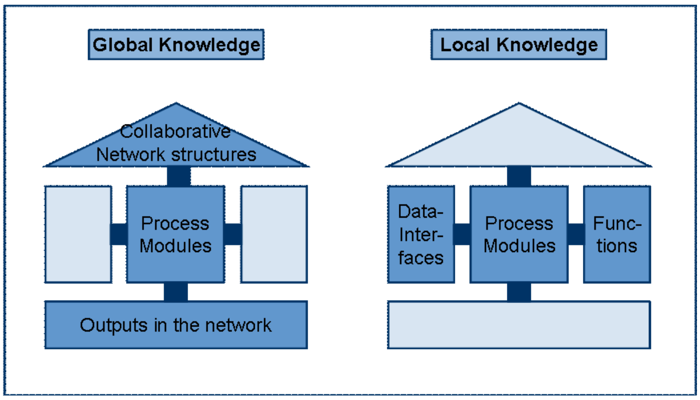

Figure 1. Global and local knowledge in value-added networks

Enterprise spanning business processes are not planned in detail at the strategic level, but are designed as concentrated, high-level process modules. Thus, they combine the public knowledge about the collaborative processes that is shared by all participants. C-Business scenario-diagrams that are used e. g. by SAP Ltd. for the description of my-SAP.com collaboration scenarios, aim at the representation of the cooperation of different enterprises and participants by means of an easily understandable method and the documentation of the value-added potentials resulting from it. The responsibility for each process step, indicated by swimlanes, is of central importance to the determination of the scenario. This method is integrated into the ARIS concept and combined with methods of (classical) business process and data modeling used at the C-Business Process Engineering layer.

The question of core competences in the enterprises is directly associated with the question which processes remain in the enterprise and which are supposed to be assigned to partner enterprises or collaboratively operated.

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3 COLLABORATIVE BUSINESS PROCESS MANAGEMENT LIFECYCLE

The lifecycle model presented in this section serves as a manual for the process-oriented setting-up and operation of cooperations. Using a consistent phase model and standardized modeling methods increases transparency and structuring of cooperations and creates a basis for communication between participants, including management that lays down strategies, process-owners in the departments and IT-experts that integrate the different application systems. The model is a fusion of classic phase models with lifecycle models of virtual enterprises.

Protecting internal know-how is of paramount importance to the network participants, even though the business process knowledge has to be used jointly. Following the view concept presented in chapter 2, the lifecycle alternates between phases that focus on global and on local issues in order to reach a coherent solution (cf. Fig. 2).

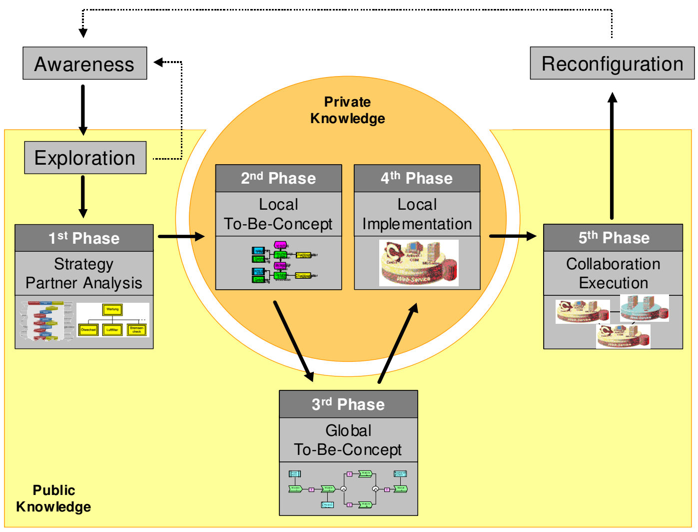

Figure 2. Collaborative Business Process Management Lifecycle

3.1 Pre-phase and reconfiguration

Prior to the use of the architecture is the *awareness* of one or more enterprises that they can profit by collaboration with complementary core competence partners. The decision if and with which enterprises a C-Business scenario should be implemented is taken by every single enterprise individually and rationally; for this reason it depends highly on the expected economical profit of the individual partner. In this model, it is assumed, that a set of potential network participants is given.

After conducting the cooperation, companies regroup or split and *reconfigurate* themselves. The lifecycle returns to its starting position "awareness".

3.2 Main-phases

In the first phase *Strategy Partner Analysis* or formation phase, also referred to as initiation and agreement of the enterprise network, the collaboration partners are determined by the shared goals of the collaboration and the aspired win-win situation of all partners. The joint aims of the collaboration have to be defined as synthesis of the individual aims.

To facilitate the collaborative service or product delivery, graphical methods, like product models, are used in this stage for the determination of a common service or product bundle. They simplify and put the often implicit objectives into concrete terms. In addition to the characteristic features of a service or a product over its entire lifecycle, the organizational units participating in the production are contained in a product model. By means of product trees, enterprises can conceal detailed service descriptions in an internal view that puts special focus on the organizational aspects of the product offered by the partners. In an external view they just provide the information required for the configuration of the common service bundle in form of product bundle models.

Having completed the strategy finding, in the second phase, *Local To-Be-Concept*, an existing or a new (local) as-is model and the (global) to-be concepts are compared. According to predefined conditions about collective product creation, intra-organizational business processes can be derived. Each partner considers his part in the inter-enterprise process. Starting with process modeling and optimization over process controlling up to implementation, the processes involved are aligned with the requirements of the collaborative scenario agreed on in the former phase.

In the third phase, *Global To-Be-Concept,* coordinated public parts are allocated over the network, establishing a collective to-be concept. Every partner is able to connect his own private model with every other public process model. Every partner gains his partial view of the collaborative process, so a virtual process chain of the whole collaboration is designed. The Business Process Execution Language (BPEL) can be considered as an appropriate exchange-language. Global knowledge is described in a public interface, which can be provided by a BPMN representation. The public processes as well as the message formats and contents can be formally defined by B2B protocols like RosettaNet or ebXML. Furthermore the semantic combination of models of the different partners is necessary. As long as ontology-based approaches don't reach a productive state this combination process is a manual action.

The integrated collaborative business process model enables all partners to configure their application systems locally in a fourth phase called *Local Implementation*. Reference systems for interfaces are

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provided by interface definitions of the collective to-be concept.

Now every partner is prepared for the execution of interactions within the collaborative framework. That is the transition to the fifth phase *Collaboration Execution*. Based on bilateral bases interacting information systems are able to communicate by using the standardized protocols and interfaces. The transactions are arranged and executed. The aim of this phase is to support collaboration through the appropriate use of ICT. That requires primarily the configuration of interfaces and the implementation of interorganizational workflows; at the same time the permanent monitoring and adaption of the collaboration, based on business ratio defined in the conception phase, must be assured.

In order to automate inter-organizational processes, the conceptual models are transformed into formal models that are used as configuration data for the orchestration of business objects. The applications of the partners have to communicate bilaterally to negotiate the interface specifications based on the formal models. The local knowledge is generated by this negotiation for a certain situation. After this collaboration task has ended, no updates of configuration changes etc. are reported to any other party except at the time when a new direct interaction occurs (Zang et al. 2004).

4 ARCHITECTURE FOR MANAGING COLLABORATIVE BUSINESSES

4.1 Requirements

Within the research project "ArKoS – Architektur kollaborativer Szenarien", a questioning of AEC experts regarding architecture requirements has been performed and led to following results: Regarding the management of collaborative business processes, preliminary planning processes of an AEC project (build time, existing of lifecycle's Pre-phase and phase 1-4) and controlling of actual running processes (run time, lifecycle's phase 5) have to be supported. This concerns analysis, simulation and optimization of business processes and collaboration structures. Therefore predefined ratios must be available, which requires a data exchange between monitoring tools and different operational IT systems.

Further on, arrangement and configuration of business processes and collaboration structures must be supported. Therefore various modeling methods have to be taken into account. At first, various corporations within the collaboration may use different modeling notations. At second, different abstraction levels of models exist, which leads e. g. to semi-formal models like event-driven process chains on an abstract level, while formal models like Petri nets may be used on a detailed level.

Another aspect is to keep business secrets of individual collaboration partners. This is realized by the presented distinction of global process knowledge from local process knowledge (cf. chapter 2).

A further requirement is to enable mobile access to various data. New mobile devices have to be integrated into the architecture.

4.2 Architecture's Concept

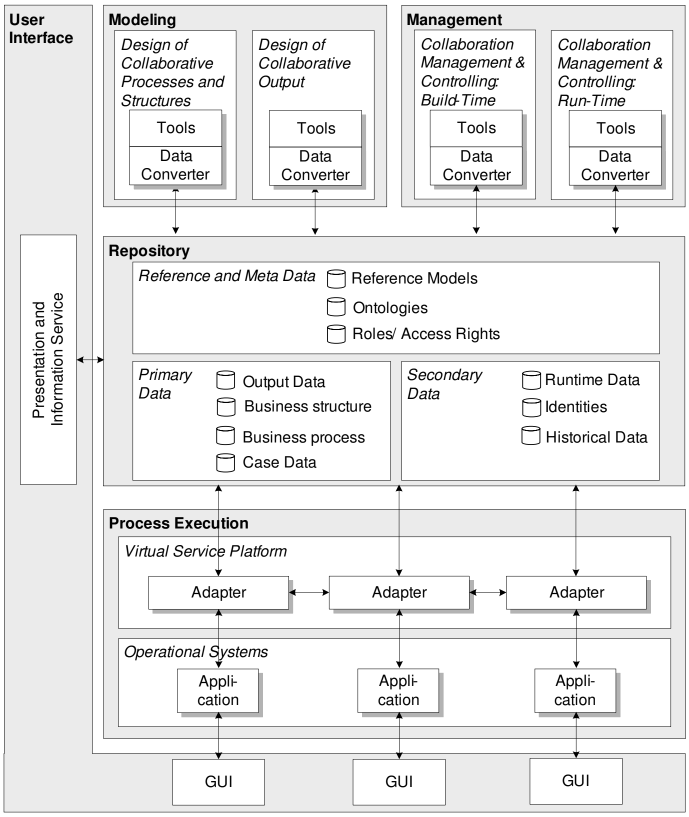

Figure 3. Architecture for Collaborative Scenarios

Based on the explained requirements, figure 3 depicts an architecture which supports collaborative business processes. It considers organizational aspects and integrates existing concepts for workflow and business process management. Relationships and components of Scheer's ARIS – House of Business Engineering (HOBE) as well as workflow management and business process management architectures are included (Hollingsworth 1995; van der Aalst 2002). Basic information for the process execution is visualized in business process models, output models, and organization models. These are created by modeling tools and stored in a distributed repository. Depending on process- and organization models, the virtual service platform executes processes and integrates different operational systems of the collaboration partners. The following sections describe components and characteristics of the architecture.

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4.3 Repository

The architecture is realized upon a physical distributed repository managing all data. It enables business process management, common work on the underlying models, and cross-enterprise process execution. Individual knowledge of each partner is stored within decentralized parts of the repository. A logical centralization of the repository represents knowledge of the overall network.

Reference and meta data comprise information, which provide a basis for the design of process models as well as organizational models and create a common conceptual understanding: *Reference models* support the construction of individual models and improve the design of specific organizational structures and processes of the enterprise network (Fettke & Loos 2003; Mertins & Bernus 1998). *Ontologies* are able to unify differing vocabulary of concepts and meanings regarding the contents and semantics of models (Gamper et al. 1999; Kishore et al. 2004). They are formal conceptual systems of a domain, which obtain a knowledge transfer between applications and users. Within the architecture, ontologies are relevant for integration of different language formats between used applications. For the design of models they establish a common conceptual understanding of modeled issues. *Roles* are parts of the security concept of the architecture and define templates for description of economical requirements on persons within the network. A role bundles access rights on resources as well as data of the repository and can be assigned to particular persons, e. g. due to the enterprise affiliation or the workplace function (Edwards 1996).

Following the distinction of primary and secondary business functions in a value chain (Porter 1985), also the used data can be distinguished into primary and secondary data.

Primary data supports the operational realization of business processes and the primary purpose of the architecture: *Output data* provide descriptions of the outputs as results of executing collaborative business processes (Scheer 1999). *Business process data* obtain process models of the value-added network. Local processes are intra-organizational processes of particular network enterprises, which belong completely to functions, roles and resources within the enterprises, though they have interfaces to the enterprise-external processes and resources. Global processes form the process structure of the overall network by aggregating the local processes at corresponding interfaces. *Business structure data* contain the organizational structural model of the value-added network. Analogue to the process data, they can be distinguished into global and local structural models. Global structural models show the relationship structure of enterprises in the value-added network, whereas the local models represent the intra-organizational structures. *Case data* are, on the one hand, task-oriented resource data of the value-added network, which pass through the processes and will be processed to a stand-alone product (Hollingsworth 1995), e. g. documents or technical drawings. On the other hand, business data describe the task and network itself. Like the network, they can continually change. Examples are data about partner enterprises and their collaborations.

Secondary data stand orthogonally to business process management and embrace recording data or phase-overlapping data for supporting the process management: Historical data and runtime data are recording data, which comprise defined execution data and possible exceptions due to disturbance of process execution. *Historical data* are about executed or former processes, whereas *runtime data* record information about the current running processes of the value-added net. Both the historical data and the runtime data serve primarily the Collaboration Management and Controlling (CMC). Besides the aforementioned roles, *identities* are basic elements for access control on data of the repository.

4.4 Modeling

The Process and Structure Design (modeling of the value-added net) is performed by business analysts of the network enterprises in the role of a designer. They use appropriated tools, which are de-centrally available, e. g. tools for graphical visualization and modeling. The created models are stored in the repository. Modeling comprises the design of global and local models, whereas business secrets have to be kept by assigning roles and access rights. Reference models can be used, which have to be loaded from the repository into the modeling tools. Furthermore, ontologies can be used for consistent semantic modeling.

The design of collaborative output allows creating basis data about the collaboration's organization and global processes. Furthermore it is also used for operational tasks like cost calculation, requests for quotation or accounting. Output can be described in two different ways: in heterarchical networks the collaboration partners describe the output in common with each other, in focal networks the output can be described by a central scheduler.

All data and models are stored in repository-wide unique data formats. By using converters different software can be integrated, although it does not support a central data standard. In particular the data formats of the process- and organization-models have to fulfill several requirements: on the one hand different modeling tools with different modeling languages can be used, on the other hand collaborative-wide and enterprise-intern models may use different modeling languages. To store the models in a standardized format, we suggest BPEL (Andrews et al. 2003), which joins several characteristics of pre-

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ceding standardizing projects. BPEL also is an advantage for the suggested architecture because many software vendors prepare their systems for using BPEL.

4.5 Collaboration Management & Controlling

Collaboration Management & Controlling (CMC) is distinguished into Build-time-CMC and Run-time-CMC. Build-time-CMC includes early life-cycle-phases (strategy and partner analysis, local to-be-concept, global to-be-concept, local implementation), while Run-time-CMC encompasses the phase "Collaboration Execution" and the reconfiguration of collaborations. Following the distinction into a processual and an organizational view of collaborations, the methods of CMC are divided into process-oriented and organization-oriented tasks.

Organizational tasks of *Build-time-CMC* are for example portfolio analysis, due diligence or boundary management for collaboration-, enterprise- and department-borders. Concerning the processes a unique project controlling has to be defined. This contains monetary methods like cost planning, revenue planning, budgeting and calculation as well as the planning of collaboration-wide processes. For a pre-evaluation of the processual and organizational behaviour of the collaboration we suggest a Petri net-based simulation (van der Aalst 1994). Herewith all process models and organizational models can be validated and verified. The simulation can also estimate lead-times, costs, and capacity utilizations and it can deliver useful data to optimize the processes and the organizational structure a priori.

An important organizational task of *Run-time-CMC* is the steering of the collaboration partners' behaviour. Used methods are e. g. collaboration-intern transfer prices or a repertory-grid-based soft-fact analysis to identify cultural weaknesses of individual enterprises concerning their cultural fit with the collaboration. Process oriented Run-time-CMC-tasks are e. g. integrated progress controls, which include process monitoring, capacity control or performance measurement.

Concerning CMC in general, the repository can consist of collaboration-internal data as well as external data. The CMC-results can on the one hand be used to optimize the collaborative processes. On the other hand the results are used as a knowledge-base for the modelling of succeeding collaborations.

4.6 Process Execution

The Virtual Service Platform is responsible for process execution and integrates operational applications of collaboration partners. It uses process data and organizational data from the repository. Workflow-functionalities (Hollingsworth 1995) realize process execution, while EAI-functionalities (Linthicum 2003) ensure data and process integration. By using *local adapters* (cf. Fig. 4), operational systems can interact with each other without implementing a central coordination instance. To perform the tasks of the adapter, used services are searched with a *location service*. When the *repository service* is triggered by an event from other adapters or by an event of an operational application, it reads the relevant process module and further belonging data like business- or output data. *Execution services* use the process definition to execute the process modules using the application services. *Integration services* convert different data formats. If necessary, the integration services have access to ontologies. When the process execution ends in the adapter, the next adapter is triggered to start the next process module. Therefore *interface services* arrange the interaction between the adapters.

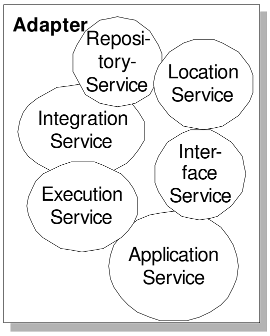

Figure 2. Components of Local Adapters

As a technical realization of the adapters, web service technologies are suitable (Werth et al. 2004). Services are available by using an extended version of Web Service Description Language (WSDL). So web services can interact with Simple Object Access Protocol (SOAP), based on internet protocols like Hypertext Transfer Protocol (HTTP) (Blake 2000). The Business Process Execution Language for Web Services (BPEL4WS or BPEL) allows the definition and execution of web service-based workflows (Shapiro 2002), while the Web Services Choreography Description Language (WS-CDL) defines the collaboration between web service components using a corresponding message exchange.

A further part used for the process execution is the *user interface*. A user in this case is a person or an organizational unit which fulfils functions and processes within the collaboration. Two different types of users can be distinguished. On the one hand they use presentation services as well as information services to get access to the repository (e. g. technical drawings, process definitions or visualizations of other data). On the other hand they use the "traditional" user interfaces of the operational systems in the companies to fulfill their tasks.

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5 APPLYING THE ARCHITECTURE WITHIN AEC

5.1 *Adapting the Architecture*

The application of the architecture is exemplarily demonstrated in the context of tender, placing and accounting within a construction project.

Basically, the structure of the established architecture components as well as the technical realization can be adapted for AEC domain. Besides the necessary instantiation of tools, applications, and systems, the repository has to be enhanced.

The previously introduced data categories of the repository will be instantiated in regard to contents of the AEC domain, e. g. by using AEC-specific reference models. These have to be stored in AEC-specific data formats. Further information is needed to address special requirements of the output design for construction projects: *Reference and meta data* additionally contain feature data, output catalogs, and product catalogs addressing the specification of output data, while feature data are meta data for output and product catalogs. The output catalog specifies all possible outputs (material and non-material output) performed during all phases of a construction process within the AEC domain. The product catalog for AEC consists of reference product data describing product features independently from producers.

Within *primary data,* the output data becomes an instantiation with AEC-specific specifications and placing units. Specifications list concrete outputs (material and non-material output) of the current construction project. They are part of the construction contract and are used for tendering, placing and accounting of outputs for the construction project (GAEB - Gemeinsamer Ausschuss Elektronik im Bauwesen 2000). A placing unit represents an order which lists the output of a selected enterprise.

5.2 *Phases of Output Description*

At first, a plan designer uses software for *designing the collaborative output.* At this stage he refers to one or more output catalogs (*reference data*) of the *repository*. Result is a specification for the concrete construction project. This is stored in the *repository* using a standardized, AEC-specific interface. Afterwards, a bidder uses his calculation software *(operative software)* and reads the dedicated specification through the *Adapter*. Using the listings from the specification, the bidder uses product catalogs from the *repository* to determine calculation-relevant product data. A quotation is sent back to the planer, who negotiates the contracts and places the orders. Based on these results, a global-to-be-concept can be modeled and the resulting models as well as placing units are stored within the *repository*. The bidder imports his placing unit into his software and re-calculates it regarding the negotiation. Simultaneously, he procures necessary materials using an inquiry tool and/or procurement software. During the procurement, pricing changes are to be considered within the calculation software to create an exact calculation before the real construction process. These software tools can interact via the adapters as shown in chapter 4.

6 CONCLUSION AND FURTHER WORK

This article discussed an architecture for collaborations within AEC based on theoretical concepts of local and global knowledge in order to support all phases of the established collaborative business process management lifecycle. The architecture is an integrative concept which combines several existing approaches and presents a distributed repository as an integrative layer. Architecture's tasks are (1) to support modeling of business processes and collaboration structures, (2) to integrate these models into a common repository, (3) to enable a collaborative management & controlling based on these models, and (4) to use detailed models for automated process execution.

Because of the wide-spread requirements, the architecture becomes a large concept, so future work is modularized: One important question is the conversion of different business process and collaboration structure models into a unique repository format. Regarding this topic first work on a common repository has been done and is presented on DAIS 2005 in Athens, Greece (Theling et al. 2005).

Based on the repository, on the one hand models are used as input for simulation within CMC. Therefore a prototype for connecting simulation-tools to the repository will be developed. On the other hand reference models should be designed to facilitate the establishment of cooperation. Further on, the SOA paradigm should be taken into consideration. This leads to research questions concerning the implementation of adapters. For a proof-of-concept, showcases within the AEC domain are intended.

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Use of business process modules for construction project management

M. Keller & R.J. Scherer
Institute for Construction Informatics, Dresden University of Technology, Dresden, Germany

ABSTRACT: Projects in the building industry are extremely dynamic and affected by several constraints. Therefore, common principles should be established throughout the construction industry that allow for flexibly specifying and combining construction project information. New members should be supported to easily join and leave the project consortium while still using their own applications. The need to rapidly set up new organisational structures and effectively manage this virtual organisation places high demands on the methods and models that are used to establish the project structure. Consequently, there is a need for an overall model representing the different building objects and functions as well as organisational and IT infrastructure of the projects. The paper presents an approach towards a common meta-model for the representation of construction project information for inter-organisational process management. Furthermore, the applicability of the proposed model for the selection and instantiation of predefined process modules will be demonstrated.

1 INTRODUCTION

Projects in the AEC/FM sector are characterized by a variety of technical and structural boundary conditions. Heterogeneous organisational structures and various IT-systems affect the realisation of a construction project. Particularly, the organisational structure is of great dynamic, since a project passes through several individual phases, such as 'planning phase', 'construction phase', or 'operational phase'. Each phase is conducted by its own organisational structure involving large companies as well as SMEs. Moreover, the building structure itself might become extremely complex with the progression of the project. Large construction projects usually comprise thousands of individual building objects and activities.

The use of appropriate IT-systems is of great importance for the management of large projects. However, seamless information processing is rarely accomplished, since each company is using its own IT-applications with incompatible or proprietary interfaces. Thus, a common strategy for the inter-organisational management of construction projects has to be established. A promising approach for integrated project data management has been established by the development of product models (e.g. the Industry Foundation Classes). However, the drawback of these models is, that they are very complex and focused primarily on design instead of management aspects. Again, just partial features are supported by software systems so far. To support inter-organisational construction project management and process coordination, general project constraints have to be described in a general model with regard to domain and project specific aspects.

Besides the benefit for inter-organisational co-operation through a general model, the model can also be employed for process management. Therefore, the oftentimes existing implicit knowledge about the construction processes should be transferred into explicit knowledge and stored in formalised process modules. A first approach for the use of predefined processes for construction projects has been realised in the ICCI[1] project (Katranuschkov et al. 2004). Within this project a great number of construction specific tasks have been defined. However, the handicap of this approach is the concentration on the activity itself as an individual task, while the correlation with the project constraints is limited.

The aim of the paper is to present an approach for supporting inter-organisational construction project management. Therefore, the paper is structured in three sections: 1) presentation of an approach towards a common meta model for the definition of general construction project constraints. This meta model can be applied for the semantic interoperability between the construction project information and the business processes.

[1] Innovation co-ordination, transfer and deployment trough networked Co-operation in the Construction Industry

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2) demonstration of the applicability of proposed model for the use of predefined process modules.
3) discussion of a first realisation of the approach.

2 CONSTRUCTION NETWORK DESIGN

For an efficient coordination of the partner activities in construction projects, it is essential to define the objects that influence inter-organisational collaboration. Thus, there is a need for a common meta model for the specification of the project's boundary conditions. Such a *Construction Network Meta-Model* should be qualified to describe and manage project specific information, that are required for an efficient and coordinated project cooperation.

The development of such a meta model will be accomplished in two steps:

- Identification of the context that influences the performance of construction networks.
- Transformation of the identified context into classes, properties and relationships among them.

2.1 Identification of construction network constraint

Construction projects are defined as complex one of a kind projects. Thus, to derive a common meta model for collaborative construction project management its complexity has to be reduced by subdividing them into integral/coherent sub-projects or project views. Therefore, the entire project has to be decomposed into its controlling elements and structured in a reasonable manner.

Based on various sources, interviews and project analyses three key dimensions that control the project's performance have been identified, namely *Project Organisation*, *Project Structure* and *Project Information*. Each of these dimensions can be subdivided again into two or three categories. The dimensions and belonging categories are represented in figure 1.

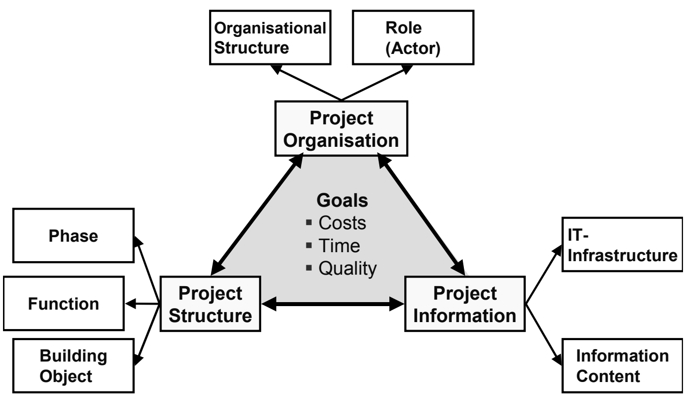

Figure 1: Dimensions and categories to structure construction project constraints

The dimension *Project Organisation* defines on the one hand the organisational structures within a project (e.g. 'general contractor' or 'joint venture'). On the other hand the roles (actors), necessary for the accomplishment of the project, are defined (e.g. 'project manager' or 'planner'). The decomposition of the project into different aspects is realised by means of the dimension *Project Structure*. The category phase divides the project into distinct, closed periods (e.g. 'planning phase' or 'construction phase'). The tasks necessary for the completion of a project are defined by the category function, whereas the category building object structures the project into spatial and/or physical sections. The dimension *Project Information* will define the IT-infrastructure and systems for inter-enterprise information exchange in a project, and will specify the information content that is exchanged between the partners. A more detailed description of the categories and their relations for the *Construction Network Meta-Model* is explained in Keller et al. 2004/2005.

Subsequent to the identification of the context, which influences the project development and the management of construction activities, common information for the dimensions and categories has been specified and classified. Description models for the representation of the categories have been developed based on several construction projects' analysis. In addition, common building data standards and technical regulations were evaluated for its applicability to describe construction project constraints.

2.2 Design of a Construction Network Meta-Model

The partial models of the categories identified in figure 1 have to be integrated into an overall model, the *Construction Network Meta-Model,* leading to a comprehensive specification of the constraints of construction projects. By means of this model the required information for collaborative project management is instantiated for a particular project and semantic interoperability between the categories is realized.

The general structure of the proposed meta-model is depicted in figure 2. In this model an interrelationship between the categories of chapter 2.1 has been established according to the requirements that have been identified in the projects analysis. The categories are represented by UML package diagrams to indicate that each package can be described in a more detailed way. These partial models will cover the requirements of each category.

The developed meta model will be capable to represent the following information for the management of construction projects:

- The definition of the building life cycle (phases) is the basis for the development of a construction project. Thus, the starting point for the construction network will be realised by the definition of the anticipated project phases on a general level (represented by a value chain).

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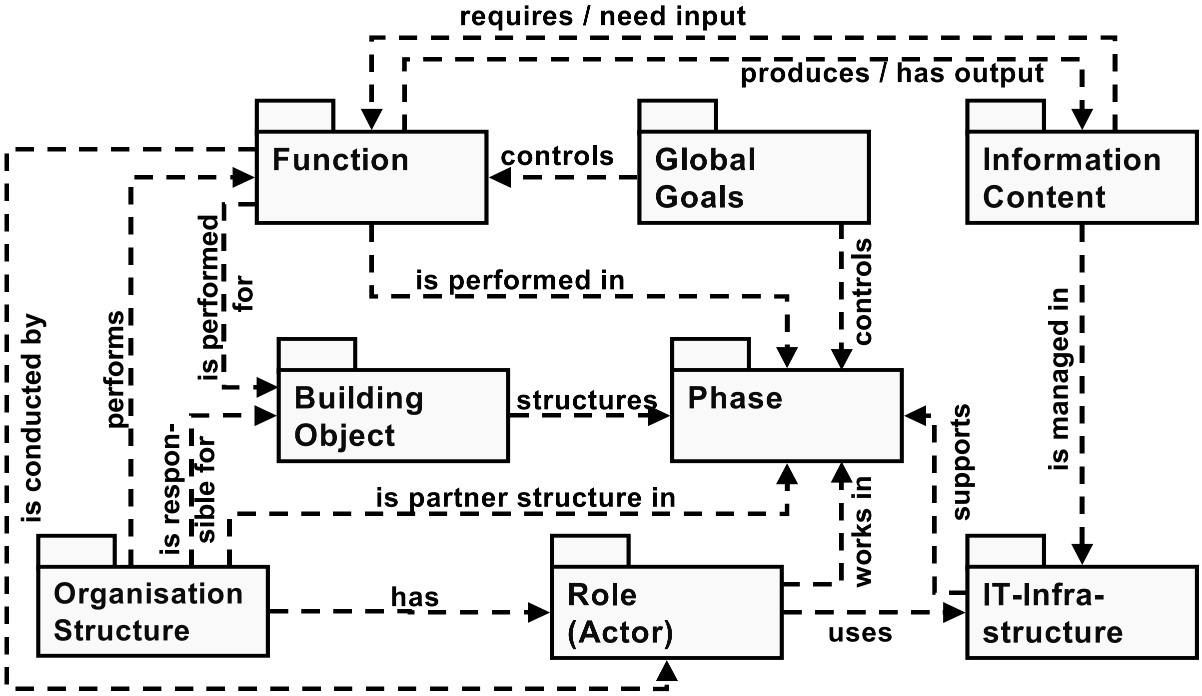

Figure 2: UML package diagrams of the proposed Construction Network Meta-Model

– Building objects provide the spatial and element structure of a construction. However, each phase can have its individual focus on the structure of the building objects.
– Functions are the activities that have to be performed within each phase. A sequence of functions creates dedicated building objects. One function can contribute to the creation of multiple objects.
– Global goals will be defined to control the performance of the functions within the different phases. Thus, a comparison of the nominal with the actual goals is feasible.
– A specific role is responsible for the conduction of several functions within a certain phase of the project.
– The category organisational structure specifies the type of the co-operation and the project partners. The partners of the organisational structure are linked with one or more phases. Furthermore, one or more partners of the organisational structure can implement different functions, are responsible for several building objects and have one or more roles.
– Information content describes the required input and produced output information for each function.
– IT-infrastructure specifies the global services and systems that support the different phases of a project. Each role can have access to the IT-infrastructure with dedicated rights. The information content will be managed by the IT-infrastructure.

For evaluation purposes the described *Construction Network Meta Model* has been partially implemented with the ontology editor and knowledge acquisition system Protégé[2] from Stanford University. By means of this editor the designed model can be exported as XML- or RDF-Schema[3] for further utilisation with other applications.

2.3 Instantiation of a Construction Network Meta-Model

In order to realise a construction network for a specific project, the classes and properties defined in the partial models have to be instantiated and the associations identified. The instantiation process is not performed randomly, but will obey certain legal, technical or organisational restrictions. Thus, the initialisation of a *Construction Network Instance* for a specific project can be controlled and supported by the employment of a sequence model. Such a model will assist the project partners to specify the content and relations of the different categories of the meta model in a structured manner. The employed sequence model should support loops, parallelism (AND-junctions) and restrictions (OR-junction). A more detailed description of a sequence model is given in Keller et al. 2005.

Figure 3 illustrates a simple example of a *Construction Network Instance*. The presented example has been developed with the Protégé system and displayed by its information browser Jambalaya. In this picture the arrows between the instances (grey rec-

[2] http://protege.stanford.edu
[3] Resource Description Framework Schema

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tangles) gives an impression about the various relationships between the objects, even in such a simple example.

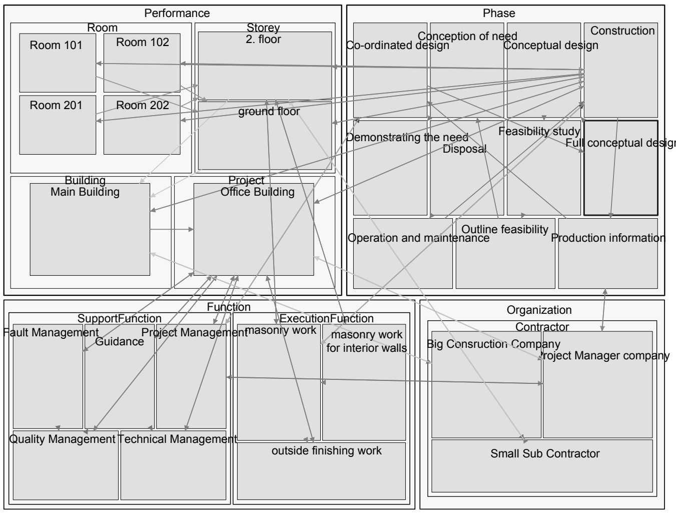

Figure 3 Construction Network Instance example

The realised *Construction Network Instance* can be stored in a common format, e.g. XML or RDF[4], to be accessible and manageable by a corresponding server. Thus, the *Project Network Instance* is an excellent knowledge base to perform various, complex queries on it. For example, it can be used for the identification of the responsible partner for a certain task at a building object (according to XSQL[5] notation):

```
<xsql:query> SELECT Organisation.Name
FROM ConstructionNetwork WHERE Project =
"Office Building" AND Floor = "second
floor" AND Function = "masonry work for
interior walls" </xsql:query>
```

3 USE OF CONFIGURABLE PROCESS MODULES

The specification of formalised business processes requires both, knowledge of the processes and knowledge of the modelling language. Thus, to preserve and reuse the generated knowledge the modelled processes should be stored in a reusable and coherent manner. Such reference information systems represent a special class of information systems. They are developed not only for one specific application context, but claim to be of general validity. The aim is to increase the economy of the information models by making the initial solutions available and adaptable. Thus they serve for the transfer of business knowledge.

In order to improve the access to the knowledge contained in reference processes, methods have to be developed, that support the adaptation of reference models for a specific application context [Becker et al. 2002]. The application context is represented by enterprise or project specific characteristics. The selection of the versions of the models will be conducted by means of these parameters.

Through the definition of a *Construction Project Meta-Model*, a standardised description for the project contexts has been achieved. Thus, the *Construction Project Instance* can be applied for the selection and initialisation of reference processes.

3.1 Design of a Process Module

Process modules are generally predefined for the performance of a certain bundle of activities and are adaptable for different project contexts. Each process module represents a logical element with distinct interfaces (Menzel 2003). These process interfaces are developed for a seamless integration of instantiated process modules into the existing workflow, defining all relevant input and output parameters.

Each process module will be identified by certain meta information that describes the parameters needed for its selection, initialisation and integration (e.g. project phase, organisation structure and output data). An example of a process module for construction processes is given in figure 4. The generic processes (modelled as an Event-Driven Process Chain) will be extended by parameters and information.

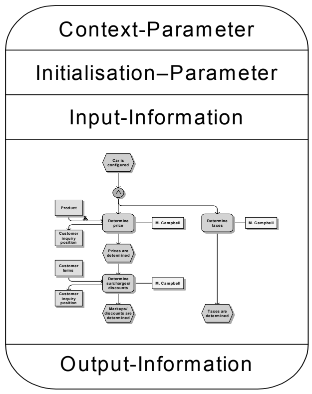

Figure 4: Process Module and its meta information

Context-Parameter define the situation required for the selection of a module

Initialisation-Parameter define the information that is needed for the customisation of a module for a specific project

Input-Information is the event/data, which is required to start the module

Output-Information is the result of a process module and thus the input for the succeeding process

3.2 Initialisation of a Process Module

In order to use the process module in a workflow management system they have to be transferred from the level of abstraction into the level of application.

[4] Resource Description Framework; W3C recommendation that defines a language for describing resources.
[5] combination of Extensible Markup Language (XML) and Structured Query Language (SQL)

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That means, the process has to be adjusted to the context of the specific project. The *Construction Network Instance* will provide the required information for the selection of the appropriate module.

> **Example:** The Construction Network Instance specifies the context (c): $c_1 = x_1$ and $c_2 = y_2$ (x_1 and y_2 are variables for the content of the context)
> A process module has the Context Parameters (CP): $CP_1 = \{x_1 \vee x_2\}$ and $CP_2 = \{y_1 \vee y_2\}$
> Thus, the Process Module is capable for the execution of the process.

The process instances can be expressed in a common modelling language like BPML[6]. Thus, different workflow management systems are capable for the execution of the process.

4 IMPLEMENTATION

For the verification of the proposed approach 'errors and omission (E&O) management processes' in the building industry have been analysed. The E&O management involves several organisations of different size and roles, comprises main and supporting functions and requires a detailed structure of the building objects.

At present the coordination of E&Os, in particular its documentation and inspection on the building site, is little supported by software applications. Differences in format are common. Thus, seamless information processing of the fault data should be realised by the employment of mobile devices (PDA) in cooperation with already existing IT tools.

The development of the showcase has been started with a project analysis and the description of its conditions. Therefore, building sites of heterogeneous structure and with different organisational types were examined.

4.1 A Construction Network to support fault management

According to the analyzed projects a *Construction Network Instance* to support fault management processes is in general characterised as follows:

E&O management processes are part of the construction phase of a project. A common organisational structure in this phase is the 'general contractor'. A feasible organisational model is depicted in figure 5. It is composed of three different types of partners: a) building owner, b) general contractor, and c) subcontractors. The building owner contracts the general contractor for the installation of the complete or major parts of the building. The general contractor itself is a consortium of two or more companies and will assign several subcontractors for distinct tasks. Each organisation will have its own internal structure. For fault management all companies have to establish the 'quality manager' role.

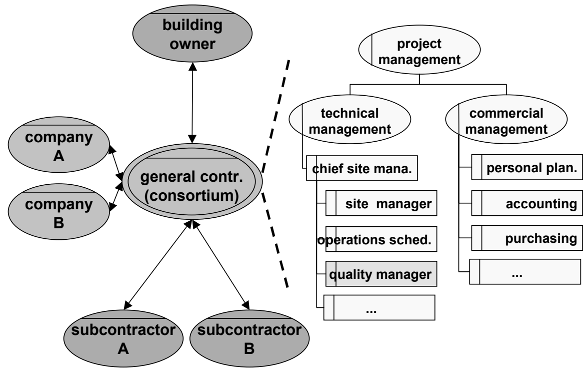

Figure 5: Organisational model

Each project is characterised by its individual structure for functions and building objects. This means that, the general contractor and his subcontractors have to conduct certain tasks (e.g. 'masonry works' or 'roofing') for specific items (e.g. 'interior walls in the basement' or 'roof of house IV'). These relationships will be described in the project specifications.

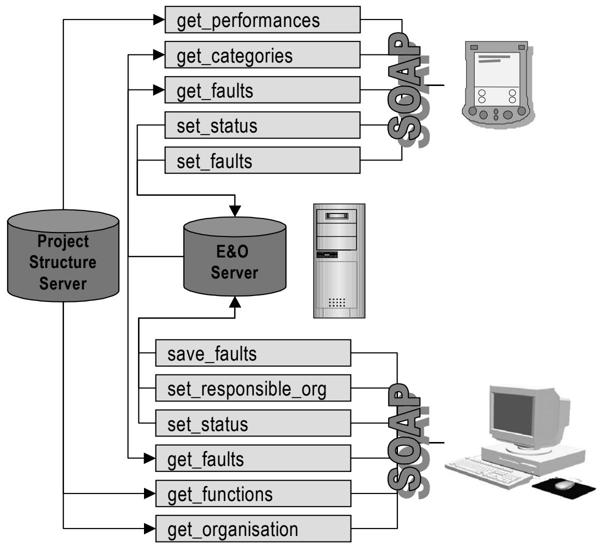

Figure 6: IT-architecture for 'E&O management'

For the management of E&O information a novel IT-infrastructure has been established. It will support the on-site E&O recording as well as its validation and management in the office. Therefore, the architecture indicated in figure 6 has been realised. Mobile and office application will access two servers that store the E&O and project information. Communication between application and server is realised by Web Services ('get' and 'set' functions in figure 6). Information exchange is handled by XML based SOAP messages. A data structure for the exchange of fault information has been developed.

By the use of Web Services different, already existing applications can be integrated into the fault management processes. Thus, each partner can participate in the project with its own application.

[6] Business Process Modelling Language

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4.2 Process Modules to support fault management

At present no standardised model for E&O management processes has been realised. Regulations are handled in a project-specific way. Thus, various fault management processes have been analyzed and combined into a general process model. Subsequently, the general process has been decomposed into coherent process modules based on the methods introduced in Hofer et al. 2005. For the identified modules the meta information described in chapter 3.1 were specified. For example the quality manager of the building owner or general contractor can conduct the 'fault recording'. A process module example is given in figure 7.

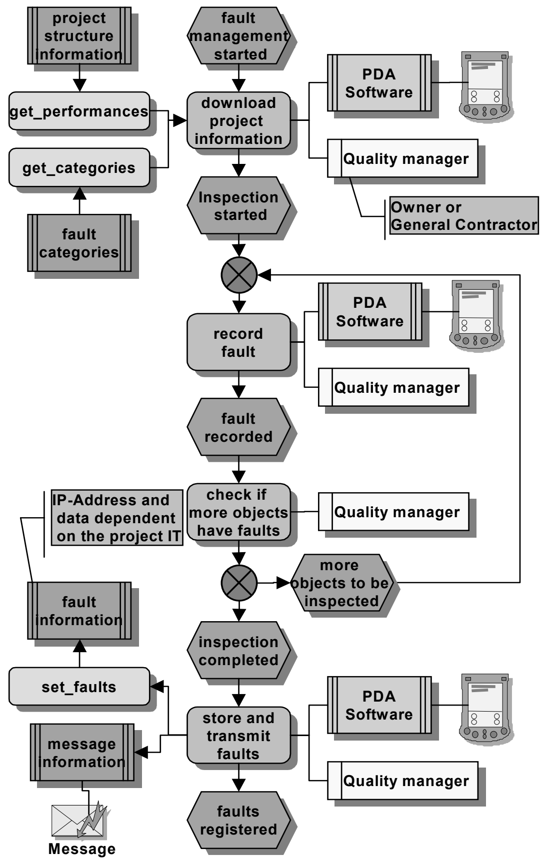

Figure 7: Process Module 'fault recording' (Event-Driven Process Chain)

For the above process module the identified meta information is:

```
Context Parameters
   Organisation Structure {General Cont.}
   Partner {Owner ∨ General Contractor}
   Role {Quality Manager}
   Phase {Realisation}
   Building Objects {all}
Initialisation Parameters
   IT-Infrastructure {Fault Server ∧ Pro-
   ject Structure Server}
   Information Content {Faults ∧ Mes-
   sages}
Interfaces
   Input {none}
   Output {Fault Notification}
```

For the instantiation of the process model it will be adjusted to the Initialisation Parameters and transferred into a common process execution language to be implemented in a workflow management system.

5 CONCLUSION

The aim of the paper was to present an approach for the support of inter-organisational construction project management. Therefore, a potential meta model, the *Construction Network Meta Model*, has been introduces. This model provides a schema for the definition of construction project specific constraints. It can employ various sources of reference data for the instantiation of a project specific *Construction Network Instance*. Such an instance can be used for the selection and initialisation of predefined process modules. Process modules are generally defining the activities necessary for the performance of a certain bundle of functions. Specific parameters and information have been identified to adapt the process modules for the context a certain project.

A common construction specific process, the E&O management process, has been analysed and qualified for the verification of the approach developed. Therefore, the required project context has been identified and the general process has been decomposed into coherent process modules.

This work has been conducted within the scope of the project 'Architecture for Collaborative Systems' (ArKoS). Within this project an holistic architecture for the management of inter-enterprise cooperation in construction is developed (Zang et al. 2004).

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Active process model supported collaboration

T. Cerovsek
Chair of Construction IT, University of Ljubljana, Slovenia

P. Katranuschkov
Institute for Construction Informatics, Technical University of Dresden, Germany

ABSTRACT: We discuss the reuse of process knowledge through conceptualized workflow patterns. Knowledge reuse in the life-cycle of projects has been widely studied, but most known solutions focus on communication issues, isolated from the processes themselves. Due to the huge potential benefits from the immediate reuse of communicated information (e.g. architectural, structural solutions, details, technical specifications, etc.) most of the attention has been given to information retrieval techniques and contextualization of the retrieved information. Actual processes, actors and tools that have led to results of work usually remained unrecorded, since this was considered technically impossible. Indeed, in contrast to intuitive ad-hoc reuse of parts of documents that fit into a given context, ad-hoc reuse of parts of actual processes together with meta-descriptors is not so straightforward. In the paper we identify the methods and media in which processes were modeled and executed as the main problem to achieve this goal. Based on analysis of process modeling techniques, we suggest a novel methodological approach and a conceptual solution for a prototype collaboration system supported by active process models.

1 INTRODUCTION

Knowledge reuse in the life-cycle of projects has been widely studied. From the process perspective we can divide knowledge into two main categories: (1) knowledge about processes, and (2) process results as containers of knowledge. Currently, most known solutions address the reuse of knowledge that is communicated through different traditional and digital communication channels – isolated from the processes themselves. Due to the huge potential benefits from the immediate reuse of communicated information (e.g. architectural, structural solutions, details, technical specifications, etc.) most of the attention has been given to information retrieval (IR) techniques and contextualization of the retrieved information. However, reuse of *all available* knowledge is the key to efficient dynamic decision making (DDM) of project teams. Gonzales (2005) aggregates three definitions of DDM: (1) the need to make multiple and interdependent decisions in an environment that changes as a function of the decision maker's actions, in response to environmental events, or in both ways, (2) real-time decision making – time constraints become an important performance determinant, (3) dynamical complexity – time delays and decisions that positively or negatively influence one another in complicated ways overtime. In this paper we focus specifically on the reuse of *process knowledge* by means of conceptualized process patterns.

1.1 *Problem Statement*

In contrast to intuitive ad-hoc reuse of parts of documents that fit into a given context, ad-hoc reuse of parts of actual collaborative processes with meta-descriptors is not so straightforward. We identify the methods and media in which processes were modeled and executed as the main problem and barrier to achieve this goal. In the past different process modeling techniques have been used to describe or prescribe the way processes were, or should be carried out (GANTT, PERT, IDEF0, UML, Process Matrix). On the other hand, actual (instance) processes, actors, and tools that led to real-world results of work – or have been used in communication – usually remained unrecorded. Consequently, support for DDM in ad-hoc AEC teams is yet quite insufficient.

1.2 *Hypothesis*

Web-mediated collaboration provides a new media for collaboration-oriented process models. We call these *active process models* (APM). We argue that processes can be improved through the utilization of *conceptualized workflow patterns,* and supported by a APM enabled, decentralized collaboration platform.

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2 RELATED EFFORTS

The study of related efforts is focused on the use of process models in collaborative environments. It is based on taxonomies for qualitative and quantitative classifications of types of collaboration, and process modeling. Identified taxonomic views provide a framework for ontological analysis, and are used for AEC-focused review with emphasis on business intelligence and process mining.

2.1 *Collaboration Taxonomy*

Collaboration in AEC is noticeably different from joint intellectual endeavors in other industries. Kalay (2004) uses the term “multi-organizational teams” and depicts the following exceptionalities of AEC teams: individuals representing often fundamentally different professions, perforce, hold different goals, objectives, and even belief system. Collaboration is by definition not possible without teamwork, and so are views for taxonomies (Table 1).

Table 1: Views for collaboration taxonomies. For detailed taxonomies of tools see (Cerovsek & Turk 2004).

View	Qualitative	Quantitative
Location	Same, Different	Number of Locations
Time	Syn. & Asynchronous	Date & Time, Duration
Group	Type of group	Size (# of Members)
Teamwork	Form, Storm., Norm, Perf.,	Dynamism, # of Teams
Processes	Type of processes	Time, Money, Resources
Information	Type of information/know.	Quantity (# of records, Mb)
C. Channel	Type of media/message	Number of channels
Interaction	Comm., Coordinat., Collab.	Modalitiy, Devices

Collaboration can be characterized by a *Collaboration Circumference*. An example based on the Process Matrix approach (Katranuschkov et al. 2004) is shown on figure 1, where radial directions represent task frequencies for specific roles.

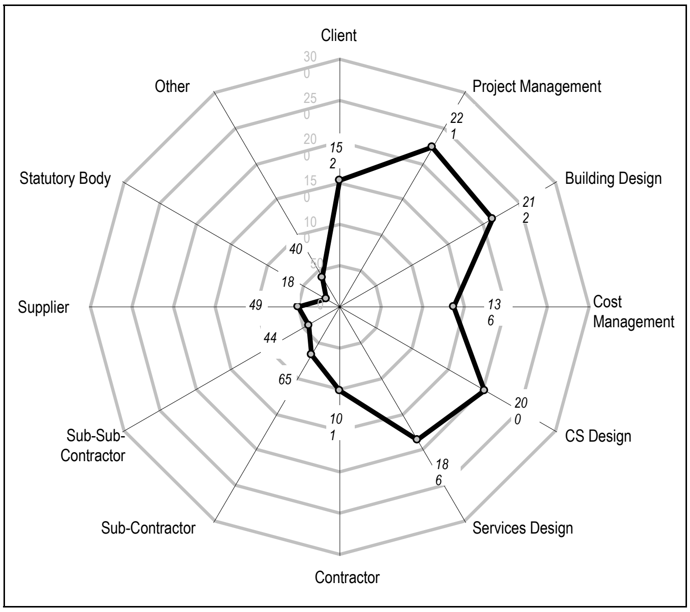

Figure 1: Collaboration circumference: involvement of different roles in communication during project life-cycle.

2.2 *Process Modeling Taxonomy*

A more complete process modeling taxonomy should address several interrelated issues, answering the questions: why, what, who, for whom, where and how? Some of the corresponding views are listed in table 2 below.

Table 2: Views for taxonomies of process models.

View	Qualitative	Quantitative
Purpose	Planning, Education, BPR …	Range of use, and ways
Basic types	Meta, Conceptual, Customized, Workflows	By type of quantities addressed in process model
Media	Active, Passive	Communication channel
Coverage	Ontological concepts	# concepts covered
Used by	Man, Machine	Single, Group, Network
Decision making	Recognition, identification, criteria, proposing, evaluating, making final choice	# of Problem parameters, Resources, Time, Criteria Taxonomy, etc.
Process groups	Initiating, Planning, Executing, Controlling, Closing	Time, Resources, Dependencies, Roles, etc.
Representation	Graph Based: Arrow Diagramming Methods, Conditional diagramming, Swim lanes, Matrix, Text-based	Single, Multiple representation methods, and ability to represent diff. quantities and ontology concepts

Each view is important for a specific perspective, and there is no universal view that corresponds to all possible aspects of process models (Cerovsek, 2003). We address below some *combined views* that are important in the focused context. More detailed explanation of views and corresponding qualitative and quantitative classifications is out of the scope of this paper.

Although several research efforts have been focusing on modeling of processes with the purpose of process reuse, most conceptual process models were modeled on paper, or as digital files, without any dynamic and/or enactment power on actual processes. The strength of such *passive process models* is mainly in their descriptive nature and conceptuality – meta descriptions improving overview, control, understanding and communication about the processes themselves. On the other hand, several *enactment enabled process models* have been studied and prototyped, usually in the form of workflow models. Such models – typically embedded into virtual working environments such as collaboration software or expert systems – operate on concrete tasks, actors and times. These models have two drawbacks: they do not provide conceptual descriptions as well as dynamicity, and they are mainly intended for machine and not for human interpretation.

A suggested taxonomy for the classification of second generation process modeling languages for software engineering divides process modeling languages into five categories (Zamli & Le 2001): (1) Modeling support covering ability to represent concurrency, artifacts roles, tools, communication mechanisms, (2) Enactment support, (3) Evaluation support with “enactment data” (4) Evolution support, and (5) Human dimension support, i.e. understandability. The next section provides more detailed evaluation of the coverage of ontological concepts.

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2.3 *Process modeling for AEC collaboration*

Björk (1999) divides processes in general into material and information processes. The focus of this section is on the latter – information processes that are carried out in virtual environments. The main purpose here is to provide process modeling support for collaboration in AEC. To achieve that, we need to study both collaboration activities in AEC, and how to model corresponding processes. As a starting point two developments are used:

1 The *Process Matrix approach* (Katranuschkov et al. 2002, 2004) – used as a foundation for the study of AEC collaboration.

2 *Bunge-Wand-Weber* (BWW) analysis of 12 different process modeling techniques with focus on ontological completeness (Rosenmann et al. 2005) – used for the selection of criteria for the description of process models.

2.3.1 *Process Matrix*

The approach termed 'process matrix' was developed in the frames of the EU ICCI project and further extended in the prodAEC project. It provides for the definition of a multi-dimensional matrix capturing the classification of roles, activities and communication, together with their inter-relationships within building construction. The matrix is designed in accordance with two main objectives: (1) to provide a suitable form for database management as well as web-based presentation and processing for the support of AEC collaboration, and (2) to improve the capabilities for information capture so that various analyses can be easily performed and reported, as and whenever needed.

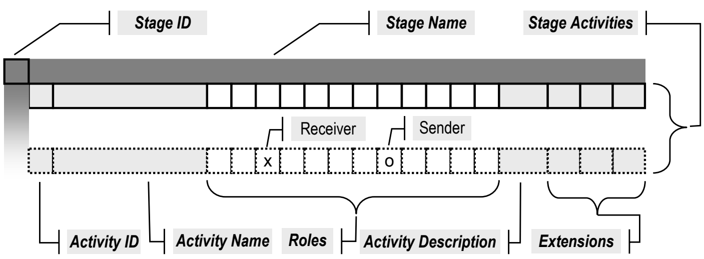

Figure 2: Process Matrix with extensions. For each extension, a separate table is specified and linked to the basic matrix via the Activity and Extension IDs.

From end user viewpoint the Process Matrix appears as a simple table that brings all stored information concerning a reference process together in one line. This approach has been adopted because experience shows that industry end users are not particularly familiar with formal modeling notations. However, they are familiar with, like, understand and respond to the tabular approach of the Process Matrix. To enable adequate capture of the data associated with an AEC process, three extensions of the basic matrix are provided: (1) *Information Requirements Extension* covering data model and data content, (2) *Communication Requirements Extension*, covering the technical aspects of communication described by communication model, communication method and exchange format, and (3) *Standards extension*, covering formal or ad-hoc standards to be applied to a process such as building codes and regulations, use of classification system for construction related information, exchange format, schema, network topology etc.

2.3.2 *Bunge-Wand-Weber*

BWW is a comparative meta ontology for Information Systems and System Analysis and Design. It consists of four elements that can be used to structure a framework for the research: (1) conceptual modeling grammar – a set of constructs and their construction rules, (2) conceptual modeling method – a procedure by which the grammar can be used, (3) conceptual modeling script – the product of the conceptual modeling method, and (4) context – the setting in which the modeling occurs.

Respectively, to assure improvement of process modeling for collaboration the study should include process capturing, modeling language, ad-hoc-ness, and model reuse.

Collaboration process capturing. Several modeling techniques have been used in order to support process capturing, but not activities in real-time. Ontological analysis showed that this is the least supported concept covered in only 8% of all known techniques. Capturing should be enabled by communication channels used in collaboration.

Comprehensiveness of modeling language. The comprehensiveness of a modeling language can be expressed through ontological analysis, since the plethora of process modeling languages (PML) currently in use for different purposes offers very diverse coverage of ontological concepts. The most comprehensive BWW analysis addressing expressiveness of PML was done in (Rosenmann et al. 2005). From ontological perspective ebXML is the most comprehensive process modeling language system.

Ad-hoc-ness support. Several applicable examples exist in the field of scientific collaborative environments – scientific workflows characterized by ad-hoc-ness and incompleteness, partial re-use, abandon/rewind and dynamic modification, tracing of individual processes, specification from case. Several other approaches have been used in practice-oriented Decision Support Systems (DSS). To facilitate teamwork, group-oriented support systems (GSS) have been implemented e.g. for code inspection meetings.

Process model reuse and improvement. A rather basic, but representative example are Network Templates – a well known concept used to expedite preparation of project network diagrams. Another important example are low-fidelity process models which specify nominal order of tasks but leave actors free to carry out their activities as their expertise and the situation dictates. This approach is grounded on three

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main components: (1) process specification based on low fidelity process models, (2) a distribution process deployment and execution mechanism for enacting low fidelity process models, and (3) a virtual repository of artifacts providing access to distributed physical repositories related to the current work.

Table 3: Overview of process modeling technologies for collaboration.

Feature	Candidate process model
Capturing	ASME diagram, ebXML, DFD, EPC, UML, Process Matrix
Comprehensiveness	ebXML, BPMN, UML, PetriNets
Ad-hoc-ness	ebXML, IDEF0, BPEL4WS, BPMN , DFD, EPC
Reuse and improve	IDEF0/IDL, PetriNets, ebXML, GPP, Process Matrix, Matrix of Change, DSM (Design Structure Matrix)

2.4 *Process centered business intelligence*

Process centered business intelligence (PCBI) refers to the web-mediated tools integrating three inter-related components for effective collaborative problem solving in virtual environments:

(1) business intelligence with data mining,
(2) process mining techniques, and
(3) real-time decision support systems (DSS).

The envisioned features of PCBI are illustrated through definition of components and exemplary applications.

Business intelligence (BI) generally refers to the process of transforming the raw data companies collect from their various operations into usable information (Quinn, 2003). Since data in its raw form is of fairly limited use, companies are increasingly electing to use business intelligence software to realize their data's full potential. BI software comprises specialized computer programs that allow an enterprise to easily aggregate, manipulate, and display data as actionable information, or information that can be acted upon in making informed decisions. BI is a broad category of applications and technologies for gathering, storing, analyzing, and providing access to data to help enterprise users make better business decisions. BI applications include the activities of decision support systems, query and reporting, online analytical processing (OLAP), statistical analysis, forecasting, and data mining (whatis.com). The information – as a candidate for mining processes in the context of construction projects is very diverse: from CAD data to Schedules and technical specifications. Thus, the traditional understanding of BI was limited mostly on knowledge produced as process results and not on processes themselves. Process Centered Business Intelligence (PCBI) extends this traditional approach through process oriented analysis. Additionally, these methods should be supported with analyses of product models.

Process Mining (PM) refers to techniques and algorithms used for mining of raw process data such as workflows and audit trails as well as conceptual models. Typical examples include pattern recognition by Dependency/Frequency Tables (DFT) containing frequencies of different tasks individually in relation with their predecessors, successors and causality (Weijters & Aalst 2001). A DFT table can be successfully applied for semi-automatic generation of process models, but not for conceptualization. Process mining techniques are also used in the field of bioinformatics – for discovery of structured multidisciplinary care plans. Lin et al. (2000) have developed a process mining technique for mining time dependency patterns for discovery of clinical pathways. The solution to these problems can be applied to the problem of providing support for DDM in the context of AEC. The uniqueness of the solution is in the algorithm for analysis of directed acyclic graphs where vertexes represent time and nodes transition between times.

Decision support systems (DSS) are an important part of PCBI. They combine both BI and PM as well as other methods. DSS for individuals are well established, in contrary to group (or intra-organizational) decision support and inter-organizational DSS which are not widespread. An interesting example of inter-organizational DSS is the emergency collaboration platform ENSEMBLE developed at ISPRA (Bianconi et al. 2004). It combines the following three features: (1) simulation through forecasting using different models, (2) spectrum of different scenarios that affect the decision making process, and (3) multi-national and multi-institute collaboration. ENSEMBLE provides an effective, web-based solution of multi-institute collaboration for long-range transport and dispersion forecasts in the event of release of radioactive material. The principles of the developed system could serve to any type of problems that require real-time consultation of large amount of information produced by a number of remote sources and tools, since it provides accessibility to several model results and real-time verifications of the models' quantitative and qualitative predictions.

Recent innovative techniques in civil engineering real-time support systems come from transport management (Zografos et al. 2002, Tavana 2004). In (Hernandez & Serrano 2000), a framework for application to real-time traffic management is suggested – intelligent system based on reflective knowledge model for human-computer-interaction with three classes of questions especially relevant for decision support of effective systems, i.e.: (1) "What is happening?" (2) "What may happen?", and (3) "What should be done?". The core of the system is a reflective architecture where a meta level layer dynamically configures reasoning strategies.

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Developed DSS can be measured by effectiveness (output of DSS) and efficiency (best possible use of resources), and can vary in complexity. An evaluation method according to steps of decision making is described in (Phillips-Wren et al. 2004), and a methodology for defining, modeling and measuring complexity is described in (Coskun & Grabowski 2001). The latter addresses Embedded Intelligent Real-Time Systems (EIRTS) which are introduced into safety-critical large scale systems to improve the system's reliability and safety, and to reduce the risk of accidents or mishaps. EIRTS are interesting since they exhibit characteristics of embedded systems, intelligent systems and real-time systems, show how to communicate with larger systems, process data and produce results based on intelligence, and complete their work in real-time. The developed metrics includes: (1) Architectural / Structural Complexity, (2) Data Processing / Reasoning / Functionality Complexity, and (3) User Interface and Decision support / Explanation complexity.

3 FRAMEWORK FOR REAL-TIME PROCESS REUSE

We define joint functioning of tools as integration and joint functioning of people as collaboration. Real time process reuse in virtual environments addresses both at the same time. Figure 3 below schematically illustrates the enabling framework in IDEF0. It contains the following main activities related to the process models: acquisition, mining, conceptualization, use, and usage analysis.

3.1 *Active process modeling*

Active process modeling (APM) is "*the process modeling for real-time collaboration*", since it aims at providing support for real-time enterprise collaboration. Snowdon (1995) was the first to make a distinction between passive models, active models that are passive, and active models. Warboys (1999) further defined an active model as the one constructed in a modeling medium which allows the modeling relationship to be maintained, even though elements of the subject may change. APM is characterized by:

- *Enactment.* The model actively affects the behavior of its subject system.
- *Adaptability.* The model actively changes in response to changes in its subject system.
- *Learn-ability.* The model has the ability to learn from the processes.
- *Predictability.* The model is capable to predict activities based on history of captured processes.
- *Interoperability.* The model and/or its parts are reusable and interoperable (according to Webster: interoperability = ability of a system - as a weapons system - to use the parts or equipment of another system).

These characteristics make from active process models real-time process-centered information management tools that enable real-time capturing, reuse, conceptualization, customization, later reuse, as well as improvement of processes through their process models.

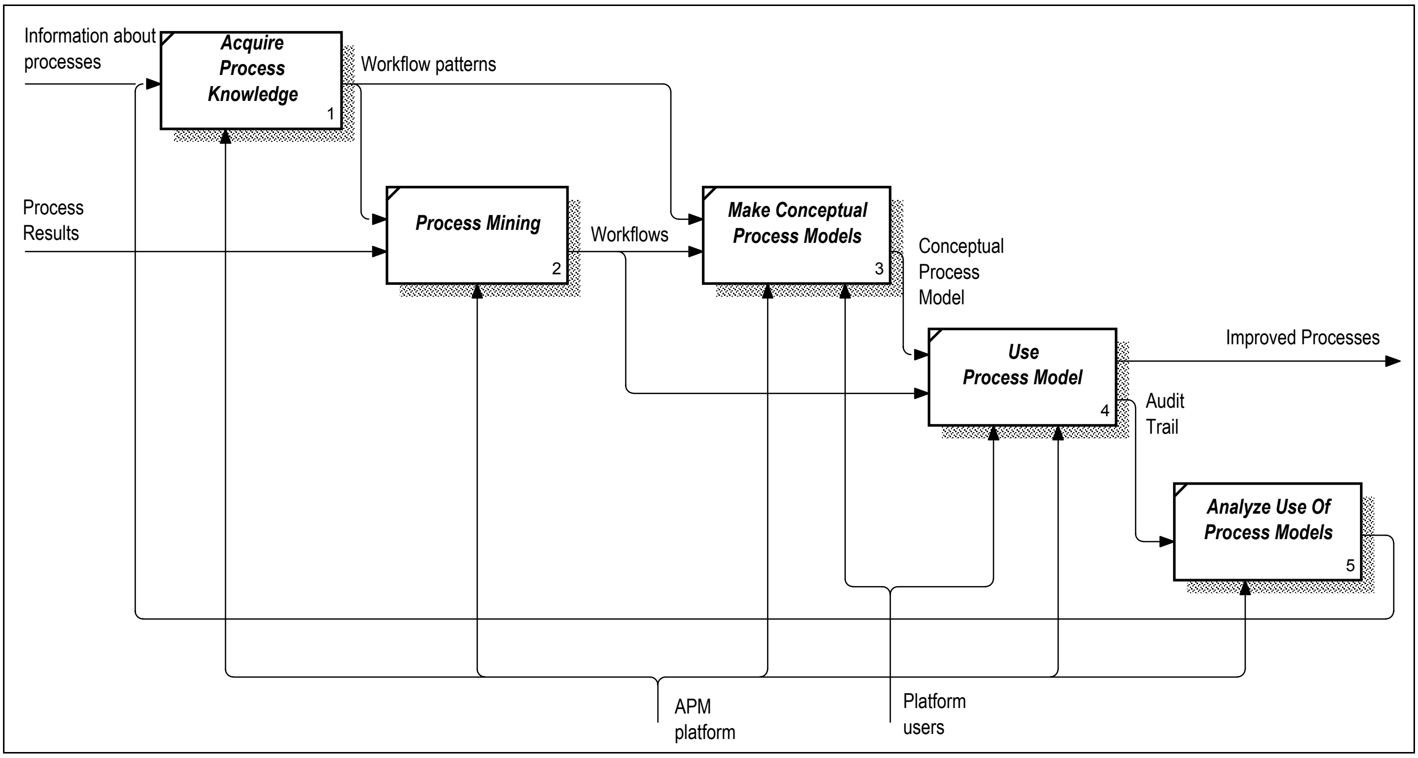

Figure 3: Simplified Framework Process Model for Active Process Model (APM) Supported Collaboration.

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Active process models can also provide a bridge between the two types of models using automatic analysis of workflow patterns. This can be enabled by: (1) the media in which processes are modeled, (2) the workspaces in which processes are carried out, and (3) the real-time paradigm of collaboration used. Moreover, active process models offer support in all stages of problem solving, and therefore enable:

- easy recognition of problems,
- identification of objectives,
- establishing criteria,
- gathering data,
- adequate provision of possible workflow patterns,
- enactment of selected processes.

One of the most important aspects of active process model systems is the combination between conceptual models and concrete, enactable process models, i.e. workflows.

3.2 *Conceptualized workflow patterns*

According to the taxonomy outlined in section 2.2, we can use process models at different granularities – from workflow models to conceptual process models. *Conceptualized workflow patterns* provide mapping between different models through simplified views of processes represented for a specific purpose. Conceptualized workflow patterns are therefore defined by history and purpose. Different models can be used interchangeably – workflows, events chains, cause-effect, IDEF diagrams etc. Diversity in representation granularity is among the main advantages of an APM framework, it provides both conceptual and dynamic, run-time modeling support. An example for the individualization of a generic process model is demonstrated in (Scott & Schachter 2005).

4 SUGGESTED APM PLATFORM

In this section a prototype APM platform is suggested on the basis of the above considerations, the anticipated user needs, the goals to be achieved, and technological and technical requirements. Upon that a generalized ICT architecture is outlined and an example based on Groove is given to illustrate the idea on more practical terms.

4.1 *User needs and goals*

With regard to the user needs and goals the platform should provide:

- infrastructure for rapidly establishing interdisciplinary ad hoc teams, aligning different stakeholders and tools to pull required discipline and project knowledge,
- instant team-focused communication infrastructures enabling real-time communication and collaboration,
- easy combination of projects' internal and external roles through collaboration and interoperability among the stakeholders, as well as their enterprise networks,
- pervasive information availability, i.e. team-specific access and retrieval of relevant information from all life-cycle phases and related enterprise networks,
- capabilities for mobile teamwork, particularly considering requirements of safety@work, and life-cycle management tasks such as monitoring, maintenance, re-design, etc,
- capabilities for training and learning of new practitioners,
- simple access to data; efficient Human–Computer interaction is the key for successful implementation of such environments.

4.2 *Technological and technical requirements*

Various technological and technical requirements need to be considered in the development process as follows.

Technological requirements include:

1 Consideration of hybrid decentralized environments: since different collaborative environments require different modality it is essential that different collaboration environments are supported.
2 Balanced use of Push and Pull Technology.
3 Platform independence with open API.
4 Provision of a software infrastructure that:
   - is highly generic and re-usable in any context of one-of-kind industries and services,
   - is ontology-based, to enable the semantic interoperability of the involved business services,
   - can wrap up heterogeneous information sources including external legacy applications,
   - supports the dynamic on-demand creation, management, and control of sustainable teams of different stakeholders,
   - provides for fast, ad hoc creation of workflows focusing on the specific team-oriented tasks on the basis of project-wide knowledge, local context and pre-defined process templates,
   - enables adequate consideration of late client requirements and the subsequent change management.

Technical requirements include:

1 Federated identity management: techniques allowing users to utilize personal(ized) information across systems.
2 Security services: all five basic security services must be enriched, with special attention to confidentiality.

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3 Process information retrieval: provision of mechanisms that enable information retrieval techniques to be used in the framework of processes.
4 Traceability of interconnected processes.
5 Information characterization by type of process.
6 Extended presence awareness with activity awareness.

4.3 *Prototype architecture*

The suggested high-level architecture of the system is divided into four main, dynamically linked layers (figure 4):

1 *Knowledge layer* with two sub-layers representing a) knowledge about processes, and b) process results as containers of knowledge.
2 *Tools and services layer*, providing utilization of specific user needs during collaborative activities.
3 *Organizational layer*, containing different intra-organizational schemes matching the project specific organizational scheme.
4 *Project layer*, providing project-related linkage between the other components.

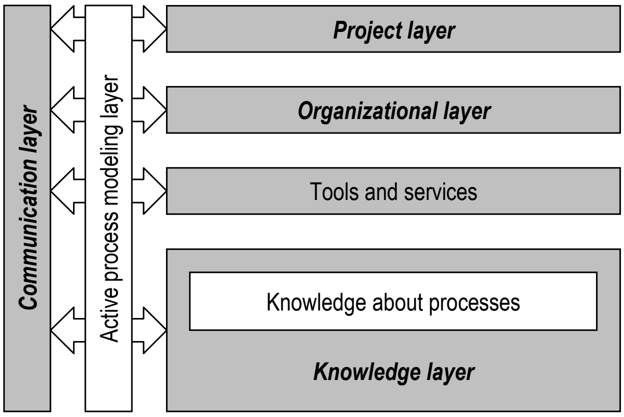

Figure 4: High level APM architecture.

These components are combined through different communication channels and supported by APM features.

For rapid prototyping purposes we have used the *Groove* peer-to-peer collaboration software (www.groovenetworks.com). Groove offers several of the required functionalities: real-time communication with presence indicators, instant messaging, customizable shared space which enables users to select and adjust tools according to the specific needs of the project. Groove also embeds *Groove Web Services* that enable Groove Workspace components to be Web services providers. Another important characteristic of Groove is its decentralized architecture which allows seamless integration of the peer-to-peer and client-server paradigms. The screenshot of the prototype on figure 5 illustrates the use of conceptual process models which are represented in the form of hypertext. These process models could be located anywhere on the Web and could be generated dynamically.

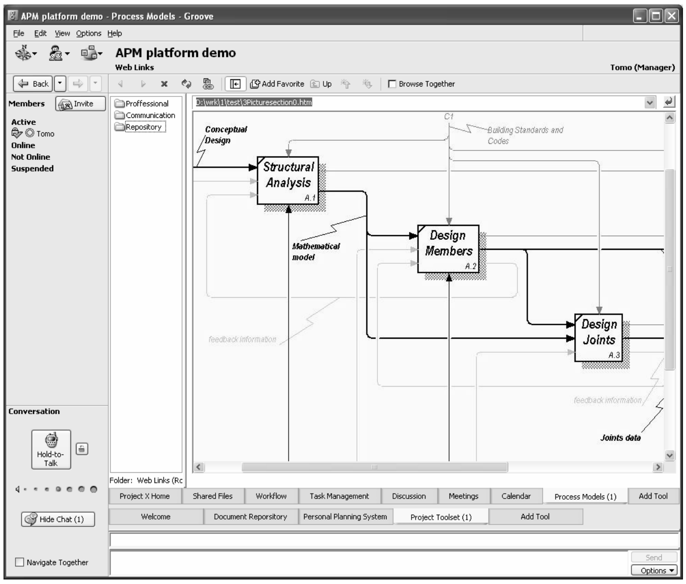

Figure 5: Prototype test bed implementation.

5 CONCLUSIONS

Support for improvement of ad-hoc problem solving in AEC collaborative environments is not yet well established. This could be improved through ad-hoc reuse of parts of processes, i.e. knowledge about prior processes. In the paper we gave an overview of relevant techniques and suggested a framework for further developments. The suggested approach has two major innovative aspects:

1 *Active process model supported platform*.
This can be characterized by:
- combined use of two paradigms: a) data centered, and b) process centered, that are used in real-time,
- flexible, variable modeling media in which processes are modeled and in which models are used, thereby leading to a hypermedia active process model,
- infrastructure supporting real-time paradigm.

2 *Enabled diversity of process models*.
The approach combines several process modeling techniques providing:
- coexistence of process models of different granularity – from event process chains and workflow models to conceptual process models,
- coherent use of conceptualized workflow patterns: repeating patterns can be used to generate conceptual process models,
- customized process models: conceptualized process models can be customized for specific purposes using specific representation formats.

Techniques supporting such kind of platforms need to include different PCBI-related components, such as data mining, process mining, and adequate real-time decision support. However, whilst the first

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two are highly generic and therefore readily reusable, the latter is tied to the targeted business domain.

Finally, it is important to emphasize two further aspects: (1) Learning and (2) Business Process Re-engineering and controlling capabilities.

5.1 *Learning - APM's facilitating factor*

It is essential to be aware of the potential of APM platforms for improvement of organizational learning. Each recognizable process should be considered as learning process. Two of the most important facilitating factors for adoptions of APM supported collaboration are:

1 *The platform should support organizational learning*. This means that it should evolve towards a knowledge platform providing information on (1) knowing what, (2) knowing why, (3) knowing how, and (4) knowing who. The APM platform could be exceptionally effective in providing information about knowing how – since process models directly address such kind of knowledge.

2 *Conceptual process models facilitate learning.* Generic processes that are either automatically conceptualized workflow patterns or ad-hoc conceptual process models can be considered as very strong teaching tool.

5.2 *Future Work - critical success factors*

The presented research is on-going work that is still in an early stage. Planned future developments can be subdivided into three directions:

1 *Process centered business intelligence*. Provision of business intelligence for product models covering the development of algorithms as well as other relevant technical data using OLAP and other text and data mining techniques. Here especially methods for defining process similarity are of interest. Hence, canonical forms should be more developed.

2 *Human-computer interaction*. Study of suitability of different process modeling techniques and their representation for use in digital media for different purposes.

3 *Study of adoption factors*. Adoptability of new ways of working is another aspect that requires detailed consideration – facilitating factors and critical success factors *need to* be established.

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Versioning structured object sets using text based Version Control Systems

B. Firmenich & C. Koch
CAD in der Bauinformatik, Bauhaus-Universität Weimar, Weimar, Germany

T. Richter & D. G. Beer
Informatik im Bauwesen, Bauhaus-Universität Weimar, Weimar, Germany

ABSTRACT: With the availability of an affordable and ubiquitous network environment the distributed cooperation of projects can be supported by computer software. Currently, the degree of support of a distributed cooperation is very different in the diverse classes of applications. While in the field of text-based applications the synchronous distributed cooperation is already state-of-the-art, the users of document-based applications can currently only cooperate asynchronously in terms of a workflow by exchanging documents. This contribution describes a solution approach for the re-use of existing document-oriented applications in net-distributed processes. The synchronous cooperation is realized by a novel procedure that stores the structured object sets of existing single user applications in version control systems, where the well proven tools of the software configuration process can be used in distributed construction planning processes as well.

1 INTRODUCTION

The construction planning process is characterized by the synchronous cooperation of a distributed team that develops a joint solution – the building instance. In practice, document management systems (DMS) are frequently used in this process to control the access and the workflow of the documents of single user applications.

Although the planning process has a lot in common with the software development process, DMSs are almost completely irrelevant in the software development process. Instead of that, cooperation in a software development team is controlled by version control systems (VCSs).

The kind of cooperation between a DMS and a VCS is completely different: While the former only supports the asynchronous cooperation the latter enables a true synchronous cooperation, either parallel or reciprocal (Fig. 1, Bretschneider 1998).

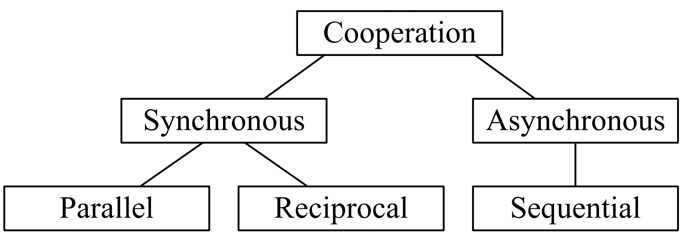

Figure 1. Classification of cooperation according to time

The goal of this contribution is to close the gap between these two worlds and to allow the tool-based VCSs to be used in conjunction with existing single user applications in the distributed planning process.

2 STATE-OF-THE-ART

It is distinguished between document based and text based applications. For these two application classes the local and the net-distributed processing are outlined according to the state-of-the-art.

2.1 *Document-based applications*

According to the state-of-the-art only applications that deal with structured object sets are considered (Fig. 2). The objects can only be accessed in the process that created them. Therefore, the object set has to be stored persistently in a document before terminating the process. Other processes can later reconstruct the transient object set via the contents of the document. Typical examples of document based applications are word processors, CAD and FEM programs.

Currently, a net-distributed cooperation of document based applications is enabled by a DMS (Fig. 3). A DMS manages documents of any format. Relationships between objects in different documents cannot be supported since the semantics of the document content are generally not known to the DMS. The goal of a DMS is the support of the workflow on the basis of a shared document pool. If a

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team member wants to edit a document a copy of that document is transferred to the user's local file system. When the editing process is completed a new copy of the document can be stored and published in the shared document pool.

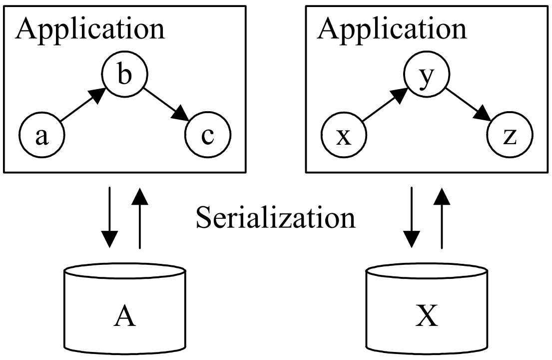

Figure 2. Document-based applications

Because existing applications tend to become increasingly complex the stored documents have a considerable file size as well. Differences between documents are not stored explicitly in a DMS. The users have to localize, visualize and merge differences by the help of very complex tools.

A DMS supports the asynchronous cooperation of a team where in general the tasks must be performed in sequential order. However, since no relationships exist between objects in different documents a restricted parallel cooperation is possible.

The DMS solution has the advantage that arbitrary document based applications can be integrated without any program adjustment.

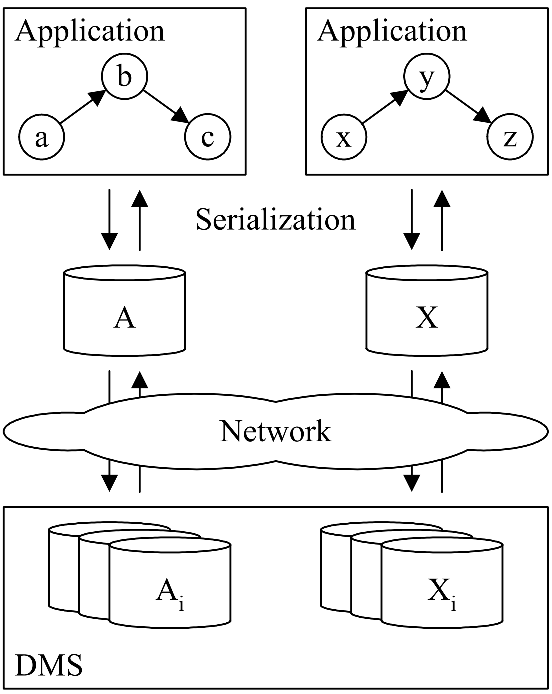

Figure 3. Document Management System (DMS)

2.2 *Text-based applications*

Text based applications are found in the software development process where the source code is stored as plain text in files. Figure 4 shows how the source code is managed by text editors.

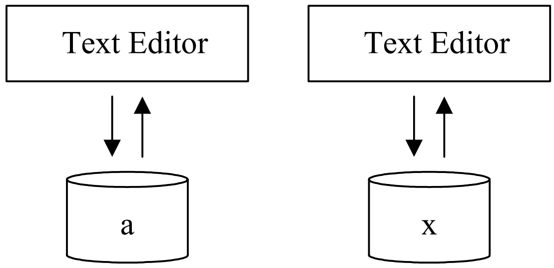

Figure 4. Text-based applications

In addition to the text editors many other tools for the processing of text editors exist. The availability of many tools is typical for a text based environment. The discipline of software configuration management (SCM) deals with the process of creating complex software systems. Figure 5 shows how the distributed software development process is supported by a VCS. Since the syntax of the file content – plain text – is known to the VCS many useful tools like *diff* and *merge* are available.

A VCS typically manages a multitude of different versions of text files that have a much smaller file size compared to documents stored in a DMS. Instead of storing the complete file contents, only the changes between file versions are very efficiently stored. Due to the requirements of the software development process the reciprocal synchronous cooperation is supported. Here, even tasks that synchronously refer to source code in the same line of the same file version must be allowed.

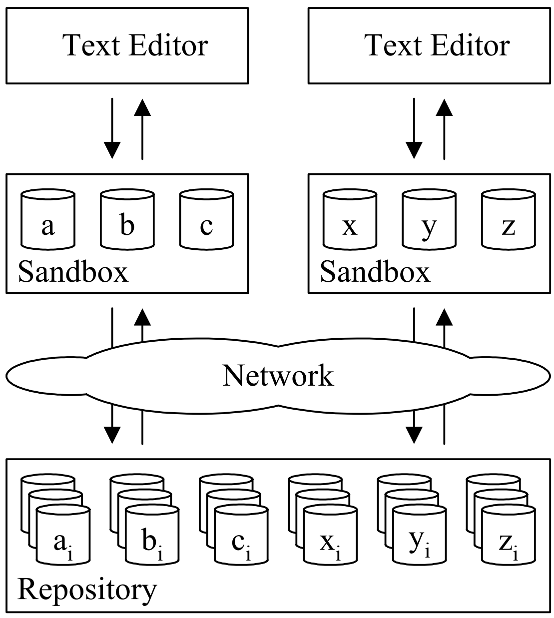

Figure 5. Version Control System

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All file versions of the project are stored in a central Repository that is accessible to all team members. Each file version can be added to an arbitrary number of file version sets by the tagging mechanism. Equation 1 below defines the file version set T_i formally:

$$T_i := \{f \in V \mid f \text{ has tag } i\} \subseteq V \quad (1)$$

where V is the set of all file versions and i is a specific tag. The tagging mechanism allows the VCS to manage configurations of file versions that belong together.

Files cannot be directly edited inside the Repository but must be previously transferred as a new copy to the user's Sandbox. The Sandbox is located in a directory of the local file system. Since only one version per file can be stored in the Sandbox existing (unversioned) single user applications can be integrated in the distributed process. The user's work is persistently stored as new file versions in the Repository. The net-distributed cooperation depends solely on the synchronization of the Sandboxes and the Repository by the VCS that provides a set of commands for this task. Conflicts are either solved automatically or by actively involving the participating users.

3 SOLUTION APPROACH

The solution approach is targeted at the reuse of existing document based applications during synchronous cooperation. This objective is achieved by storing the application's structured object set in a text based VCS. The procedure proposed is named *objectVCS*.

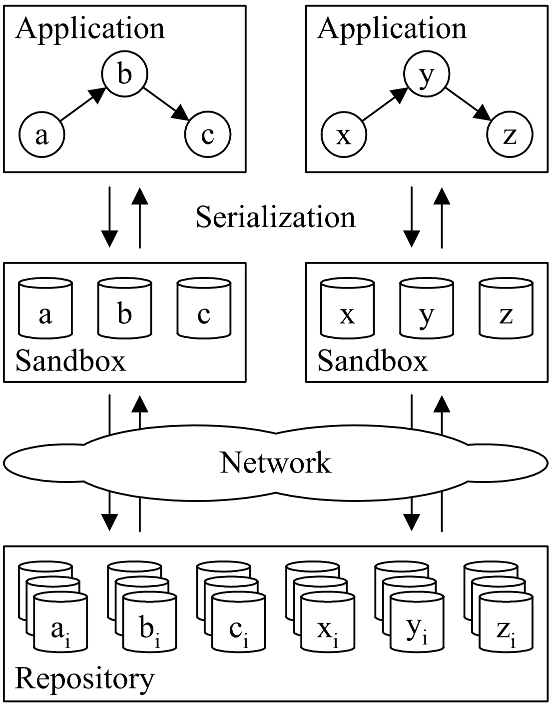

Figure 6. objectVCS: object Version Control System

Contrary to the state-of-the-art the unit of representation is not the document but the object with its attributes and relationships. Storing the objects in a VCS allows the tools of this VCS to be applied to the stored object set. This is particularly true for the tools that support the distributed synchronous cooperation and the versioned data management.

Figure 6 shows the system architecture of objectVCS.

3.1 *Serialization*

This mechanism establishes the interface between the document based applications and the text based VCS. The serialization is the method of representing a structured object set as a character stream, the deserialization in turn is the method of creating a structured object set from a character stream. Unlike the DMS approach objectVCS always requires a certain extension of the participating applications. While the former represents the object set in one single document (available functionality of a document based application) the latter requires that each single object is stored in a separate text file.

objectVCS knows the mapping between objects and files. A unique persistent name (*POID: persistent object identifier*) is assigned to each object and all its versions (Beer et al. 2004a,b). The object is stored in a file named after the POID. Objects are instances of different data types. It is distinguished between single valued and multi valued data types.

The serialization of an object of a single valued type consists of writing the data type followed by the object attributes as (*type*, *name*, *value*) tuples. There is a difference between a primitive and a reference attribute whose value is the POID of the referenced object.

Figure 7a shows the parameters of a circle as an example.

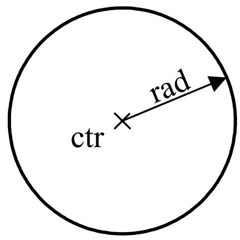

Figure 7a. Parameters of the circle

The related Java classes are listed in Figure 7b: The circle's center is represented as a Point object with two primitive attributes x and y. The Circle object has a primitive attribute for the radius and a reference attribute for the center point.

The serialized XML files are shown in Figure 7b. The POIDs are *PointInst* for the point and *CircleInst* for the circle.

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```
class Circle {
  Point ctr;
  double rad;
  Circle(Point p, double r) {
    this.ctr = p;
    this.rad = r;
  }
}
```

```
class Point {
  double x;
  double y;
  Point(double x, double y) {
    this.x = x;
    this.y = y;
  }
}
```

```
class Application {
  static void main(String[] args) {
    Circle cir = new Circle(
      new Point(1.2, 1.8), 1.5);
  }
}
```

Figure 7b. Java classes to represent the circle

```
<?xml version="1.0"?>
<CircleInst>
  <Point name="ctr" value="PointInst"/>
  <double name="rad" value="1.5"/>
</CircleInst>
```

```
<?xml version="1.0"?>
<PointInst>
  <double name="x" value="1.2"/>
  <double name="y" value="1.8"/>
</PointInst>
```

Figure 7c. XML files to represent the circle

Objects of a multi valued data type are represented as a sequence of elements, where an element can either be a primitive value or a reference value as a POID. The serialization consists of writing the data type, a signature for the multi valued data type and the sequence of elements.

Sets represent a special case: Even though the order of elements is arbitrary, sets are always serialized in a fixed sequence: This algorithm has been convenient for the representation of sets in a text based VCSs.

The Java language has been selected for implementation. The serialization could be realized without any intervention of the application programmer exclusively on the base of the reflection package.

XML was selected as text format. The implementation was very efficient thanks to available XML tools like parsers. It should be noted that objectVCS is not limited to text files. Since the serialization interface is based on character streams, the object set can be stored in data bases as well.

3.2 *Repository*

The text file versions of the project are stored in the Repository. Between the file versions relationships exist. objectVCS ensures the referential integrity by adding object versions to the same version set if they belong together.

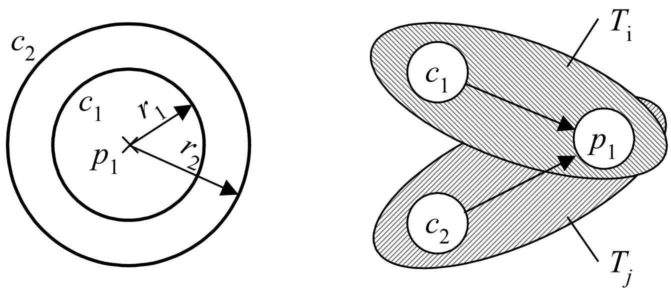

Figure 8. Building object version sets

Figure 8 shows an example for building version sets. The first version c_1 of the circle has a primitive radius attribute r_1 and a reference attribute for the center point p_1. The second version c_2 of the circle has a changed radius r_2 but still refers to the same center point object p_1. Equation 2 describes the definition of the two version sets by tagging:

$$
\begin{aligned}
T_i &:= \{f \in V \mid f \text{ has tag } i\} = \{c_1, p_1\} \\
T_j &:= \{f \in V \mid f \text{ has tag j}\} = \{c_2, p_1\}
\end{aligned}
\qquad (2)
$$

where V is the set of all file versions, i and j are specific tags and T_i and T_j are the respective version sets.

Available applications store their documents as a single file in the file system. This is shown in Figure 9a where rectangles denote directories. This procedure is not appropriate for objectVCS that depends on storing each single object in a separate file. As a solution to this problem the document is not stored as a file but as a directory representing at most one single document. This procedure ensures that the known mode of operation can be retained by the users.

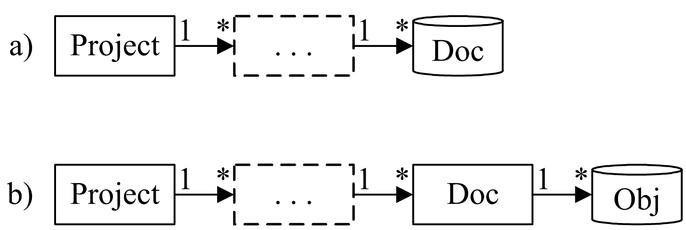

Figure 9. Storage of a document in the file system (a) and in the Sandbox/ Repository (b)

In addition to the well known document based approach a novel kind of processing across document boundaries is possible. Links between objects in different documents can be realized by adding the referencing and the referenced object to the same

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version set. For the theoretical foundations of the management of structured object version sets the user is referred to (Firmenich 2002a, b, Firmenich & Beucke 2002). An approach for defining consistent releases on a structured object version set has been proposed by Beer & Firmenich (2003).

3.3 *Sandbox*

The sandbox is located in a directory of the user's local file system. The structured object set of the application can be stored to and loaded from the Sandbox. The Sandbox must be synchronized with the Repository.

3.4 *Synchronization of Repository and Sandbox*

The synchronization of the Sandboxes and the Repository is the basis for the net-distributed cooperation. The VCS is responsible for this task. The process of storing the application's object set consists of two phases:

1. Each object is serialized into a separate file stored in the Sandbox. Storing can be done online and offline.
2. The changes become public by storing the files as a new versions in the Repository.

Likewise, loading the structured object set is also a two-phase process:

1. Selected files are transferred from the Repository to the Sandbox.
2. The applications' object set is deserialized from the files stored in the Sandbox. Loading can be done online and offline.

As a matter of principle, all tools of the underlying VCS are applicable in an objectVCS environment.

3.5 *Version Control System and API*

The selection of the free Concurrent Versions System *CVS* (Fogel & Bar 2002, Vesperman 2003, cvshome 2005) as the underlying VCS has proved of value. The available Java CVS Client (javacvs 2005) of Suns Netbeans IDE open source project was chosen for the prototypical implementation of objectVCS. The CVS client allows the establishment of a connection with the CVS Server and the execution of the subsequently described CVS commands:

- *add:* Adds a file or directory to the Repository.
- *checkout:* Creates a new Sandbox or actualizes an existing Sandbox.
- *commit:* Writes changed files from the Sandbox to the Repository.
- *diff:* Shows the differences between two file versions.
- *log:* Shows versioning and administration information about files located in the Sandbox.
- *remove:* Removes a file or directory from the Repository.
- *status:* Shows status about files.
- *tag:* Tags a file or a set of files with a unique name.
- *update:* Transfers changed files from the Repository to the Sandbox. This command allows the reciprocal synchronous cooperation.

4 VERIFICATION EXAMPLE

The solution approach has been verified as an extension of an available single user CAD system that is currently being developed at Bauhaus University for education and research (Firmenich & Beucke 2005).

4.1 *Implementation*

The CAD system has been extended by a set of commands for the synchronous cooperation of a team. The implementation of these commands is based upon our proprietary Java XML serialization package and the available Java CVS Client package.

During development of objectVCS it turned out that extended functionality concerning CVS was needed. An example is the synchronization of a single directory between Sandbox and Repository for performance reasons. The extended functionality has been realized as a wrapper class of the existing Java CVS Client.

The following CAD commands refer to directories and files of the Sandbox only. Online or offline execution is possible:

- *Project settings:* Defines a project as a CVS module in the Repository.
- *New:* Initializes a new drawing in the application.
- *Load:* Loads a document from the Sandbox into the application.
- *Store:* Stores the application's object set in the loaded document of the Sandbox.
- *StoreAs:* Stores the application's object set in a new document in the Sandbox.

The subsequently listed CAD commands refer to the Repository and can only be executed online.

- *UpdateNewDirectories:* Updates the Sandbox by directories stored in the Repository only.
- *UpdateOverride:* Replaces a document in the Sandbox by the head version of the Repository.
- *Update:* Issues the *update* command and performs a merge in case of conflicts.
- *Commit:* Synchronizes the Sandbox and the Repository by an *Update* command. Both new and changed files are stored in the Repository.
- *Server settings*: Sets the password, the local path of the Sandbox and a *diff* and *merge* tool.

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4.2 *Scenario*

Figure 10 is the schedule of the verification example. The two Sandboxes *A* and *B* and the Repository are shown as vertical bars very similar to a UML sequence diagram (Rumbaugh et al. 2001).

The time coordinate proceeds downward. Labeled arrows describe the user action and the direction of data transfer. For instance, arrows starting at the Sandbox bar and ending at the Repository bar denote operations that transfer data from the Sandbox to the Repository. Arrows starting and ending at the Sandbox bar denote operations referring to the Sandbox only. Circles with text denote versions of Sandbox or Repository data. For instance, *A2* denotes the second version of data in Sandbox *A* and *R4* denotes the fourth version of data in the Repository.

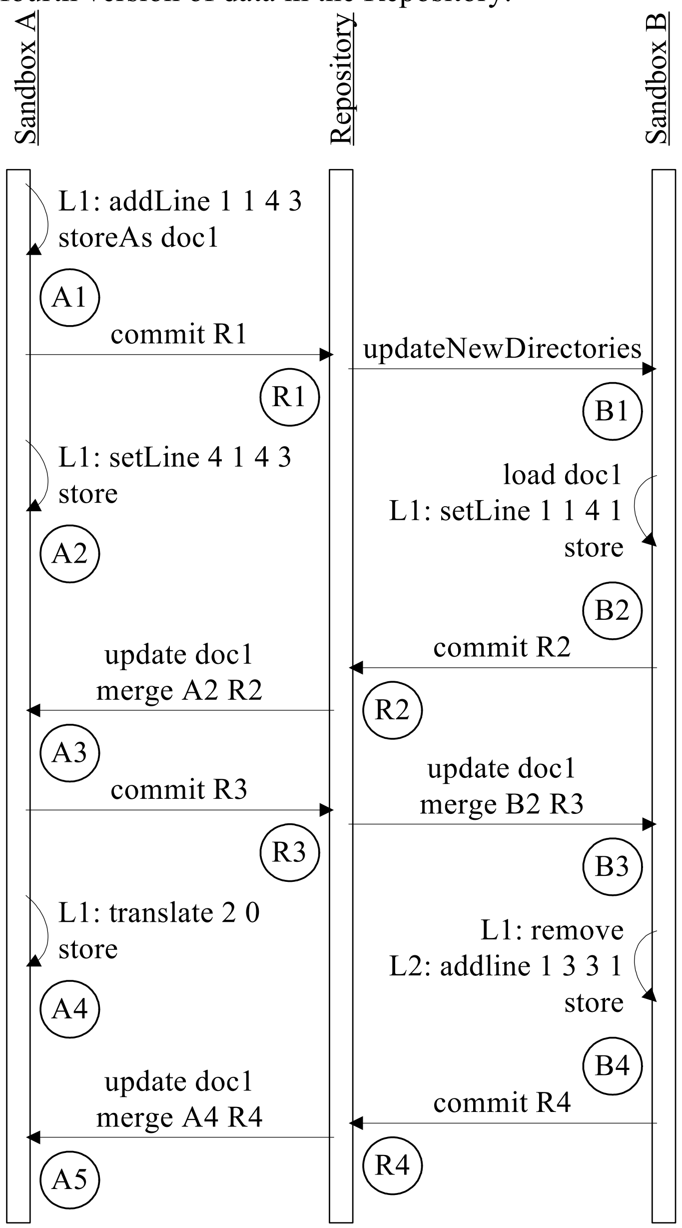

Figure 10. Schedule of the verification example.

Version A1
User *A* adds a line component to the database and stores version *A1* of document *doc1* in Sandbox *A*. The document contains a single line *L1* at (1, 1, 4, 3).

Version R1
User *A* commits the document as version *R1* from the local Sandbox to the Repository.

Version B1
User *B* updates his local Sandbox *B* by new directories created in the Repository. This operation stores version *R1* of the document in his Sandbox.

Version B2
User *B* loads the document version *B1* and changes the endpoint of line *L1* to (4, 1). The document is then stored locally as version *B2*. It contains a single line *L1* at (1, 1, 4, 1).

Version A2
After committing the document as version *R1* user *A* has continued the editing process. Thus, user *A* and user *B* are cooperating synchronously on different versions of the same document.

After changing the start point of the line to (4, 1) the document is stored as version *A2* containing a single line *L1* at (4, 1, 4, 3).

Version R2
User *B* commits the document version *B2* as version *R1* to the Repository.

Version A3
The synchronous cooperation of document versions *A2* and *R2* resulted in a conflict that has to be solved by user *A*. In the update operation the two versions have to be merged to a resulting version *A3*.

As a first implementation the authors have decided to generically merge the two object versions by the help of a simple text based *diff* tool referring to the serialized XML files. Figure 11 shows the *diff* tool in use. As was expected, the approach had some shortcomings since the semantics of private attributes are not clear to the users. In the example shown, instead of the familiar user coordinates internal world coordinates are presented to the user. The interpretation of the data shown requires a deep understanding of the underlying data structure.

The right panel in Figure 11 shows the textual representation of version *A2*: The coordinates (4, 1, 4, 3) of *L1* are shown as normalized world coordinates (scaled by a factor of 1 / 1000 in the specific case).

The left panel shows the differences between the two versions. The conflicting values of the start point's x-coordinate are shown in line 6 (original value '4' of version *A2*) and line 9 (selected value '1' of version *R2*). The conflicting values of the end point's y-coordinate are not marked: Since the value '3' has not been changed in version *A2* the merge tool automatically selects the value '1' of version *R2*.

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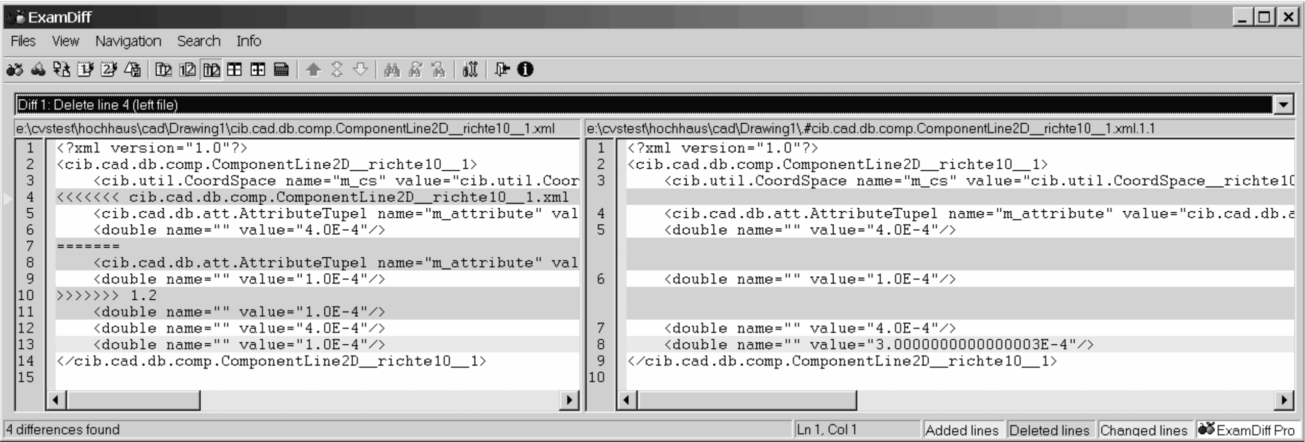

Figure 11. Text based merging of version A2 and R2

In the merge procedure user *A* has decided to retain his version unchanged. Therefore, version *A3* of the document contains a single line *L1* at (4, 1, 4, 3).

Version R3
User *A* commits document version *A3* to the Repository as version *R3*.

Version B3
User *B* updates and merges versions *B2* and *R3*. No conflicts are detected because user B has not changed his document version in the meantime. The resulting version *B3* consists of line *L1* at (4, 1, 4, 3).

Version B4
User *B* removes *L1* form the database and adds the new line *L2* at (1, 3, 3, 1). The database is stored as version *B4* of the document.

Version A4
At the same time user *A* has transformed line *L1*.

```
<?xml version="1.0"?>
<java.util.HashSet—A-1
  <cib.db.cmp.ComponentLine2D
    name=""
    value="cib.cmp.ComponentLine2D-A-1"
  />
</java.util.HashSet-A-1>
```

Figure 12a. Serialized XML document with version A4 of the database.

```
<?xml version="1.0"?>
<java.util.HashSet-A-1>
  <cib.db.cmp.ComponentLine2D
    name=""
    value="cib.cmp.ComponentLine2D-B-1"
  />
</java.util.HashSet-A-1>
```

Figure 12b. Serialized XML document with version B4 of the database.

Version R4
User *B* stores version *B4* of the document as version *R4* in the Repository.

Version A5
User *A* now updates and merges. The two versions of the serialized database HashSets are shown in Figure 12. The diff tool does not detect a conflict. In the resulting version *A5* line *L1* has been automatically been removed and line *L2* has been automatically added. It should be noted that this is not the expected result from the user's view!

Conclusion
In the opinion of the authors, the example shows the general applicability of the proposed solution approach in the planning process. However, a lot of research topics remain open.

5 PERSPECTIVE AND CONCLUSIONS

With the proposed solution approach object-oriented applications of the planning process can benefit from tool-based version control systems. The potentials of this approach would exceed the possibilities of currently used DMSs. Since the versioning granularity is changed from documents to objects, subsets of objects can be flexibly composed and loaded. The explicit storage of object versions considerably simplifies the process of locating, visualizing and merging differences. Finally, available VCSs ensure a very effective storage of the object versions.

The verification example revealed that important aspects of the solution approach remain to be investigated. Future work will address the problems of visualizing the differences and merging object versions as well as the problems of selecting, loading and storing consistent subsets from the versioned model. Another research directive will be the consistent management of cross-document and cross-project relationships.

The proposed solution approach could be a step towards a true synchronous reciprocal cooperation in the planning process.

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Characterizing the visualization techniques of project-related interactions

B. Otjacques & F. Feltz
Public Research Centre Gabriel Lippmann, Luxembourg

ABSTRACT: All construction projects can be considered as cooperative undertakings. Their strategic management as well as the daily operations causes numerous interactions to occur, either among persons or among persons and resources. These interactions have been studied from various viewpoints but few researchers have focused on their visualization. The graphical representation of the cooperation is however a powerful tool to help the project participants to get a correct understanding of the situation. This paper proposes thus a structuring framework (IVF - Interaction Visualization Framework) of the visualization techniques used to display such interactions. Three basic axes of classification are used to structure the study. Which objects are visualized? Why are they visualized? How are they visualized? For each axis, several properties have been identified and the admitted values have been specified. This work can be considered as a first step towards a structured view of the 'visualization of cooperation' domain.

1 INTRODUCTION

Any construction project projects can be considered as a cooperative undertaking. Indeed, considering that several persons join their efforts towards the project common goal, the three basic functions of cooperative situations, namely communication, co-production and sharing, and coordination (Lonchamps, 2003), are always present to a certain extent. In order to produce the promised deliverables, numerous interactions occur all along the project life cycle, either among persons or among persons and material or immaterial objects. These interactions can really be considered as the visible face of the cooperation. It is thus not very surprising that many researchers have studied them in different contexts.

In the Architecture, Engineering and Construction (AEC) industry, the interactions among the participants of a project have been studied from very various viewpoints such as supplier management (Clark et al. 1999), trust (Mohamed 2003), distribution of communication media (Howard & Petersen 2001), modes of information dissemination (Otjacques et al. 2003), influence of communication media on design performance (Kvan & Gao 2004), as well as distributed cognition (Perry 1997) or turbulence (Fyall 2002).

Nevertheless, notably fewer researchers have focused their work on the specific challenges associated with the visualization of these interactions, or in other words, on the visualization of the cooperation. This viewpoint is, however, really worth being investigated. Indeed, human beings know for centuries how powerful may be a graphical representation of a problem for helping to solve it, which is usually summarized by the famous citation '*A picture is worth a thousand words*'. This paper proposes thus a global framework aiming to characterize the visualization techniques used to represent some interactions such as those arising during a project.

2 MOTIVATION OF THE RESEARCH

The intended result of this work is thus to propose a framework which could be used as a basic tool by researchers studying or designing some visualizations of interactions. Indeed, to the limit of our knowledge, no taxonomy especially dedicated to this kind of visualization techniques has already been proposed. Such a framework would, however, be clearly of prime interest as the following reflections point it out.

Herbert Simon stated some decades ago that '*the first step to understanding any set of phenomena is to develop a taxonomy*' (1969). In the information visualization domain, several researchers have also drawn the attention on the reasons why taxonomies, classifications or frameworks (these terms are sometimes used with quite similar meanings) are required. According to Lohse and his colleagues (1994), '*Classification lies at the heart of every sci-*

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entific field. Classifications structure domains of systematic inquiry and provide concepts for developing theories to identify anomalies and to predict future research needs.' Wehrend and Lewis (1990) explain that, with a common conceptual framework, '*workers in any area can place their techniques, so that abstract similarities among problems in different application areas can be identified, and new techniques can be readily transported across application lines*'. Gruia-Catalin and Cox (1992) mention that a taxonomy is a '*vehicle through which we carry out a systematic review of current systems, techniques, trends, and ideas …*'.

In any scientific domain, taxonomies are necessary for multiple reasons, among which the most important are probably:

- allowing a systematic and rigorous review of current techniques and ideas;
- positioning specific works in the whole research field;
- clarifying the concepts of the field, which is a required step before elaborating a new theory;
- identifying similarities and differences among the research findings;
- pointing out new research directions;
- highlighting lacks in research proposals.

This list is certainly not exhaustive but it is believed to include the most significant elements and it offers enough good reasons to reflect on a new taxonomy.

3 VISUALIZATION IN AEC RESEARCH

First of all, it may be useful to remind the scope of some scientific domains dealing with graphics and data. Card, Mackinlay and Shneiderman (1999), who are among the most renowned authors in this field, define '*visualization*' as '*the use of computer-supported, interactive, visual representations of data to amplify cognition*'. They also propose a list of working definitions aiming to clarify the relationships among the concepts related to information visualization. The most useful of them in the context of this paper are the following. '*Scientific visualization*' concerns '*the use of interactive visual representations of scientific data, typically physically based, to amplify cognition*'. '*Information visualization*' deals with '*the use of interactive visual representations of abstract, non physically based data to amplify cognition*'.

These generic definitions can be instantiated in the specific case of the AEC research field. According to the above-mentioned definitions, the visualization of physical artifacts (e.g. steel structure, heat transfer properties of a building, building site spatial organization) belongs to the *scientific visualization* discipline. This domain encompasses most of the research works on visualization in AEC. For instance, numerous papers can be found on Computer Aided Design, Virtual Reality, Building Rendering or Lighting Simulation (cf. for instance, ITCon 2003; eCAADe 2004).

The *information visualization* domain has a completely different purpose. It regroups the initiatives aiming to graphically represent abstract objects, such as meetings, document storage systems, e-mails or access to shared documents. This aspect has been notably less studied in the AEC research field. In fact, most of the time, this issue is tackled as a side effect of the study of information exchanges. For instance, project web sites (PWS) obviously include some *information visualization* (*InfoVis*) techniques but, in almost all the cases, PWS have been studied in terms of real usage, efficiency, or cost (e.g. Andresen et al. 2003) rather than in terms of *InfoVis* techniques. Similarly, project planning has been intensively explored with various techniques, such as Petri nets (Rueppel et al. 2004), knowledge base system (Castro & Dawood 2004), and *scientific visualization* techniques (e.g. adding temporal properties to a 3-D representation to show the state of the building site at a given moment of time). Few researchers, however, focused on the best manner to graphically represent the interactions between the actors. The choice of traditional representations, like Gant charts, is often taken for granted and is rarely questioned in order to assess the appropriateness of these *InfoVis* techniques to convey information in the situation under study.

The research work described in this paper relates to the *information visualization* field. It aims to study the visualizations techniques used to display the interactions occurring during a project. Therefore, the concept of '*interaction*', which is a central element of the research work, has to be defined. In this paper, an '*interaction*' is defined as '*any kind of communication or exchange among two or more actors, or between one or many actor(s) and some resources used in the project*'. Typical examples of such interactions are phone calls between an architect and a contractor, e-mail exchanges between a project manager and the project members, face-to-face meetings between the project manager and the client, successive operations on a document located on a web site, or planning modification requests by some project participants.

4 IVF FRAMEWORK

4.1 *General Approach*

A global framework, called IVF (*Interaction Visualization Framework*), has been designed to underpin the analysis of the visualization techniques aiming to display some interactions (called *InterVis* techniques in this paper). The IVF framework is not

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specific to the AEC industry but it is generic by nature and can be applied in any sector.

The IVF framework has been designed according to the following methodology. It was decided to study the visualization techniques from three viewpoints:

- which objects are visualized?
- why are these objects visualized?
- how are these objects is visualized?

Numerous papers have been collected about information visualization in general, about taxonomies of information visualization techniques, and about visualization of interactions. On the basis of this material, a set of properties was identified in each of the three above-mentioned aspects, and the values allowed for each property was specified. Some of the properties (e.g. *Retinal Variables*, *Entity Covering Level*) are derived from previous taxonomies in the information visualization domain (Bertin 1998; Card & Mackinlay 1997; Roth & Mattis 1990; Tweedie 1997). Other properties (e.g. *Interaction Media*, *Integration*) do not belong to these previous taxonomies. They result from the analysis of current visualization techniques and from conceptual reflections on the properties of interactions. In is also important to note that, most of the time, the property values are not exclusive, which means that a given *InterVis* technique can simultaneously take several values.

This generic framework has been instantiated in the AEC research context and has been applied to characterize some *InterVis* techniques.

4.2 *Objects to be visualized: What?*

First we have to discuss the objects to be visualized. In accordance with our previous definition, two kinds of objects are concerned: the interacting entities (persons and / or resources) and the interactions themselves. Very logically, the associated properties are thus grouped in two distinct sets: those qualifying the entities in interaction and those describing the interactions.

4.2.1 *Entities in interaction*

- Two kinds of entities are distinguished: ‘*persons*’ and ‘*resources*’. Obviously, in this approach, the persons are not considered as resources, which are limited to material (e.g. device) or immaterial (e.g. document) objects. Two values are allowed for the ‘*Interacting Entities*’ property, namely ‘*person-to-person*’ and ‘*person-to-resource*’.
- The ‘*Entity Visualized Objects*’ property allows specifying whether the visualization technique displays entities and / or attributes of these entities. It may take two values: ‘*entities*’ or ‘*entity attributes*’. For instance, in this context, a project participant is considered as an entity while the role of this participant in the project (e.g. architect) is an entity attribute.
- The ‘*Entity Temporal Aspects*’ property specifies whether some time-related aspects (e.g. history) of the entities are displayed. Due to the very specific nature of time, a dedicated property has been added while time-related aspects might have been considered conceptually as attributes of the entities. This property admits two values: ‘*time sensitive*’ and ‘*not time sensitive*’. For instance, if the visualization shows only the presence of interacting persons, this property takes the ‘*not time sensitive*’ value, but if it also displays the moment when the persons joined the project the ‘*time sensitive*’ value is set.
- The next property, called ‘*Entity Covering Level*’, expresses the level of covering of the data space. It can take three values: ‘*one entity*’ (i.e. visualization of one specific object), ‘*some entities*’ (i.e. a specific subset of all objects) and ‘*all entities*’ (i.e. all objects). The example of project participants can still be used to illustrate this property. If one specific participant is displayed, the property takes the value ‘*one entity*’. If the visualization concerns the subgroup of all participants employed by a given company, the property takes the value ‘*some entities*’. Finally, if all participants of the project are showed, the property is set to ‘*all entities*’.
- The ‘*Entity Granularity*’ property refers to the level of data aggregation allowed by the visualization technique. If only individual entities can be displayed, the property value is set to ‘*individual entities*’ but if some groups of entities can be visualized as such, the property gets the ‘*aggregated entities*’ value. For instance, if the visualization technique only allows displaying documents as separate graphical objects, the ‘*Entity Granularity*’ property gets the ‘*individual entities*’ value. If it allows showing a group of documents as a single graphical object, the property is set to ‘*aggregated entities*’.

4.2.2 *Interactions among entities*

- The ‘*Interaction Visualized Objects*’ property allows specifying whether the visualization technique displays interactions and / or attributes of these interactions. It may take two values: ‘*interactions*’ or ‘*interaction attributes*’. For instance, in this context, an e-mail is considered as a basic object while the ‘priority’ of this e-mail is an object attribute.
- The ‘*Interaction Temporal Aspects*’ property specifies whether some time-related aspects (e.g. history) of the interactions are displayed. Due to the very specific nature of time, this dedicated property has been included but, conceptually, time-related aspects might have been considered

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as attributes of the interactions. This property admits two values: '*time sensitive*' and '*not time sensitive*'. For instance, if the visualization shows the moment when each interaction occurred, it gets the '*time sensitive*' value but if it displays only that some interactions occurred, the '*time not sensitive*' value is set.

– The next property expresses the level of covering of the data space. The '*Interaction Covering Level*' property can take three values: '*one interaction*' (i.e. visualization of one specific interaction), '*some interactions*' (i.e. a specific subset of all interactions) and '*all interactions*' (i.e. all interactions). The example of e-mail exchanges can still be used to illustrate this property. If the technique permits to show a specific e-mail, the property takes the value '*one interaction*'. If the visualization concerns all the e-mails sent by a specific participant, the property takes the value '*some interactions*'. Finally, if all e-mails exchanged during the project can be displayed, the property is set to '*all interactions*'.
– The '*Interaction Granularity*' property refers to the level of data aggregation allowed by the visualization technique. If only individual interactions can be displayed, the property value is set to '*individual interactions*' but if some sets of interactions can be visualized, the property gets the '*aggregated interactions*' value. For instance, if the visualization technique visualizes each individual e-mail as a single graphical object, it gets the '*individual interactions*' value. If it allows representing all the e-mails exchanged between two project participants with a unique graphical object, the property is set to '*aggregated interactions*'.
– The '*Interaction Arity*' property is defined by the number of entities that take part in the interaction. Two values are allowed for the interaction arity: '*binary*' (i.e. interaction between two entities) and '*multiple*' (i.e. interaction between more than two entities).
– The '*Interaction Centricity*' property specifies whether the interactions that are visualized are relative to a given central person ('*egocentric'*) or concerns all interacting people without favoring a specific individual ('*sociocentric*'). For instance, an e-mail client is typically '*egocentric*' as it shows all interactions between the connected user and the other persons.
– The '*Interaction Media*' property refers to the tool(s) supporting the interactions. Some possible values are '*face-to-face meetings*', '*e-mail communications*', '*phone calls*', '*video-conferencing*', '*web site access*', …

4.3 *Goal of the visualization: Why?*

The goal of the visualization is the second aspect that we use to classify the visualizations of interactions. This aspect concerns the context of use for which the visualization is designed. Three properties are associated with this viewpoint.

– The '*Visualization User Role*' property specify whether the technique is dedicated to be used by an actor which takes part in some of the interactions ('*participating actor*') or by someone which is external to the interactions ('*external observer*').
– The '*Visualization Purpose*' property indicates the essential purpose of the visualization. Two basic goals are identified: '*interaction support*' and '*interaction analysis*'. The first value concerns the cases when the basic purpose of the visualization is to support the user to interact with other entities and the second value applies when the visualization is used to analyze the interactions between some entities.
– The '*Visualization User Expertise*' property refers to the level of expertise, in terms of graphical representation reading, of the user for which the *InterVis* technique is designed. It can take three values: '*novice*', '*normal user*', or '*expert*'. For instance, a treemap can be considered to be designed for '*expert*' users while a pie chart can be dedicated for '*novice*' users.

4.4 *Visualization techniques: How?*

The last classification axis concerns the visualization techniques themselves. Intentionally, no property is defined to specify what might be called the 'visualization type' (e.g. *pie chart*, *tree* or *parallel coordinates*). In fact, such a property would not be consistent with the framework philosophy that aims to characterize the *InterVis* techniques in a way as generic and lasting as possible.

– The '*Display Space Dimensions*' property is used to indicate how many space dimensions are used to represent the data graphically. Three values are allowed: '*1-Dimension*', '*2-Dimensions*' and '*3-Dimensions*'. This property is defined as the number of coordinates necessary to position any data in the visualization display space. It may be useful to point out that it does not refer to the number of dimensions of the data. In Bertin's terminology (1998), this property refers to 'plan variables'. It does not concern the retinal variables such as color or size. For instance, a timeline is '*1-Dimension*', a planar tree is '*2-Dimensional*' and a virtual reality representation is '*3-Dimensional*'.
– The '*Entity Graphical Mapping*' property indicates which kind of graphical object is used to represent the entities in interaction. The possible

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values are '*point object*', '*linear object*', '*surface object*' and '*volume object*'. For instance, in usual 'node-links' graphs, this property takes the value '*point object*' because the entities are displayed as point-like nodes.

- The '*Interaction Graphical Mapping*' property indicates which kind of graphical object is used to represent the interactions among the entities. The possible values are '*point object*', '*linear object*', '*surface object*' and '*volume object*'. For instance, in usual 'node-links' graphs, this property takes the value '*linear object*' because entities are displayed as links.
- The '*Retinal Variables*' property specifies which retinal variables are used to represent data values in the visualization technique: '*color*', '*grey level*', '*shape*', '*orientation*', '*size*', '*grain*', and '*texture*'. For instance, in a node-link graph, the frequency of the interactions can be represented by coloring the links ('*color*') or increasing the link width ('*size*').
- The '*Display Space Boundaries*' property is used to specify whether the graphical representation uses a fixed ('*fixed*') or variable ('*variable*') display space, depending on the size of the data set. For instance, this property is set to '*fixed*' for a treemap and to '*variable*' for a classic node-link graph.
- The '*Geometrical Distortion*' property specifies whether the visualization technique shows distorted views of the data ('*distorted*' vs. '*not distorted*'). In a distorted view, the values of the data are not all equally mapped with their geometrical representation within the display space. The fish-eye lens and the 'Perspective Wall' are some examples of distorted techniques.
- The '*Abstraction Level*' property indicates whether the graphical elements used in the representation are purely abstract shapes ('*abstract*'), remind some real objects via metaphors ('*metaphorical*') or mimic reality ('*pseudo-real*'). To illustrate these values, representing e-mails by arcs takes the '*abstract*' value; using expressive faces to display e-mail priority takes the '*metaphorical*' value; and representing meetings within a virtual 3-D world takes the '*pseudo-real*' value.
- The '*Animation*' property indicates whether some movement or animation is included in the graphical representation of the interactions. Two values are allowed: '*animated*' or '*static*'. In order to avoid confusion, it must be mentioned that this property does not refer to the dynamics of the interactions themselves.
- The '*Interactivity*' property refers to the presence or absence of means for the user to interact with the graphical representation. A visualization technique will be called '*interactive*' if the user can dynamically modify the selection of objects to be displayed, the displayed properties of these objects, or a parameter of the graphical output used to display them. If the user cannot modify any aspect of the data representation, the visualization technique is called '*not interactive*'.
- The '*Integration*' property explains whether the visualization technique is integrated with the interaction tool ('*integrated*') or not ('*independent*'). For instance, an e-mail visualization module can be integrated within an e-mail client ('*integrated*') or it can be used to display an e-mail log file issued from an external application ('*independent*').

5 APPLICATION OF THE IVF FRAMEWORK

This section illustrates how the IVF framework can be applied to characterize and support the improvement of some current visualization techniques.

5.1 *Nodes-links diagrams*

Sociograms, imagined by Moreno in the early 1930's (Freeman, 2000) are considered as the most ancient example of visualization of social interactions. They are graph-like drawings in which individuals are represented by points and relations between them by lines. They became the most popular technique to display 'interaction' data and, for this reason, will be taken as example to illustrate the use of the IVF framework.

The Figure 1 is an example of a very simple sociogram that might be drawn by a researcher to study the interactions by e-mail between the members of a project. It will be considered as our reference of basic nodes-links diagram.

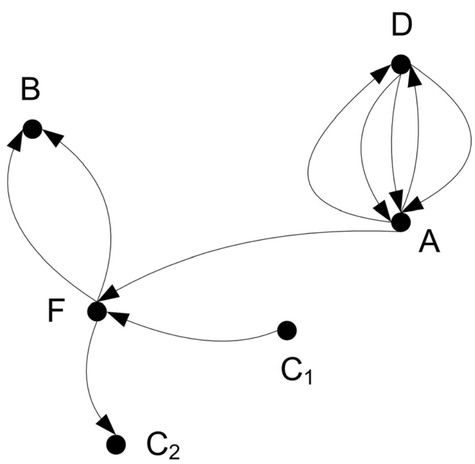

Figure 1. Reference nodes-links diagram

The IVF framework can be used to qualify this simple *InterVis* technique. Table 1 summarizes the values of the IVF properties for this sociogram.

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Table 1. IVF properties of the reference ‘nodes-links’ diagram

What? Properties	
Interacting Entities	*person-to-person*
Entity Visualized Objects	*entities*
Entity Temporal Aspects	*not time sensitive*
Entity Covering Level	*all entities*
Entity Granularity	*individual entities*
Interaction Visualized Objects	*interactions*
Interaction Temporal Aspects	*not time sensitive*
Interaction Covering Level	*all interactions*
Interaction Granularity	*individual interactions*
Interaction Arity	*binary*
Interaction Centricity	*sociocentric*
Interaction Media	*e-mail communications*
Why? properties	
Visualization User Role	*external observer*
Visualization Purpose	*interaction analysis*
Visualization User Expertise	*normal user*
How? properties	
Display Space Dimensions	*2-Dimensions*
Entity Graphical Mapping	*point object*
Interaction Graphical Mapping	*linear object*
Retinal Variables	-
Display Space Boundaries	*variable*
Geometrical Distortion	*not distorted*
Abstraction Level	*abstract*
Animation	*static*
Interactivity	*not interactive*
Integration	*independent*

5.2 *Diagram modeling with IVF*

Node-link diagrams have been adapted in many ways by AEC researchers to represent some kinds of interactions linked to a construction project. These evolutions can be formalized by the modification of some IVF properties, as the following examples point it out.

5.2.1 *Howard & Petersen: Sociograms*

Howard & Petersen (2001) studied the information flows relative to four housing projects.

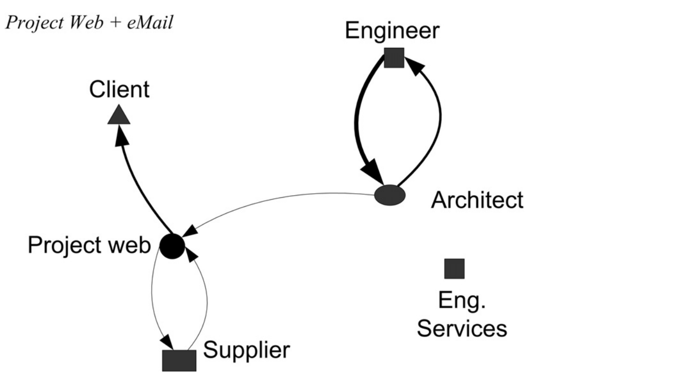

Figure 2. Adaptation of the reference nodes-links diagram to be similar to Howard & Petersen’s proposal.

They proposed to graphically represent communications with sociograms (cf. Figure 2). Nevertheless, the analysis of their proposal shows that the values of several IVF properties (cf. Table 2) are modified in comparison to the reference diagram (cf. Table 1).

The IVF characterization of Howard & Petersen’s work rapidly highlights in which sense it differs from our reference nodes-links diagram.

– Most of the modification relate to the dataset to be displayed (cf. *What* properties). Indeed, a larger set of interactions is concerned. For instance, a given sociogram can be used to show both e-mail communications and interactions with the project web. Some attributes of entities, such as the role in the project, are also displayed.
– Howard & Petersen’s sociograms have a similar purpose as our reference diagram (cf. *Why* properties).
– Finally, the *InterVis* technique itself (cf. *How* properties) has been slightly modified. Among the adaptations, one may note the use of the retinal variable ‘*size*’ for making the line width proportional to the number of interactions. In the same context, the companies of the interacting people are represented by the shape of the associated node (e.g. circle, triangle…).

Table 2. Modified IVF properties in Howard & Petersen Sociograms (compared with the reference nodes-links diagram)

What? properties	
Interacting Entities	*person-to-person* *person-to-resource*
Entity Visualized Objects	*entities, entity attributes*
Entity Granularity	*individual entities* *aggregated entities*
Interaction Visualized Objects	*interactions* *interactions attributes*
Interaction Granularity	*aggregated interactions*
Interaction Media	*e-mail communications* *face-to-face meetings* *postal mail, phone calls…*
How? properties	
Retinal Variables	*size, shape*

5.2.2 *Thorpe & Mead: Network Sociograms*

Thorpe & Mead (2001) studied the communications within three projects that uses a project-specific web site. They represented the communication flows with network sociograms (cf. Figure 3). The IVF-based analysis of their work (cf. Table 3) points out to which extent it differs from the reference diagram.

– The data displayed are not identical. For instance, the visualization does not show some specific instances of interactions but rather the value of a specific attribute of the interactions, namely the frequency of occurrence (e.g. daily, weekly…).
– The goal of the reference nodes-links diagram and the network sociograms are similar.
– The visualization technique is quite similar to the reference nodes-links diagrams. Thorpe & Mead

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propose, however, some adaptations, such as color coding to help the user navigate the diagram. Moreover, the length of the links is inversely proportional to the frequency of interactions.

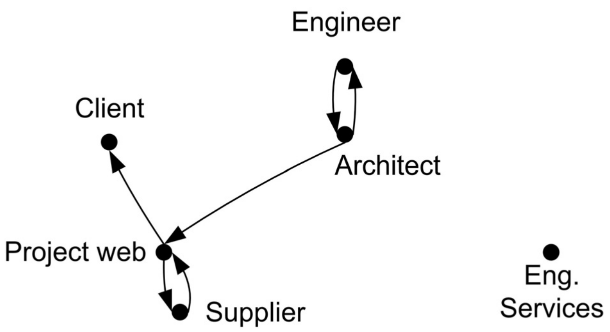

Figure 3. Adaptation of the reference nodes-links diagram to be similar to Thorpe & Mead's proposal.

Table 3. Modified IVF properties in Thorpe & Mead Network Sociograms (compared with the reference nodes-links diagram)

What? Properties	
Interacting Entities	*person-to-person* *person-to-resource*
Entity Visualized Objects	*entities, entity attributes*
Interaction Visualized Objects	*interactions* *interactions attributes*
Interaction Granularity	*aggregated interactions*
Interaction Media	*e-mail communications* *postal mail, phone calls…*
How? properties	
Retinal Variables	*color*

5.2.3 *Halin et al.: Hypergraphs*

Halin et al. (2004) studied cooperative tools in architectural design. They proposed to visualize the information about the project with hypergraphs (cf. Figure 4). In fact, this representation also appears to be an adaptation of the reference nodes-links diagram, which can be modeled as a modification of some IVF properties (cf. Table 4).

- The data to be visualized are different. For instance, the representation shows the interacting persons but also some project resources (e.g. documents, directories…) as well as the project activities. The temporal precedence of some interactions is also graphically represented.
- The purpose of the visualization basically differs from the reference diagram as it is mainly dedicated to the project participants (i.e. people being involved in the interactions).
- The visualization technique has been quite significantly modified. For instance, the interacting entities are represented by icons. Some retinal properties (*color*, *shape*) are used to convey some information. Another example is provided by the possibility for the user to add new entities and interactions directly in the representation.

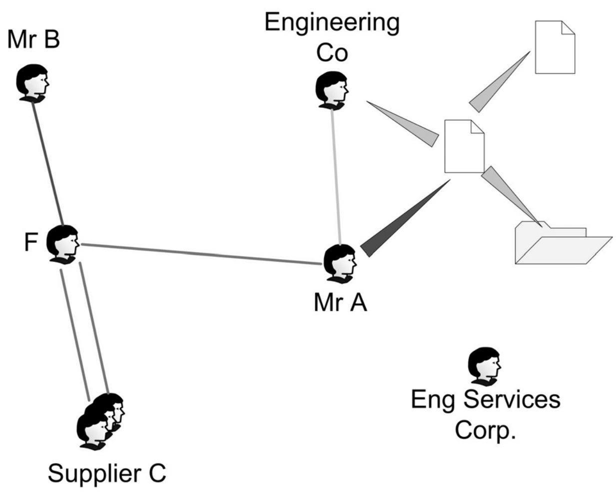

Figure 4. Adaptation of the reference nodes-links diagram to be similar to Halin et al. hypergraphs.

Table 4. Modified IVF properties in Halin et al. Hypergraphs (compared with the reference nodes-links diagram)

What? Properties	
Interacting Entities	*person-to-person* *person-to-resource*
Entity Visualized Objects	*entities, entity attributes*
Entity Temporal Aspects	*time sensitive*
Entity Granularity	*individual entities* *aggregated entities*
Interaction Visualized Objects	*interactions* *interactions attributes*
Interaction Temporal Aspects	*time sensitive*
Interaction Granularity	*individual interactions* *aggregated interactions*
Interaction Media	*web site access* *face-to-face meetings …*
Why? properties	
Visualization User Role	*participating actor*
Visualization Purpose	*interaction support*
How? properties	
Retinal Variables	*color, shape*
Abstraction Level	*metaphorical*
Interactivity	*interactive*
Integration	*integrated*

5.2.4 *Remarks*

In the previous sections, three examples of interaction visualization techniques were examined with the IVF framework. They were chosen for illustrative purpose but the reader should be aware of the fact that other approaches have been proposed in the literature. For instance, Lottaz et al. (2000) proposed a 3-D view of the interactions on documents in a collaborative authorship context. Moreover, the IVF framework can be used to describe other diagrams than nodes-links diagrams. For instance, completely different techniques, such as smartmaps (Prinz et al. 2004), can also be characterized with this method.

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6 CONCLUSIONS

The IVF framework described in the paper allows classifying the *InterVis* techniques, i.e. graphic representations of interactions, such as those occurring during a construction project. It offers three main advantages. First, it allows characterizing the *InterVis* techniques in a structured and standardized way. Second, it helps to identify similarities and differences among the proposals. Finally, it highlights some possible enhancements to the techniques encountered in the literature. Further works will focus on refining the list of allowed values for each IVF property, in order to achieve a greater precision for describing each technique.

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Digital assistant for the cooperative construction process in AEC

S. Kubicki, J. C. Bignon & G. Halin
MAP-CRAI (Research Centre in Architecture and Engineering), Architecture School of Nancy, France

ABSTRACT: The article focuses on specificities of the building construction stage as cooperative activity. We identify methods and tools of coordination at present used and detail their limits. Modelling the concepts of cooperation in design / construction and the relations between these concepts allows us to describe the domain and suggest new tools. We present an experiment in progress with the prototype *Image.Chantier*. This tool provides a new form of distribution of coordination information, based on the meeting report document structure. The assessment of this experiment has led us to suggest new specifications for a building construction management system: *a digital assistant for cooperation during building construction stage*.

1 INTRODUCTION

The AEC sector can be distinguished from other industrial sector by the nature of the product that is designed and realised. Processes set up during design and construction activities are adapted to meet particular requirements:

- The building as a product has to face many constraints such as functional, technical, economical, esthetical constraints varying from one project to another. These constraints are specific to the particular context of each project,
- Numerous actors carry out project development. Some professionals are reproducing standard methods instead of solutions adapted to singular project,
- Design and construction team is ephemeral. During a project, the composition of team is evolving. Actors play at different time, so the production periods are long and irregular.
- Professionals comprising the project team are independent. They don't have strong hierarchical relations. These relations are often contractual, based on negotiation between actors.
- Time development of a project is sequential. Succession of stages is characterised by the made of irreversible decisions and the preservation of uncertainties.

In this particular context, the mastering of cooperative processes is very important for project success. Our hypothesis is that final product quality (or building quality) depends highly on the quality of cooperation between actors during the project: interactions, exchanges, and communication…

We are interested in the building construction stage. During this stage, many goals are achieved:

- Controlling construction delays,
- Controlling costs,
- Ensuring the final quality of built works (i.e. conformity to plans).

Cooperation during the building construction stage focuses on coordination of the different actors of the construction process.

We present the cooperative particularities of the building construction activity and the associated methods and tools.

We describe the conceptual model we have developed to represent the concepts of cooperation in AEC. This model is the base of our propositions for cooperation assistance tools using potentialities of digital technologies.

We have implemented this model in a prototype tool and we are experimenting with it on a real building construction site.

This experiment and its results allow us to formulate new specifications for a *digital assistant to cooperation in building construction stage*.

2 THE BUILDING CONSTRUCTION ACTIVITY

The building construction stage is the project stage where the object (the building) moves progressively from a virtual state to a realised state.

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2.1 *Cooperative activity vs. internal strategies*

We can identify some characteristics of the building construction activity (Kubicki et al. 2005):

- New actors are integrated into the project team[1]: security surveyor, pilot, environmental officer, contractors… The relation between actors becomes more hierarchical (i.e. contractors follow the architect's demands),
- New objects appear resulting from the design stage studies: materials, equipments, tools,
- Architectural and technical design evolves integrating new information relative to the execution tasks. New documents are produced as execution plans, building or construction site plans,
- Coordination activities have to determine elementary construction tasks and their time sequence. Planning has to take into account resources (human and material) and technical constraints.

2.2 *Coordination methods used at present*

The survey of building construction consists of ensuring the coordination of teams' actions. We can distinguish between "multi-actor" coordination and "inter-actor" coordination.

2.2.1 *Multi-actor coordination*

Multi-actor coordination aims to inform the entire group of what is happening in the project. It's an explicit activity. Its objectives are to define the conditions of building construction activities and to allow a strict surveillance of progress. There are two major activities in this coordination type:

- Planning consists of the examination of each intervention in the elementary tasks to determine the sequence of these tasks and the critical path to follow.
- "Building construction meeting report", generally once a week, allows the coordinator to verify the progress statement with all the actors involved in the project, and particularly to identify and solve the existing and anticipated problems. A meeting report is produced, validating the decisions taken during the meeting and the information distributed.

The tools to carry out these activities are textual documents or planning diagrams.

We can identify some limits to this coordination form:

- Generally, multi-actor coordination is the source of a large quantity of information (i.e. written document, note, sketch, plan). The problem is that the methods used don't allow the creation of links between information (i.e. points of meeting report) or the easy tracing of events,
- The information is distributed in its totality and to each actor involved in the project (even if they are not concerned). We can note that not all the information is useful to every actor,
- The data formats are a real problem in information exchange: digital document format, media used (fax, email…),
- The shared documents have no links between them (i.e. planning and meeting report). The result is that searching for information in the documents is difficult.
- Finally these methods are not easily adaptable to the changes in the project. Refreshing information to represent the building construction progress is difficult (i.e. planning changes). These problems penalise the representation of activity and therefore the adaptation of working teams to the development of the project (implying delays, mistakes, defective works).

2.2.2 *Inter-actor coordination*

Inter-actor coordination can be defined as peer-to-peer coordination. It consists generally of implicit activities from an actor to another one. It allows the actors to work together, adapting their actions to the action of other actors and to the project development. This type of coordination, at the "actor level", can get around problems generated by the complexity and slowness of multi-actor coordination.

For example two actors coordinate together to make a decision about a construction detail or to solve a small problem efficiently.

Tools existing to support these exchanges are very well-known and much used: GSM phone, meeting, fax or e-mail…

This type of coordination ensures the adaptability of the system to the evolving project definition.

There are some limits to these coordination activities:

- Informal exchanges (such as orality), at the basis of these interactions, don't allow the actors to trace the exchanges and to keep trace of the decisions made,
- Decisions could be taken without conferring with the person responsible or the coordinator,
- Finally, we can note too that exchange formats are not really shared (sketches, language used etc.).

By identifying coordination methods existing at present we are able to reflect on *how to take them into account in a new tool proposition.* We think that inter-actor coordination needs its highly implicit form to function. Further propositions don't suggest the need to replace it…

[1] In this article, we focus on the specificities of the French building construction context.

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2.3 *New methods and tools*

New methods and new tools have been developed for some years in order to take into account these limits of multi-actor and inter-actor coordination. They have been developed to assist the design stage, construction stage or both.

"Digital plans servers" are used for important project to facilitate document exchange. "Project management servers" allow the users to organize and manage different activities (Le Begge et al. 2004) such as requests between actors, tasks etc. Other collaborative tools try to associate planning and information exchange.

The interoperability of tools used by different actors is at the basis of many research works. It becomes a reality in some CAD tools. This is possible by the use of exchange data formats, which are "object" oriented, such as the IFC format[2].

Finally, we have seen the development of the use of digital photography. This media appears to be interesting for its qualities of context representation (Dossier 2005).

But these new methods remain quite unusable for every-day work. They come from other activity sectors such as manufacturing industry and are not well-adapted to the AEC context and its particularities (cf. part 1).

3 MODELING COOPERATIVE ACTIVITIES IN AEC PROJECTS

Representing the particularities of the domain is the first step towards propositions of new assistance tools for cooperation.

3.1 *Meta-model approach and objectives*

The definition of a meta-model allows us to highlight essential concepts to describe context of cooperation in design and construction. These "meta-concepts" of the meta-model (*M2 level*) will be instantiated in specific cooperation models (*M1 level*) (meeting-report model, project management model etc.).

For example, the class "object" of our meta-model should be instantiated at the model level as "space" or "built work".

The meta-modelling approach (Frankel 2003) used in the standard MOF (Meta Object Facility) is proposed by the OMG[3] (Object Management Group).

Our proposition consists of defining a relational cooperation meta-model that takes into account the *existing relations between the elements of a project*. The objective we want to reach with this type of modelling is the description of the meaning of a project and then the proposition of adapted graphical representations (Halin et al. 2003).

3.2 *Relational meta-model of cooperation for design and construction*

To model the activity in a building construction project we suggest an approach from the point of view of cooperation between actors (i.e. exchanges or dependencies). Modelling these concepts of cooperation in the AEC sector will allow us to develop specific applications structured on the base of the *cooperation meta-model for design and construction* (Fig. 1).

The context of cooperative design and construction activities has to represent relations and interactions between the actors, their activities, the documents they produce and the object of the cooperation (building elements or spaces) (see figure 1):

Actor (M2): in a project, each actor has a limited capacity of action and restricted decision-making autonomy. The actor acts inside the activities that constitute the project, gives an opinion, and keeps up a relationship with the environment while collaborating with other actors and producing documents.

Document (M2): a document represents a professional « deliverable » part of a contract.

Activity (M2): the activities inside a project have several "scale" levels: project, phase, stage, and task. The activity can also be characterised by its nature: design, execution, planning, coordination, or prevention activities.

Object (M2): The object is the goal of the cooperation project. We distinguish two types of objects: building elements and spaces. Its definition evolves from design to construction stage: from virtual to real building.

Relationship: a relationship identifies a type of link existing between two elements:

- The relationship between actors depends on the social organisation of the group (hierarchical or cooperative relationships),
- The relationships between actors and activities define the role of an actor in an activity (operational role, organisational role),
- The relationships between actors and objects depend both on the role and the activity: drawing, calculating, building,
- The documents describe the object (graphical, textual or table information). They are generated by actors during activities,
- The relationships between activities are relative to planning: following, preceding, being included in, and so on.

[2] IFC format is a data format for construction oriented « object ». http://www.iai-international.org
[3] http://www.omg.org

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Information regarding the context of the collaborative project can be represented and described by our meta-model.

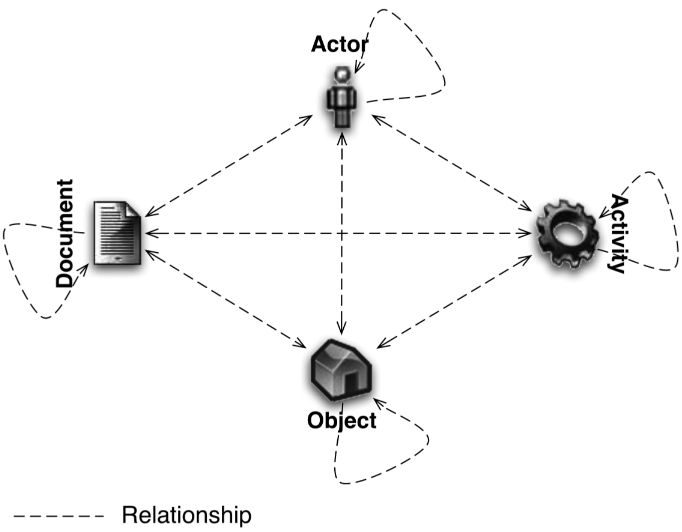

Figure 1. Concepts of the meta-model (M2) of cooperation in design and construction.

In the framework of the development of a new tool, the meta-model will allow us to structure the information exchanged in the cooperative project and to control the management of this information (visualisation, exchange…).

4 A DIGITAL ASSISTANT FOR COOPERATION DURING BUILDING CONSTRUCTION

4.1 *Experimenting some potentialities of digital technologies*

The quality of cooperation between actors is fundamental for the quality of the building construction processes.

The latest development in Information Technology Science should allow us to increase the quality of cooperative activities in AEC.

We carried out experiment on these IT potentialities through the development of a prototype tool. The results we obtained enable us define specifications for a *digital assistant tool for cooperation during building construction.*

4.1.1 *A prototype tool to diffuse coordination information: "Image.Chantier"*

In the framework of this development we have focussed on the meeting report document. This document is produced after each meeting. It contains a large amount of "multi-actor" coordination information exchanged.

We have developed the tool *Image.Chantier* to manage the diffusion of this information to each actor.

To begin with, we suggest a model (M1) of cooperation centered on the meeting report (Fig. 2). It describes the structure of the document (Grezes et al. 1994) and its links with other activities such as meeting and planning.

This model (M1) is the instantiation of the cooperation meta-model (M2) described in part 3. It demonstrates the central role played by the meeting report in cooperation during building construction.

We identify 3 main parts comprising the document:

– General information on the building construction activity, such as numbers of company workers, bad weather days or other meetings planned… We will not detail this part here,
– Information relative to construction progress (detail of real progress compared to planned progress),
– Observations that describe solved or to-be-solved problems. They are emitted by an actor and can concern one or more actors.

Entities of the model (M1) are instantiated from entities of the meta-model (M2).

The "*construction task*" (M1) concept is an "activity" particular to the building construction activity. It describes particular characteristics of building construction tasks (cf. model): it concerns one or more built works situated in a zone, it's carried out by one actor and is defined in terms of time (planning).

It could be a "real task" (i.e. constructing a work) or a "wait task", before another task (i.e. preparation).

The "*zone*" (M1) concept is an instance of the "object" entity (M2). "Zone" refers to "space" (M1). It allows us to situate the built work. It represents both a group of built works (i.e. bone structure comprising many pieces) or a topological delineation of the building site (i.e. ground floor walls).

The definition of the zones varies from one site to another depending on the nature of the project (size, complexity, professionals and tasks groups).

We have also defined and used "*points of view*" on the project context. It will give the users personalised access to information concerning them.

"Points of view" should be identified as particular views on the meta-model (M2) (i.e. representing every objects concerning one actor in an activity). In a tool, the point of view is a particular view on the model (i.e. the mason will see the built works that he is working on at the meeting date).

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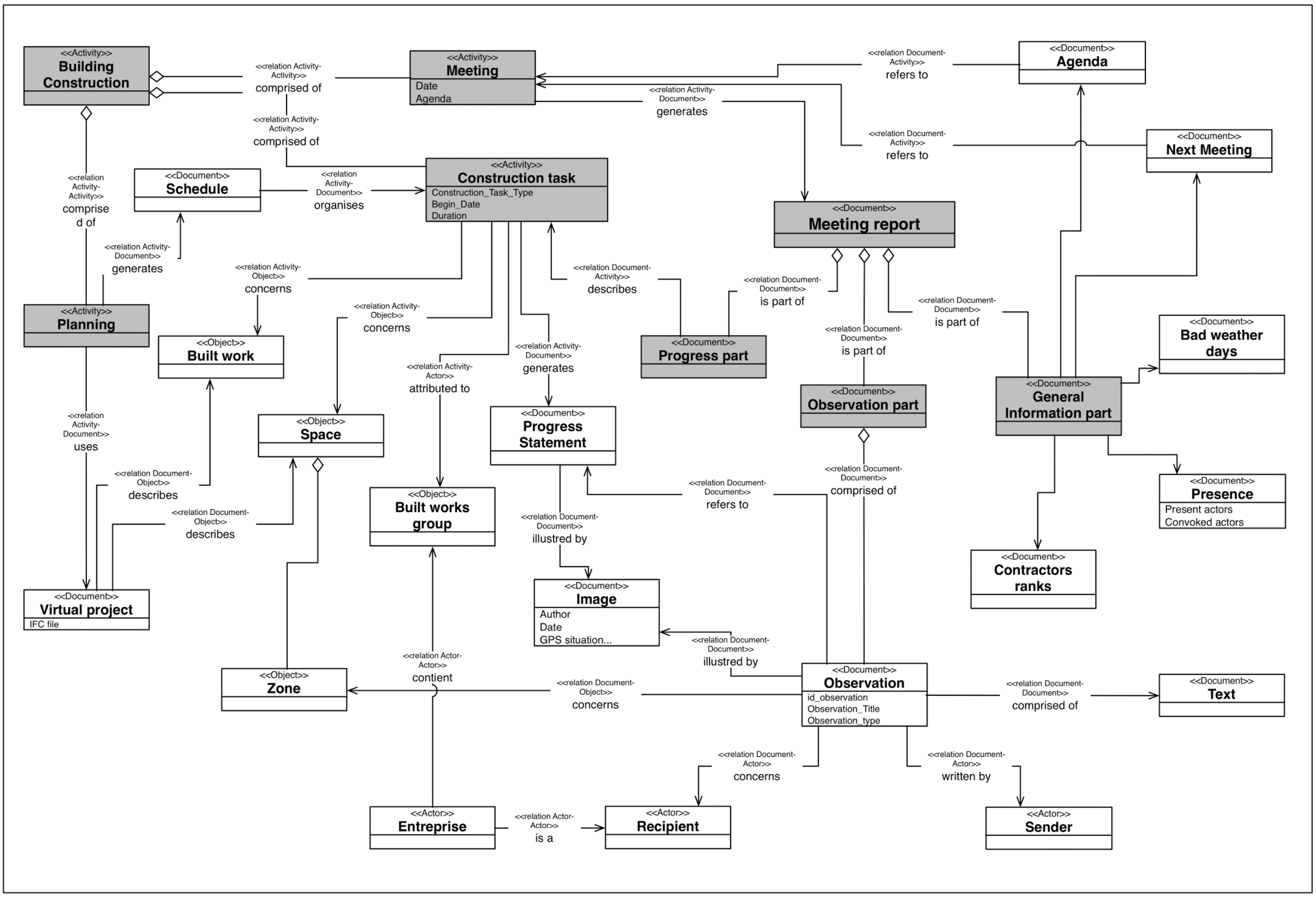

Figure 2. Cooperation model centered on the meeting report.

We distinguish between two types of points of view, "a priori" and "on demand":

– "A priori" point of view can be defined on the base of analyses. For example, we know that in usual cases of use, a contractor needs to restrict information to his activities (i.e. built works in progress). To the contrary, architect needs to have a global view on the activity.
– "On demand" point of view should be build by the user of a tool, dynamically and relative to his needs. The structure of the point of view is the ideal structural view to help understand the system (Rousseau 2003).

Finally we have experiment with the benefits of digital image use in information transfer for coordination. The role of the image is to be a trace of the activity in progress.

Modelling these concepts linked to the meeting report allows us to build the database structure implemented in our prototype tool.

The objective of our prototype[4] is to demonstrate the capacities of a new distribution of coordination information.

In this framework, we have restricted our development in order to isolate some concepts:

– The progress points: information relative to the progress of a building element,
– The particular points: information and description of a singular problem. They are characterised by a sender (author) and one or many receivers,
– The integration into an Information System allows us to manage some points of view: the prototype, in its present state, offers the user filters of the information,
– The model demonstrates that links can exist between different types of information: i.e. a particular point should concern one or many progress points. The tool suggests a chronological link (pictures of many state of progress) and a topological link (surrounding building elements).

The user just needs a web-browser to visualise information. Access to the tool is personalised by the actor role (identification by login and password).

4.1.2 *Experiment*

In order to validate these first propositions, we are now experimenting with the tool in a real building construction site[5].

We distinguish between three main objectives:

[4] Demo available at http://tsunami.crai.archi.fr:9292/ (login: *demo* and password: *demo*)

[5] Reconstruction of the "Vincent Van Gogh" middle school in Blénod-lès-Pont-À-Mousson (France). Cartignies & Canonica Architects.

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– Defining what information is exchanged for co-ordination,
– Validating functionalities of the provided tool: structure and visualisation of information,
– Verifying the benefits of digital image use for as-

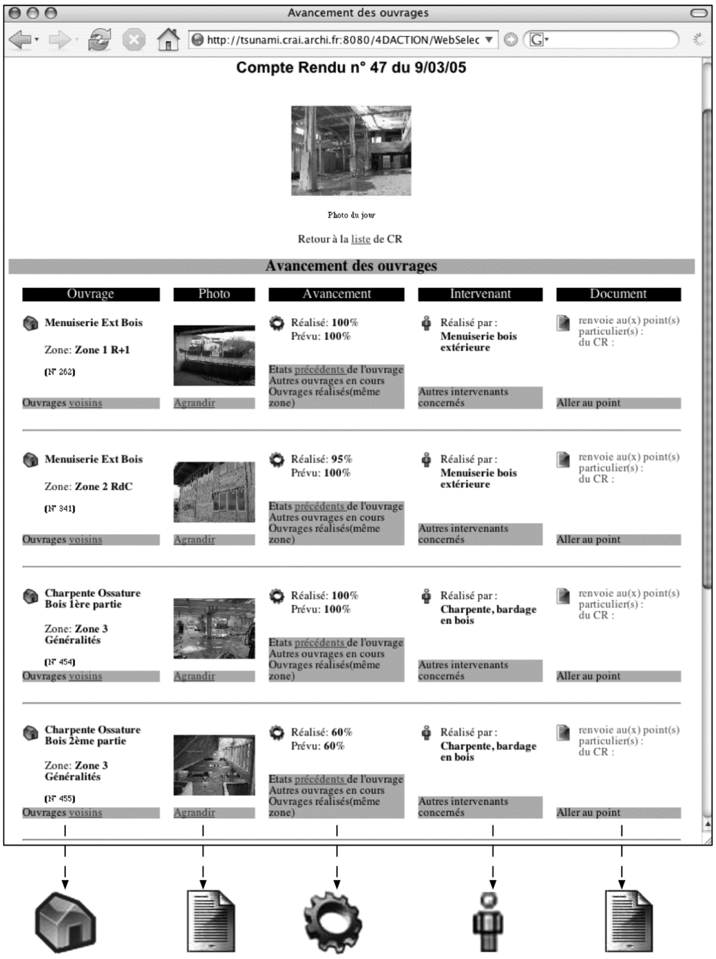

Figure 3. Screenshot of the interface (progress information)

sisting communication between actors.

Different stages have been planned in this work:

– Analysis of user needs and development of the tool prototype,
– Use of the tool in the building construction framework as a visualisation tool of coordination information by the different actors,
– Validation stage by oral interviews. The goal is to determine the interest of a new assistance tool in general and more particularly to assess our propositions.

4.1.3 *Comments on experiment results*

Despite the fact that the validation stage is still in progress we can underline some interesting results rising from interviews of actors:

– First, the tendency to use new tools based on IS seems to be largely admitted by actors. Nevertheless they are not ready to use such tools in their companies,
– Then, we have noticed a regular use of our tool by some actors: the owner and some members of the engineering team. They were interested in the possibility of having a look at the building construction process without regular visits to the site,
– We can say too that the "proof effect" of the building construction image is globally acknowledged (verifying of the observed result compared to the expected result),
– Finally, it seems to be confirmed that the image carries out a function of anticipation and identification of new problems, particularly for distant users.

4.2 *Specifications for a digital assistant for cooperation during building construction stage*

The theoretical analysis and experiment described above allow us to suggest some hypotheses on the utilities and benefits of an assistance tool for cooperation during building construction.

Beyond the propositions of instrumentation of the meeting report explored in the prototype called *Image.Chantier*, it appears that a larger tool should assist building construction management.

We have identified the visualisation and representation of the project context as fundamental for actors.

The model of cooperation centered on the meeting-report, used in our prototype tool allowed a logical representation of context elements in the interface (*activity*, *actor*, *object* and *document*).

The meeting report is a limited document. Latest developments of our cooperation meta-model and work on the meeting report model let us imagine new specifications for a *digital assistant for cooperation during building construction*. Such a tool has to:

– Integrate *time* management (*activity* M2) through a link between coordination information (meeting report) and task planning (e.g. situating the problem in time),
– Favour *spatial* (*object* M2) comprehension of the built works related in the documents. Built works properties come from the design stage and can inform construction activities (i.e. situating the problem spatially). Different representation modes are available to provide such information: digital mock-up for 3D representation or digital image taken on the site,
– Display *actor* (M2) organisation and structure, i.e. hierarchy? ,
– Inform about links between activities or actors and *documents* (M2), i.e. what are the documents referring to this built work?

4.2.1 *Linking coordination information and planning information*

Numerous research works focus on the integration of the time dimension in the designed object. 4D consists of integrating 3D mock-up and execution planning. These works try to anticipate the building con-

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struction activity by providing a link with design activities…

Building construction management is composed of two major activities of coordination:

- Building construction "setup" consists of planning the execution of the different building construction tasks within the time scale,
- Building construction surveillance allows the coordinator to control progress and schedule.

At present we observe that the link between coordination documents (e.g. meeting report) and planning does not exist. However this link is essential, i.e. for analysing the effects of a coordination problem on the work schedule or a new task combination etc.

The different sources of "multi-actor" coordination information have to interoperate in order to ensure the surveillance of construction progress (increasing quality of information).

The comprehension of coordination information *related to time* is part of *project context* comprehension. It favours quality of individual actions and "inter-actor" coordination.

4.2.2 *Using digital medias to situate the objects*

Different medias should be used to situate the objects spatially. Their properties allow us to imagine specific use cases:

- 3D representation allows us to represent "designed built works" (i.e. digital mock-up),
- Construction site image represents built works under construction or already built.

The 3D digital mock-up and image let us display information relative to the point of view of the user on the project context.

For example the visualisation of interfaces should be the point of view of the pilot. In the model, an interface is represented by the link between tasks (e.g. follows). A digital mock up can isolate the built works in question and display it.

4.2.3 *Visualisation*

The 4D methods that we analysed suggest that we complete information coming from the design stage with building construction planning information.

Tanyer and Aouad (Tanyer et al. 2005) describe the limits of these propositions especially concerning visualisation that "*should include more than just the graphic representation of the building*". Planning activity is another subject of research. In 4D research works, planning information completes the 3D model of the project (Chau et al. 2005).

Visualisation of information is a problem because of the complexity of the 3D model and the size of the planning document.

The combined use of different visualisation methods should allow us to facilitate the comprehension of the organisational context by the user. The choice of a visualisation method depends very much on the entity (M2) to be represented:

- Objects (M2) are described by the image or the digital mock-up,
- Activities (M2) and links between them are represented by graphs (as Gantt or Pert graphs),
- Documents (M2) and actors (M2) are described in lists of text or tables,
- The relations (M2) between entities (the context in general) should be visualised by a hypergraph.

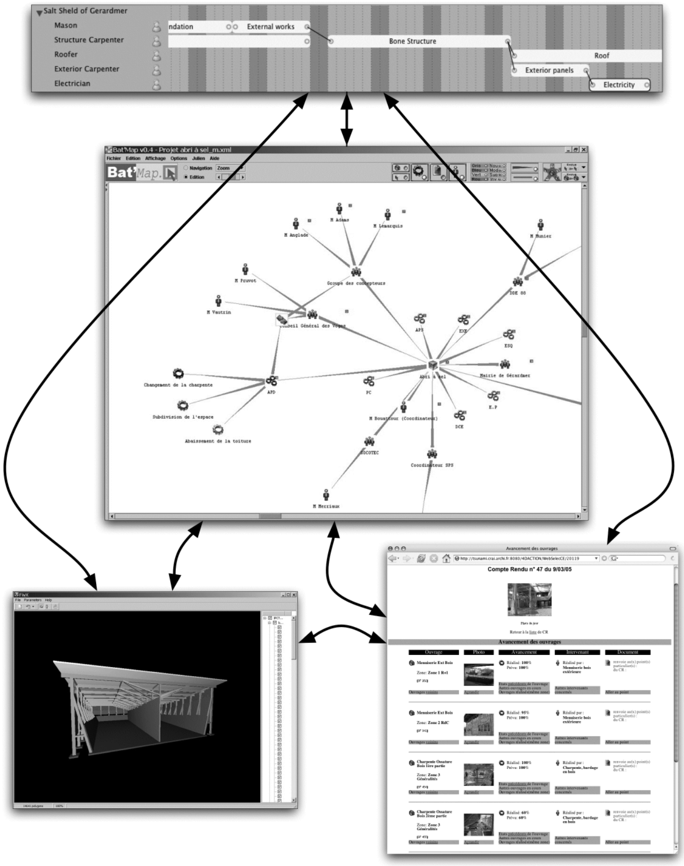

Figure 4. Representation modes, links and transitions between information.

Technologies of hypergraphs have been experimented with in recent works, allowing the user to have a graphical visualisation of the organizational context. Bat'Map prototype tool, developed by the CRAI (Halin et al. 2003), focuses on the design stage. In Bat'Map, the hypergraph is used to represent the organisation in design activity.

We suggest using such a representation method in a tool for the building construction stage. The point of view should be centered on the *building construction task.*

These different modes of visualisation should become *visualisation modules* of a *digital assistant for cooperation in building construction stage.*

In order to optimise the interface of the tool, it will be necessary to think about the needs of the different types of users.

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The system should suggest a group of predetermined modules, relative to the identified needs or actions of a user.

For example, planning and text allow the user to visualise the consequences of a coordination problem for the activity (i.e. delays). Planning and digital 3D mock-up allow him to locate spatially the built work(s) in question…

5 CONCLUSION

The AEC production sector is at present undergoing significant changes. Particularities of the building, resulting from design and realisation activities, require the adaptation of the work methods of the different actors involved in a project.

New tools have been appearing for some years capable of assisting the different professionals in their activities. But we observe that these tools are designed to serve the strategies of independent actors, in their own companies. They do not favour or facilitate dialog and cooperation between the different actors.

The cooperation meta-model (M2) described in part 3 of this paper focuses precisely on the relations existing between the different entities comprising the project context. These relations are the basis of cooperation.

In the building construction stage, cooperation between actors is essentially a coordination activity, especially the coordination of tasks carried out by the contractors. The model centered on the meeting report (M1) is an instantiation of the meta-model (M1). It shows the central role of this document in construction activity coordination.

We have experimented with a prototype tool to establish the potential benefits of Information and Communication Science on the diffusion of coordination information:

- Managing points of view of the information,
- Creating and using links between diverse information sources,
- Adapting visualisation of information, based on the meta-model concepts.

The experiment shows that such new tools interest the professionals and they are conscious of the potentialities of these tools in their everyday work.

Our study is now being directed towards building construction management and cooperative activities, beyond the meeting report document.

Time management begins with the building construction setup when execution planning is drawn up. The digital mock-up, coming from the design stage, is enhanced with schedule information (4D).

During the construction activity, coordination information is produced and exchanged (meeting-report). Capitalising this information is essential to manage building construction knowledge (technical, organisational etc.) and to re-use it during design stages.

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Why interactive multi-disciplinary collaboration in building design is better than document based design

K.K. Yum
CSIRO, Manufacturing Infrastructure Technology Division, Highett, Victoria, Australia

ABSTRACT: This paper presents a theoretical framework of Interactive Multi-Disciplinary Collaboration (IMDisCo) for building design. This framework puts the whole design and communicative process into a project-based problem solving setting that is compatible to today's supply chain management framework. It also offers a set of evaluation methods based on (1) quality, and (2) cost of the design. An analysis of the framework shows that IMDisCo offers more design options than the conventional approach of document based design. With the help of suitable technology, the turn-around-time of design in IMDisCo can be shorter than the conventional approach. And thus the (theoretical) optimal design quality (cost) can be higher (lower) than the document based design. Three critical success factors for the framework have been presented. Finally, this paper discusses the future work of establishing the IMDisCo framework as an *industry* framework. In the longer term, the emerging new software that supports goal setting, design and evaluation will further enhance the paradigm shift of interactive multi-disciplinary design.

1 BACKGROUND

There has been a number of persistent issues in using Information and Communication Technologies (ICT) in the building and construction industries: (1) any rational arrangements of ICT in a project have to be reorganised in another project because project partners are different and software/hardware are all different; (2) the uses of advanced ICT in professional practice are scant and they do not sufficiently integrate with each other to present a coordinated benefit to the owner; (3) there is no incentive for the professionals to work together if they are not paid for that purpose; (4) except for the very few high profile projects (such as the National Museum Australia Project, Peters *et al.* (2001),) owners are generally not experienced enough to be able to exercise their potential and preference to seek optimal benefits from the price they have paid for the project.

With the advent of Industry Foundation Class data standard (IAI–International 2005), it is now possible to organise industry data in a standard way so that different partners, software and hardware can interpret the same piece of data with no loss of information. There are emerging advanced ICT tools that can communicate on IFC data. So the issues (1) and (2) can be resolved by adopting IFC technology. Issues (3) and (4) cannot be resolved completely via technology. They will have to be addressed from the point of view of benefit: What is in it for them to work together using common data standards like IFCs?

This paper presents a theoretical framework for interactive multi-disciplinary design. This framework puts the whole design and communicative process into a project-based problem solving setting that is compatible with today's supply chain management framework. It offers a set of qualitative evaluation methods based on (1) quality and (2) cost. It is hoped that this framework can be recognised by the construction industry, and will evolve into a stable industry framework of interactive multi-disciplinary design for various design innovations to plug in.

2 INTERACTIVE, MULTI-DISCIPLINARY COLLABORATION FRAMEWORK

The proposed Interactive, Multi-disciplinary Collaboration (IMDisCo) framework is as follows:

1 Establish collaboration structure to share goals, profits, and risks.
2 Set goals (quality, budget, time.)
3 Align processes.
4 Each discipline selects their solutions and shares critical data for design and management that affect each other's work.
5 Evaluate and coordinate solutions.

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6 Repeat steps 2-5 until a satisficing, solution is agreed upon.[1]
7 Adopt the selected solution.

The framework has a few underlying assumptions. First, it is not an idealistic framework requiring people coming together to work for the common good of a project. It is the owner's benefit to drive the adoption of collaboration. The owner pays for the collaboration in which they can access and influence decision making in the design. The owner pays to control sustainability and life-cycle value. See Section 3.

Secondly, this is a collaborative framework across disciplines. Project participants are working to deliver value to the owner of the project. They share the profit and the risk. They are not in the business of pushing the risk to project partners. They share the goal of solving problems and delivering overall value to the client or the ultimate user of the building.

Thirdly, the collaboration works on a unified interpretation of a common building model. This is a technology adoption that offers productivity and efficiency.

Fourthly, the evaluation stage within each design pass is important – it decides how well the designs of various disciplines are put together to form a satisficing solution for the owner.

The following sections expand the discussion of the framework.

3 ESTABLISH COLLABORATIVE STRUCTURE

When the professional project team is working for a client, they are in fact part of the total supply chain of the client. According to Cohen & Roussel (2005), p.20, the supply chain has to collaborate to meet the following criteria: (1) aligned with the client's business strategy, (2) aligned with the client's customer needs, (3) aligned with the client's power position, and (4) adaptive. Similarly, the IMDisCo framework also requires the work strategies and structures of the professional team to meet the above criteria.

The alignment with the owner's interest is central to the organisational aspect of the construction business. It is related to procurement, contracting, and risk sharing, as opposed to *risk shedding*, according to Dawson, *et al.* (2004). This is out of the scope of this paper. For a practical example of aligning work strategies and structures with the client's strategic interest, the reader is referred to the Acton Peninsula Project Case Study (Peters, *et al.* 2001).

[1] *Satisficing*, a term coined by Herbert Simon, is a cross between 'satisfying' and 'sufficing'. It refers to the fact that when human are presented with numerous choices, we usually select the first reasonable option, rather than the best one available.

4 COLLABORATIVE WORKING

Figure 1 shows the schematic workflow and data sharing of the iterative part of the framework. The design process iteration is equivalent to the steps (2) to (6) in Section 2. Traditionally there are at least three key "stages" of design iteration:

1 Outline design – The goals focus on general approach to function, mass, space, layout, overall relationships and building performance requirements.
2 Schematic design – The goals are to work out site plan, floor plan, basic building mass, façade layout, basic materials and physical systems (structural, mechanical and electrical,) estimated construction costs.
3 Detail design – The goals focus on constructability, surface details, physical systems engineered and layout.

There can be more than one iterative passes for each of the above key design stages.

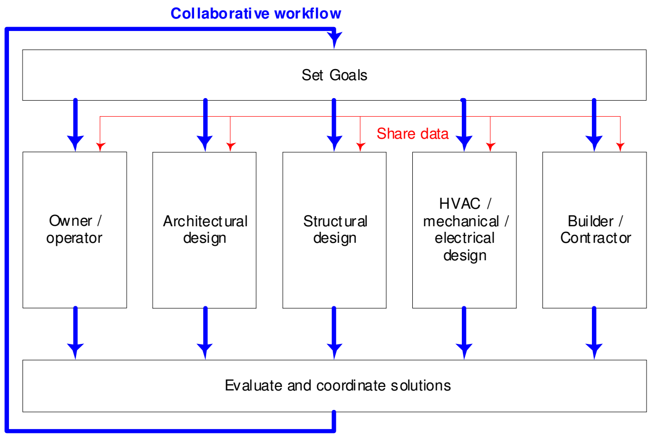

Figure 1: Collaborative workflow and data sharing

In the following subsections, the key process elements in the outline design pass will be examined through examples.

4.1 *Outline design*

According to Figure 1, the outline design stage involves many disciplines as well as the owner (the owner's representative) In this paper, we cite examples from the perspective of HVAC design to see how they work with other disciplines.

4.1.1 *Set and share goals for HVAC systems*

ASHRAE (2004), pp.11-14, lays down the following energy design goals for small office buildings:

1 Reduce load on energy-using systems.
2 Size HVAC systems for reduced loads.
3 Use more efficient systems.
4 Integrate building systems to increase energy savings potential.

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These goals are recognised and shared at the beginning of the outline design stage by *all* project participants. They will work together to achieve these goals to deliver value to the client.

4.1.2 Align processes

All collaborating companies align their processes so that they chain their process and data together:

1 Select team*‡
2 Prepare owner's project requirements*
3 Select the site*
4 Define budget*
5 Prepare design and construction schedule
6 Define specific system preferences*
7 Define energy cost / efficiency program opportunities*
8 Code standard requirement / targets
9 Establish prioritised list of energy goals*

* HVAC/Energy actions.
‡ Absorbed into Section 3.

The above action list is taken from ASHRAE (2004), p.6. Actions are not particularly designed for IMDisCo framework; however, many of them can be arranged to fit into the framework. Similar aligned processes for the schematic and detail design stages can be arranged respectively.

4.1.3 Run design processes

The collaborative team (including the HVAC engineer) step through the aligned processes in Sub-section 4.1.2 to run their design; i.e. expand design goals into strategies, and select solutions from the strategy to fulfil the goals. At this stage, each discipline (architecture, Structure, HVAC, etc.) may have their own design model. They will have to integrate their outline design solutions into one at the next phase (Sub-section 4.1.4.)

4.1.4 Integrate, evaluate and coordinate solutions

The multi-disciplinary design team gets together to merge their solutions into an integrated model (Section 5.) They then run evaluation sessions (Section 6) on their integrated model and coordinate changes if necessary to produce an integrated, consistent outline model for the next stage of schematic design.

5 SHARE AND CHANGE DATA

There are three different types of data sharing in the IMDisCo framework. Firstly, the underlying model for collaborative work must be shared at the beginning of each design pass, so that all disciplines start their work on a common ground. For example, at the outset of the schematic design stage, they share the same *underlying* outline model; and at the outset of the detail design stage, they share the same *underlying* schematic model.

Secondly, within each design discipline, the designer and/or engineer can make any changes to deliver their design goals. However, in a multi-disciplinary collaborative design situation, there are changes that affect more than one discipline. This is where the idea of "interactive design" comes from. With the advent of interoperability technology and software tools (Dawson, *et al.* 2004), building design data can be changed into the (shared) building model to become readily accessible by all relevant disciplines; and the designer/engineer of these disciplines can immediately run design simulation and visualisation to determine whether such changes will have positive or negative impact on their bottom line. Simply put, the multi-disciplinary team can interact with computer programs to determine the merit of changes of design data. For example, the builder (who represents the interest of cabinetmaker and the tiler) may insist on maintaining certain dimensions of internal wall-to-wall measurements of kitchens and bathrooms so that they can use of standard sizes to save time and cost.

Thirdly, when the multi-disciplinary team start integrating, evaluating and coordinating their design solutions into a newly refined model, they will have to share the data that have formed the basis for integration. For example, the size and construction of some windows may be changed to enhance the thermal performance of a thermal zone of a building. The size of windows may have some aesthetic impacts on the building appearance. Such changes will have to be agreed by the architect and the changed data will be shared with the rest of the multi-disciplinary team.

5.1 Data type for exchange

Before running an efficient data sharing session for interactive multi-disciplinary design, data types must be prepared and organised in advance for the use of various software applications (design tools.) The efficiency is derived from the fact that the shared data of the building model from the upstream application can be interpreted correctly and used readily by the software tool downstream. The Finnish "Product Data Model in the Construction Process" Project (ProIT 2005) publishes a set of data exchange use cases, identifying the data requirements for multi-disciplinary exchange scenarios. In the domain of HVAC design, ProIT identifies the information/data type for exchange between the architect and the HVAC designer/modeler depicted in table 1.

5.2 Data standard

Given the change of clients, project partners, software and hardware between projects, the organisation of data types requires repeated definition from project to project. If there is no data standard to adhere to, the

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transfer of data organisation on each project will incur a penalty cost (money and time), which reduces productivity and efficiency (NIST 2004.)

The ProIT (2005) use cases map their data requirements to corresponding sets of IFC standardised data elements (IFC Aspects.) When the software tools are all developed to standardised data requirements, they will be able to correctly interpret data from upstream with little or no human intervention.

Table 1: Data type required in the Architect to HVAC engineer data exchange use case, (ProIT 2005.)

• Identification	• Logical location of building elements
• Project	• Building elements
• Site	• Building element shape
• Building	• Building element construction type
• Storey	• Building element material properties
• Space	• Special properties of building elements
• Space shape	• Equipment elements
• Project containment structure	

6 EVALUATE AND COORDINATE SOLUTIONS

Evaluation may come from inside the design team or from outside the design team. External evaluation is for the purpose of evaluating the design result completed by the design team. (See Section 7.) Internal evaluation is concerned with the evaluation from within the design process for the purpose of selecting a design solution (This section.)

Integrated design alternate solutions can be evaluated by considering the following factors: (1) Client's requirements and preferences, (2) overall quality and quality of the design of each design discipline, (3) overall cost and cost of design of each discipline.

6.1 Client's requirements and preferences

All design solutions should be able to satisfy, as much as possible, the client's requirements and preferences. Over time, the following questions will be asked and answered at the design solution evaluation session in each pass of design iteration (Figure 1.) Has the strategic position of the client been taken care of? Does the client want whole life cycle value in the design? Does each discipline offer whole life cycle value in the design option? Can the design team and members offer qualitative or quantitative measures for the fitness of their design solution to the client's requirements?

6.2 Overall quality and quality components

Peters *et al.* (2001) offer an example of how quality measures of a building should be considered. Their measures are primarily designed from the usage perspective (how good the designed building is used by the end user) (p.53.) Their measures are for external evaluation, which is different from the purpose for internal evaluation in this framework. However, the way they measure quality can be a good way for the IMDisCo framework.

For internal design solution purpose, quality measures can be broken down into the following major types:

1 Matching corporate identity and requirements
2 Meeting urban planning and sustainability requirements
3 Site, neighbourhood
4 Building, including buildability
5 Usage of building
6 Environment
7 Health and Safety

Each of the quality type can be further broken down until they are related to a design discipline. For easy referencing, the notation Q_j will be used to refer to the quality measures, where $j = 1, \dots, n$; and n is their total number. Generally the number n can be large; however, the quality measures can be *aggregated* into corresponding disciplines, so that each (aggregated) measure has a discipline to look after it. These quality measures change from project to project; and even within the same project, they can be different from designer to designer due to personal preferences.

The overall quality is the sum of weighted measures of all quality measures Q_j, where $j = 1, \dots, n$. As the weights can be different from project to project, it is as convenient to consider the overall quality as the tuple $Q = (Q_1, Q_2, \dots, Q_n)$ in general discussions – weights will be added in specific projects.

There is no simple or proportional relationship between overall quality Q and quality component Q_j. Sometimes there can be adversarial relationships between qualities Q_j and Q_k ($j \neq k$). For example, in a particular building site, it is better to have a ceiling-to-floor window facing west because the opening window is facing the sea in that direction. However this site orientation may have sub-optimal effect on the thermal design as well as service life of windows. In many cases, the designers have to trade in their optimal preferences for the overall quality.

As the quality measures $(Q_1, Q_2, \dots, Q_n)$ are dependent on the design parameters in a complex way, the collaborative team can change the parameters in the model by observing how such changes can improve individual quality measures and the overall quality. Traditionally the effect of changing one design parameter on various qualities of the building

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could not be readily seen or felt because it took time to make the changes (e.g., redraw all changed windows) and it took time to comprehend the effect of changes (e.g. their effect to thermal performance of building.) With the help of interactive design tools based on the same building data standard (Subsection 5.2), the effect of changing can be readily seen and computed in the computer in a matter of minutes or hours rather than days or weeks. Interactive multi-disciplinary collaborative design is now feasible.

6.3 Overall cost and cost components

In the area of design, cost is really cost estimation. The cost of the design is generally proportional to the quality and quantity of items/materials/systems available. The total cost also depends on the expertise of and the methods used by the cost estimator. The latter consideration is outside the scope of the paper.

The error of cost estimation is roughly inversely proportional to the detail level of design. A more detailed design reduces the probable percentage error. (Merritt & Ricketts 2000).

Each quality aspect Qj is associated with a cost Cj, where j = 1, …, n, and n is the number of qualities. Without automatic quantitative tools, it has been difficult for the designers to get the cost quickly, especially at the detail design stage. This is all possible now, thanks to the emerging automatic quantity takeoff tools and cost estimation tools running under the unifying common IFC model.

The total cost is the sum of all costs $C_1 + C_2 + \ldots + C_n$ – any overlapping costs. So C may not be equal to $C_1 + C_2 + \ldots + C_n$. For example, the cost of wall materials may be duplicated in the costs of acoustic design, thermal design, construction and sustainability considerations. It is natural to seek optimal quality Q with minimal cost C. However in the real world, higher quality is usually bought with higher price; and there is a minimal quality that is desired by the building control authority. The owner and the design team must seek for a satisficing solution, a compromise between quality and cost. For this to happen, more iterative design passes are in order.

7 IMDISCO EVALUATION (EXTERNAL)

How does the IMDisCo framework compare with the traditional document based design? From the owner/client's point of view, the following issues matter: (1) quality, (2) cost for quality, and (3) time for reporting design progress, feedback and consultation.

In order to make comparisons, it is appropriate to formulate each quality/cost measure as a function of three types of variable:

Quality $Q_j\left(i_1,\ldots i_r, p_1,\ldots p_s, o_1,\ldots o_u\right)$, and

Cost $C_j\left(i_1,\ldots i_r, p_1,\ldots p_s, o_1,\ldots o_u\right)$, where

$i_1,\ldots i_r \in Q_j Inputs$, $Q_j Inputs$ is the set of all exchange data from upstream applications as discussed in Subsection 5.1 (e.g., sizes, orientation and constructions of windows that will affect the HVAC design / performance);

$p_1,\ldots p_s \in Q_j Parameters$, $Q_j Parameters$ is the set of all intrinsic parameters for the design;

$o_1,\ldots o_u \in Q_j Outputs$, $Q_j Outputs$ is the set of all design outputs for quality measure Q_j (e.g. HVAC loads and equipment sizes.)

Due to the use of Building Information Model (BIM) technology, e.g. (Khemlani 2003.), and a common data model standard (IFC), it is possible for changing and evaluating the quality Qj value by changing design variables $i_1, \ldots, i_r$ from the upstream and the output variables $o_1, \ldots, o_u$.

7.1 Comparison baseline: Document-Based Design

The IMDisCo framework is compared with the conventional document-based design (DocBaD) framework.

In this paper, the DocBaD framework is assumed to have the following characteristics.

1 It adopts a *waterfall* model from design to build to operate/maintain. Design is separated from the build process. Generally the build process follows the design plan. However, if it is not possible to follow through, the build process may take its own course. In the end, design and build may have divergent results.
2 Members of the design team work on their own designs. They communicate with each other at the beginning of each design pass. Generally they work around with what they are given. They seldom, if not never, ask the upstream collaborator to make changes for their design benefits. After they have done their work, they may share their final design plans (documents) around, but they seldom share computerised data, or any other things that do not make a profit, or make them liable for lawsuits.
3 Once a design is integrated and documented and sent out, it implies certain degree of "design completeness". Changes are seldom made unless they are necessary. For the reputation of the design team and its members, consultation with the

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owner and public offices (fire, police, regulatory body, etc.) is done at a relatively late stage (when design work is complete) rather than at the early stage.

7.2 IMDisCo may offer more quality and cost effective alternatives for design consideration

In the DocBaD framework, changes are slow and costly to make. Each design document of the upstream process has an unintentional dominating influence on the downstream discipline: Once a design decision is made in an upstream discipline (e.g. architecture), the downstream discipline, most likely, accepts it as a design requirement and thus restricts their design options. ((2) of Sub-section 7.2.)

Suppose i_1*, …, i_r* are (fixed) inputs variables from the up stream plans, then the following inequality is true for each quality aspect j, j = 1, …, n, where n is quality number (defined in Section 6.2):

$$\max_{\substack{i_1,\dots i_r \in Q_j Inputs \\ p_1,\dots p_s \in Q_j Parameters \\ o_1,\dots o_u \in Q_j Outputs}} \left\{ Q_j\left(i_1,\dots i_r, p_1,\dots p_s, o_1,\dots o_u\right) \right\} \geq \max_{\substack{p_1,\dots p_s \in Q_j Parameters \\ o_1,\dots o_u \in Q_j Outputs}} \left\{ Q_j\left(i_1^*,\dots i_r^*, p_1,\dots p_s, o_1,\dots o_u\right) \right\}$$

(Formula 1: quality optimisation at pre-documentation stage)

Proof: The left hand side of the inequality represents the quality optimisation of the IMDisco framework. The down stream designer can ask for changes in the up stream value i_1, …, i_r to accommodate for their quality optimisation because such request in the upstream discipline can be easily fulfilled with the help from the data sharing standard and ITC tools.

Whereas in the traditional DocBaD practice (represented by the right hand side of the inequality), the up stream inputs cannot be easily changed. Even if they can be changed, the number of variations is severely limited. For the sake of simplicity, we assume that i_1*, …, i_r* are inputs variables from the up stream plans; and they cannot be changed.

Therefore the range of values for optimisation for the left hand side covers the range of values on the right hand side. Hence the inequality is established.

After design decisions are made and design documentation is done, in the IMDisCo framework, all design variables (Q_jParameters and Q_jOutputs) can be changed as easily as before because the computerised building model is the documentation. However, in the DocBaD framework, the designers cannot afford too many changes in their design parameters (Q_jParameters' and Q_jOutputs') as they have been *fossilised* in documentation, not in every collaborator's computer. So we have the following containment relationships after design documentation:

Q_jParameters (in IMDisCo) $\supseteq$ Q_jParameters'(in DocBaD), and Q_jOutputs $\supseteq$ Q_jOutputs'

Therefore we have the following formula:

$$\max_{\substack{i_1,\dots i_r \in Q_j Inputs \\ p_1,\dots p_s \in Q_j Parameters \\ o_1,\dots o_u \in Q_j Outputs}} \left\{ Q_j\left(i_1,\dots i_r, p_1,\dots p_s, o_1,\dots o_u\right) \right\} \geq \max_{\substack{p_1,\dots p_s \in Q_j Parameters' \\ o_1,\dots o_u \in Q_j Outputs'}} \left\{ Q_j\left(i_1^*,\dots i_r^*, p_1,\dots p_s, o_1,\dots o_u\right) \right\}$$

(Formula 2: quality optimisation at post-documentation stage)

Along similar reasoning, the inequality for cost minimisation between the IMDisCo framework and the DocBaD framework can be established – with operators ≥ being replaced by ≤, *Max* being replaced by *Min*.

Formulas (1)-(2) imply that the IMDisCo framework offers more choices for quality optimisations and cost minimisation than the DocBaD framework.

In reality, quality optimisations and cost minimisation cannot be achieved due to the complex relationship between design parameters and due to the positive correlation between quality and cost.

When a downstream quality design Q_k asks its up stream design process j for changes in the output parameter Q_jOutput, this may restrict the limitation of the output range Q_jOutputs in the quality design process j and hence the validity of formulas (1)-(4) is not always true. However, in many cases, given all things are equal, it seems that IMDisCo framework does offer many more design options than the DocBaD framework does.

In summary, the final design is one that offers a satisficing overall quality Q = (Q_1, Q_2,… , Q_n) with a total cost C.

7.3 Critical success factors for IMDisCo

Currently there are few projects, if any, that are running under the IMDisCo framework. There are cultural barriers as well as technical difficulties that

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make people resist changing to a higher level of productivity. In order to make IMDisCo a reality, the following three critical success factors (CSFs) for the IMDisCo framework must be made available *simultaneously*:

1 The owner recognises the benefits of the IMDisCo framework and offers commercial incentives to make it happen -- *Sharing profits, sharing risks, and aligning goals*. The owner has to have an understanding of the penalty of the adversarial lowest cost tendering approach.
2 The collaborating professionals adopt data standards (such as Industry Foundation Classes, IFCs) so that *sharing data* can be readily achieved across project structures to cut down cost.
3 Advanced software design tools are available so that design solutions can be made and compared in terms of *quality* and *cost*.

CSF (1) is outside the scope of this paper as it is related to the procurement issue. However, without acknowledging the strong influence of this factor, nothing can be achieved.

The technical support for CSF (2) is available from the IAI community. For further technical details and support, the reader is referred to IAI (2005.)

Here this paper provides a summary of what software is now available for CSF (3).

Key CAD software packages are currently under gone transformation. They are gradually moving from documentation (drafting) to 3D design and performance measurement with visualisation capability, based on the integrated Building Information Model (BIM) for down stream applications. See e.g., (Khemlani 2003.)

In their promotional materials, major CAD companies emphasise smooth data transfer between their key CAD platform and their associated products (e.g. structural engineering tool, HVAC engineering tool, etc.) within their proprietary data format. In practice they cannot be consistently applied across multiple projects and teams, and there are few or no methodologies for linking them up in an integrative framework like IMDisCo. Despite impressive complexity, they generally do not support goal setting, and they do not offer explicit support for the evaluation of design option. At present, the evaluation approach of many design software tools can be regarded as *ad-hoc*.

Fisher & Kam (2002) present a report on the evaluation of the benefits of applying product data model technology in the Helsinki University of Technology Auditorium Hall 600 (HUT-600) project in Finland. The way in which product data modeling was used is, again, ad-hoc; but it is compatible with the IMDisCo framework in this paper.

Setting design goals, visualising simulations and running design iterations to select a design option offers a new design paradigm – interactive design by visualisation and by simulation. Tucker *et al.* (2003) present a case study of how their LCADesign software package was used to evaluate the life cycle performance of design options.

There will be more design tools in software to support this “set goals-design-evaluate” interactive design framework in the future.

7.4 Turn-around time

Turn-around time in this paper is defined as the time required for running a pass in the iterative design loop in Figure 1. Thus

Turn-around time =

> Goal setting time + Input-data coding and verification time + Overall design time + Coordinating solution time + Evaluating solutions time + Output solution time

Where overall design time = max of design time over all professional services working on the design (architecture, structural, building services, construction planning, etc.), as they are designing in parallel.

Turn-around time is important for the client / owner. This is roughly the time for the design team (or its leader) to finish a round of design, ready to report progress to and seek feedback from the client/owner.

Without any data collected in hand, we may compare, qualitatively through logical analysis, the turn-around time in the IMDisCo framework with that of DocBaD (Business-As-Usual) framework:

Table 2: Turn-around time for the IMDisCo framework as compared against the DocBaD framework (BAU)

Turn-around-time component	*IMDisCo time as compared with BAU*
Goal setting time	Roughly the same.
Input-data coding and verification time	Shorter, with the help from automatic data exchange / sharing.
Overall design time	Shorter with the help from software tools.
Coordinating solution time	Should be shorter based on software tools and a data exchange standard. But can take long time if more details need to be coordinated. (E.g. performing clash detection in design time instead of in construction time.)
Evaluating solutions time	Should be shorter based on software tools and a data exchange standard. But can take long time if more options are considered, and if the justifications are more objective and refined.
Output solution time	The time should be shorter with the help from software tools. Will have longer time if more details is needed to output.

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According to the above analysis, given all things equal, the turn-around-time for the IMDisCo framework can be shorter than that of the DocBaD framework. However, additional turn-around-time can be spent in the IMDisCo framework to ensure higher quality in design. In either case, extra value is added to the client/owner.

8 FURTHER WORK

This paper presents the IMDisCo framework (Sections 1-6). Because the scarcity of projects that are running in the IMDisCo framework, it makes sense to conduct a logical analysis of the benefits of the framework. It appears that there are more quality and cost options in the IMDisCo framework than those of BAU; and the turn-around-time is shorter (Sec. 7.)

However, because of the lack of a collaborative culture, collaborative infrastructure and collaborative design software in the industry, it is not easy for industry partners to adopt any framework in unison. In order to make it happen, the next important step is to promote a high level framework (such as this IMDisCo framework, or similar industry roadmap) as an *industry framework*. With the support of an industry-government collaborative programme, industry partners can start introducing small pilot projects under the industry framework. Once we have projects, we can start collecting data to evaluate their performance within the industry framework, which will then prove the credibility of the approach.

In the data collection process for evaluating IMDisCo, there are several results that will be interesting:

1 How is a satisficing quality solution $Q^* = (Q_1^*, Q_2^*, \ldots Q_n^*)$ and its related cost in the IMDisCo framework compared with that in the DocBaD framework? Are they uniformly better in one framework than another?

2 for each quality measure Q_j, there is a need to establish an *explicit relationship* between Q_j and its design variables $i_1, \ldots, i_r, p_1, \ldots, p_r, o_1, \ldots, o_r$. The established relationship will enable designers to compare and evaluate quality solutions through the negotiation of design variables.

In the longer term, once the industry framework is recognised and established in the construction industry, productivity design tools will be developed to include design goal setting, design processes and evaluation processes. Once these new generational design tools are on the market, the paradigm shrift of design process will be established. At that moment, design will be just like playing today's interactive games with multiple players – each player interacts with the computer, but, in effect, they are working collaboratively with other human players in a digital collaborative environment.

The final goal of these tools is to enable the delivery of a complex integrated solution accurately, quickly, and cost effectively.

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Socio-technical management of collaborative mobile computing in construction

A. Löfgren
Department of Industrial Economics and Management, Royal Institute of Technology (KTH), Sweden

ABSTRACT: The constant changes of plan and unanticipated events in the production process at construction sites result in communication patterns that are dynamic, spontaneous and informal. Most of the existing ICT tools do not sufficiently support informal communication for powerful collaborative problem-solving, management of site resources, handling of parallel process activities and do not correspond to the basic needs and work patterns at the construction sites. Mobile computing technologies have the potential to provide an inclusive wireless mobile ICT platform (voice and data) that can enable improved support for informal communication and on-demand data at construction sites, which can result in improved project collaboration leading to increased efficiency and productivity in the construction process. Still, an implementation strategy for collaborative mobile computing at construction sites is complex and must consider numerous issues regarding system capabilities, mobility, applications, services, integration of existing ICT systems, user interface and user devices to meet the requirements and behaviors of site workers in the mobile distributed heterogeneous construction environment. A mobile computing platform needs to be designed, implemented and managed with a socio-technical bottom-up approach realizing end user and group needs, understanding the separate issues of adoption on different organizational levels, and recognizing mobile computing as a process integrated enabling technology for improving collaboration and project communication throughout the whole construction process.

1 INTRODUCTION

It is widely known that since the boom of the personal computer and the Internet, companies and industries have experienced increased efficiency and productivity through the use of Information and Communication Technology (ICT). In the construction industry much effort has been made to improve processes with the help of ICT, but the industry has not achieved increased productivity to the same extent as others. Samuelson (2003) shows that while the utilization of ICT was high in the design phase and in facility management, the use of ICT by contractors and site workers in the construction process is surprisingly low. Part of the poor productivity figures in the construction industry could be explained by the fact that the information needs and communication behaviors in the production at the construction sites are not adequately met. Most of the available project oriented ICT tools are meant for formalized "white-collar" office use. These tools give modest support to the craftsman-like construction activities and the unpredictable, dynamic, spontaneous and mobile environment that the "blue-collar" site workers work in. Improving ICT support for the core activities at construction sites and for site workers' information and communication needs is a strategic challenge for the construction industry to increase efficiency and productivity in the construction process (Samuelson, 2003).

The construction site can be described as a reactive environment, where unplanned changes to work regularly occur (Ward et al., 2004). Unanticipated events and temporary critical problems are in this environment inevitable. The high frequency of unanticipated problem situations at construction sites is due to the inherent complexity and dynamics of construction projects (Magdič et al., 2004). Construction activities are dispersed and site locations frequently change, which is problematic when giving construction sites sufficient ICT support. The required ICT infrastructure is often deployed to the site office, but rarely reaches the construction site itself (Čuš Babič et al., 2003). De la Garza & Howitt (1998) observed that the main communication issue in construction is to provide a method to exchange data between the site operations and the site office. The communication requirement in the construction process can vary from off-site to on-site communications (Kuladinithi et al., 2003). Example of off-site communication requirement is the need to connect to networks of suppliers and other related organizations participating in

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the project. On-site communication requirements involve the direct communication between project participants at the construction site.

Quality, quantity, and timing of information are the three fundamental variables which can either hinder or facilitate successful results in a construction project (De la Garza & Howitt, 1998). As much of the administrative tasks at a construction site are still paper based, this delays the flow of data and the available information may become obsolete or insufficient. In addition, low efficiency occurs because of the gap in time and space between the paper based administrative tasks at the site and the subsequent computer work back at the office (Kimoto et al., 2005). A shift to a complete ICT-based exchange of information can improve the timely instant delivery, access and computing of information (De la Garza & Howitt, 1998). Innovative implementation and use of ICT can also enable businesses to structure and coordinate activities in ways that were not possible before, leading to new strategic advantages (Attaran, 2004).

Aouad et al. (1999) observe that during the last decade of the 20th century the construction industry has started a technological shift from ICT driven solutions to ICT enabling ones. However, the industry has become frustrated with the failing of ICT as many companies have invested in the wrong technologies without addressing business needs. Another aspect that complicates this picture is that the involved participants in a construction project typically are at disparate levels of organization and ICT use. Therefore, they are forced to use mutual project oriented ICT tools at a very low level of integration (Čuš Babič et al., 2003).

In recent years the construction industry has moved towards Internet based collaboration and project management systems, hoping to solve the fragmentation problems of construction projects and allowing project participants to get more involved at the early stages of a project. These collaborative working solutions are tailored primarily towards the needs of desktop-based fixed computers. The consequence of this is that the flow of electronic information typically reaches selected personnel in the site office (Bowden & Thorpe, 2002), leaving collaborative information and communication needs of mobile site workers inadequately addressed (Aziz et al., 2004). Many of the efficiency and knowledge-based benefits of the collaboration tools are therefore lost. Developing and extending ICT-based collaboration and project management tools to include information and communication needs at construction sites is an essential factor in eliminating these problems.

Much of the inefficiencies at construction sites arise from interruptions between activities and processes as well as delays within individual operations. These interruptions are often a result of poor planning, insufficient information and supply-chain problems (Boussabaine et al., 1999). A site based ICT platform that enhances coordination, communication and provides quick access to relevant data could reduce many of the common on-site delays present today.

The development of wireless and mobile technologies is progressing rapidly. Over the past ten years wireless networks have increased their speed more than tenfold which allows for more useful and compelling mobile computing applications and services. Similarly, the cost of handheld computing devices has plunged and their performance and user interfaces have improved. Therefore mobile computing has become a consideration for many enterprises and industries. It is believed that mobile computing has the potential of providing solutions to the ICT issues at construction sites and enabling better use of knowledge and experience of site staff to effectively handle on-site problems caused by unanticipated events (Magdič et al., 2004).

However, designing, implementing and managing a mobile computing platform in a mobile geographically distributed and heterogeneous construction project is far from trivial. This paper reflects upon some of the socio-technical collaborative aspects of mobile computing in construction. A Socio-Technical Systems (STS) perspective on technology management is the starting point for the analysis. This STS perspective focuses on the design of work for both organizational and human good and how the complex interactions between people, organizations and technology should be arranged to enhance the quality of work (Griffith & Dougherty, 2002). One of the aims of the STS perspective is to provide insights for understanding the relationships between people, technology and organizational outcomes (Griffith & Dougherty, 2002). In this paper the main argument is that a user oriented bottom-up approach is needed to succeed in adopting mobile computing in the construction industry. The purpose of the paper is to outline a schematic framework of the broad socio-technical issues of mobile computing at different organizational levels of a construction project. This can serve as a suggestion for further research in the topic of managing the technological and organizational collaborative aspects of mobile computing in construction.

2 THE ROLE OF INFORMAL COMMUNICATION IN COLLABORATIVE WORK

Informal communication plays an important role in handling unanticipated events and solving critical problems. Informal communication is not a planned activity with a set agenda or fixed location. It occurs spontaneously, almost everywhere and has a large impact on work processes and outcomes that can be

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even greater than formal communication (Johansson & Törlind, 2004). The spontaneous interactions in informal communication enable frequent and instant exchange of useful information resulting in issues being discussed and resolved as they occur, instead waiting for a suitable and scheduled time to make a formal decision (Johansson & Törlind, 2004). The nature of formal communication, on the other hand, is that it tends to be used for coordinating relatively routine transactions within groups and organizations (Kraut et al., 1990).

Informal communication supports organizational and group coordination, especially under conditions of uncertainty. It helps members of a group in learning about each other and understanding their work. Informal communication supports both the actual production and the social relations that underlie the work, and is a critical activity to initiate collaboration, maintain it, and drive it to a common goal (Kraut et al., 1990). Informal interactions are also important in getting people to know and like each other to create a common context and perspective to achieve better planning and coordination in group work. Collaboration is less likely to start and becomes less productive if informal communication does not occur (Kraut et al., 1990).

Informal communication is distance sensitive and happens most often between people who are physically close to each other (Kraut et al., 1990). Designing ICT systems that enable better support to informal interactions in dispersed organizations is a great challenge. It is difficult to overcome the distance between the space where a person is located and the space where some valuable source of information or another person is placed. Rebolj et al. (2004) argue that it is essential to shorten the distance between the real world and the virtual space to achieve efficient mobile computing. Physical distances in the real world are often expected to be reduced by the use of ICT, but the fact is that many ICT systems actually introduce a new distance in the virtual space instead. Systems that do not create the "virtual shortcut" that improve the flow of information or enable better support for interpersonal communication, make communication even more complicated.

Kraut et al. (1990) note that the more spontaneous and informal communication is, the less it is supported by information technology. ICT systems must hold special requirements to efficiently support informal interaction between people at physical distance (Kraut et al., 1990). For example, the group of people that are working together have to be connected to the same network and must be easy to get in touch with. For informal interaction to occur, people need an environmental mechanism that brings them together in the same place at the same time. Tools that inform who is online, where persons are physically located and their current activities are important in this aspect. The personal cost of communication, the effort needed to initiate and conduct a conversation, has to be low. It is therefore necessary that a system enables contacts with other persons as easy as bumping into each other in the hallway. The visual channel of a system plays an important role for informal communication. The visual channel provides a means for recognizing the presence of other persons and their availability for interaction, and creates incentives to initiate conversations. A system that supports both video and audio communication is especially suitable for enabling informal communication (Kraut et al., 1990).

Studies (Johansson & Törlind, 2004, Törlind & Larsson, 2002) have shown that many of the contemporary collaboration tools for distributed teamwork, e.g. video conferencing and shared applications, can support formal meetings to a certain extent. But to adequately support informal meetings, distributed social activities and informal communication processes that often arise spontaneously in between the formal meetings are important issues yet to be resolved. The vital informal component in teamwork communication has so far been difficult to support in collaboration applications (Johansson & Törlind, 2004). Larsson (2002) points out that the formal approach of holding meetings through telephone or videoconferences do not entirely fit the way in which geographically dispersed teams need to interact in order to "get the work done". These tools are often useful and critical to the project, but are missing the elements of day-to-day interaction between members. Finding a good time to interact, and being able to establish easy and rapid connections with co-workers need to be better supported in the technologies for distributed collaborative work. Otherwise there is a risk that the social collaboration process is reduced to a formal process where team members are "explaining to each other" instead of "thinking together" (Larsson, 2002). Extra formality and inflexibility should not be introduced into distributed collaborative teamwork without special consideration (Larsson, 2002).

3 COLLABORATIVE MOBILE COMPUTING

Often when mobile computing is adopted to improve collaborative work, the existing concept of the desktop-based computer is transformed to mobile platform. It has resulted in that the potential of mobile computing have not properly exploited (Rebolj et al., 2004). York & Pendharkar (2004) make a distinction between mobile and portable computing and their respective user groups. Users of portable computing are typically professional white-collar workers using wireless communication from laptop computers to remotely access office documents, e-mail, and corporate knowledge applications, while users of mobile computing are a more diversified group ranging

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from health care providers to blue-collar service workers (York & Pendharkar, 2004). Kristoffersen & Ljungberg (1999) explain the fundamental differences between the mobile work context and the office setting. In mobile work the tasks external to operating the computing device are most important, as opposed to tasks often taking place "in the computer" in the office setting. The hands of the mobile worker is often used to manipulate physical objects, as opposed to users in the traditional office setting, where hands are safely and ergonomically placed on the keyboard. In a mobile work environment users may be involved in tasks "outside the computer" that demand a high level of visual attention to avoid danger as well as monitor progress, as opposed to the traditional office setting where a large degree of visual attention is usually directed at the computer. Mobile workers may also be highly mobile during the actual task, as opposed to in the office, where doing and typing are often separated (Kristoffersen and Ljungberg, 1999).

Mobile computing often takes place in a heterogeneous environment with a varied context of time and space. Context changes can vary in frequency, speed, and predictability. In some mobile applications the time in which a task takes place can be just as critical as the location, and could have implications for the fit of a computing device (Baber et al., 1999). Additionally, the change of user needs as users change work contexts while using an application needs to be regarded (York & Pendharkar, 2004). Central to mobile computing is that technologies should disappear into the background so that users can unconsciously apply them to the task at hand. Mobile computing is often related to the concept of "ubiquitous computing", meaning that machines should fit the human environment instead of forcing humans to enter theirs (Weiser, 1991). To accomplish this, the practices and every day work of people must be understood and supported by an appropriate technology solution. Furthermore, heterogeneous solutions should be available to offer a variety of interactive tools for different situations, and when these solutions are networked they should provide a holistic user experience (York & Pendharkar, 2004).

Johansson & Törlind (2004) underline that mobility support is essential for both formal ICT applications and informal communication tools in distributed work environments. Mobility is vital to create awareness - awareness of people (a sense of who is around) and awareness of process (what they are doing). Maintaining awareness across distance is crucial for successful collaboration (Johansson & Törlind, 2004). In the daily activities on a construction site interactive personal communication is the basis on which unanticipated events and critical problems are solved. Magdič et al. (2004) suggest that the continuous process of problem solving is most effective if it relies on a personal decentralized level supported by mobile computing technology. Čuš Babič et al. (2003) describe that there is a twofold information flow in the construction process; an official flow of documents (progress reports, cash-flow reports, survey reports, daily plans, etc.) and an informal communication between different levels of organization concerning work progress, quantities, financial data and on-site problems. If the informal communication is not effective in this complex process it may cause delays and disruptions with lower productivity and financial losses as a result. Mobile computing can provide powerful tools to support these activities and make the information more available and the communication faster and more reliable (Čuš Babič et al., 2003).

This paper argues that mobile computing can enable better support for informal communication which is essential in handling unanticipated events and solving critical problem situations that constantly occur at construction sites. Improved informal communication has positive effects on many intangible factors like improved collaboration, mutual understanding and enhanced team relations that result in better project results and increased productivity. Mobile computing can enable information control and that data collected in the field will be more structured and consistent. All submitted and received information and data is saved, which enables their immediate use and subsequent control (Magdič et al., 2004). Mobile computing can deliver good access to timely and accurate information, and quick and efficient communication with on- and off-site personnel. This can reduce or maintain project durations, make better use of resources, increase labor and equipment productivity and decrease cost (Bowden & Thorpe, 2002). Olofsson & Emborg (2004) imply that mobile computing systems can cut lead-times, create better workflows, use resources more efficiently and increase the value for the customers. Much of the positive effects can be derived from the fact that mobile computing can save hours in travel. That time can be used in doing productive work. Mobile computing can enable delivering information "just-in-time", which allows contractors to reduce work-in-progress inventory, and thereby working capital. Reduction of cycle times and flow variation are additional benefits derived since resources materials, equipment, and personnel will spend less time in queues waiting to progress forward (De la Garza & Howitt, 1998). Other time saving effects that mobile computing can bring are improved problem solving speed which reduces the risk of crisis and cooperation between personnel becomes less distance sensitive (Magdič et al., 2004). Boussabaine et al. (1999) indicate that a wireless ICT system at a construction site could enable time savings in the order of 40-120 days per year.

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It is not difficult to understand the great potential of mobile wireless data communication in a construction environment. Just look at the case of walkie-talkie and its impact on wireless voice communication at construction sites. The walkie-talkie has played an invaluable role in wirelessly supporting the spontaneous informal verbal communication for handling unanticipated events and solving critical problems that constantly arise at construction sites. But what is missing in a walkie-talkie is the spontaneous on-demand flow of information-rich data, documents and drawings which is a vital component of construction projects today. If this information combined with improved communication tools could be obtained wirelessly at the specific location where a construction task is being carried out, mobile computing has the potential of improving productivity more than has been achieved so far by the walkie-talkie (De la Garza & Howitt, 1998). To accomplish this, mobile computing platforms must be able to deliver powerful applications with an interface as simple and intuitive as the "push to talk" feature of the walkie-talkie. To create a future all-inclusive handheld mobile wireless ICT platform (voice and data) for project collaboration is a major challenge and incentive for improving productivity in the construction process.

4 SOCIO-TECHNICAL ASPECTS OF IMPLEMENTATION

The issues of implementing a mobile computing system are complex and numerous. Network architectures, wireless infrastructure equipment, handheld computer devices, information systems, communication services, distributed collaboration tools and other applications have to be chosen and planned carefully in detail to meet the requirements and behaviors of the mobile workforce. This section will briefly highlight some important socio-technical issues of an implementation strategy for collaborative mobile computing at construction sites. Different wireless infrastructure and networking alternatives as well as capital and operational costs will not be considered here.

4.1 *The socio-technical gap*

To strategically implement and integrate an ICT system into an organization there has to be an alignment between the work processes and the technology (Aouad et al., 1999). ICT systems and work processes have to be co-developed to be able to improve organization and increase productivity. When introducing collaborative ICT systems into existing work environments and business processes it is important to recognize the fundamental socio-technical gap between what is required socially and what can be done technically (Ackerman, 2000). This social-technical gap is difficult to overcome, but it can be better understood and approached. It is critical to understand the targeted environment, the needs and behaviors of the intended users and how people really work in groups and organizations to be able to prevent the introduction of unusable systems that are mechanizing and distorting collaboration and other social activities. In stead, a problem-driven demand-pull approach should be applied to identify and utilize the potential application areas for ICT tools in construction (Björk, 1999).

4.2 *Organizational perspectives*

Based on Samuelson (2003) the implementation and use of ICT in construction can be described consisting of three levels of organizational perspective; individual/personal, project/group and corporate/industry level. Many of the problems associated with ICT in the construction industry are related to its adoption, which has been relatively uncoordinated, and its strategic application appears to have been determined by its availability rather than its suitability (Aouad et al., 1999). When introducing new ICT solutions into organizations it is important to review all three of the organizational levels and realize that different viewpoints of adoption strategy are needed on different levels.

First of all, the individual user perspective is especially important to recognize to achieve user acceptance and profitability of the mobile computing system (York & Pendharkar, 2004). Otherwise the integration of information systems into the work environment could hinder the workflow or frustrate users, who will struggle with operating the user device instead of doing the intended work (Larsson, 2002). The three main factors limiting the broad appeal of mobile and wireless computing are deficient ergonomics and usability of mobile wireless systems and user devices, the lack of practical, personal, and timely interaction tools, and that the workflows for mobile workers are still largely paper-based and lack automation and integration (York & Pendharkar, 2004). The lack of openness of the information and communication culture of an organization can also limit the adoption of a mobile computing platform. In contrast, an open culture can encourage the adoption and utilization of new ICT tools to improve availability and visibility of project deliverables, and strengthen involvement and feeling of responsibility by all project participants (Aouad et al., 1999).

4.3 *Level of mobility*

The mobility issue itself gives rise to several aspects that need to be handled in the implementation strategy. Pierre (2001) accentuates that a true mobile computing infrastructure should be able to support

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different wireless and wireline communications devices optimized for their specific environment. In this way, a person would be able to communicate and receive information anywhere, any time. Service portability represents a dynamic relationship between a terminal and a user to provide applications and services to a user's present terminal or location. The applications and services that can be provided to a user depend on the capability of both the terminal and the network in use. Service portability can be provided through so-called Intelligent Network capabilities (Pierre, 2001).

The needed level of mobility is decided by the specific requirements of the construction site. For example, is the system required to support continuous operation of applications while users move between network boundaries? What level of mobile awareness should be supported by the system? Does the system need to support multipoint distributed conference applications? How heterogeneous are the networks and the devices? The answers to these and other relating mobility issues assist in narrowing down the possible choices of suitable technology solutions for a collaborative mobile computing platform.

4.4 *Applications and services*

An implementation strategy of a mobile computing network must also include an appropriate mix of applications and services. On a general level, there are two types of mobile applications and services; horizontal applications which are domain independent (e.g. web-based public information services), and vertical applications which are written for a specific application domain that respond to the specific needs of a mobile work force (Pierre, 2001). It is important to identify what information and communication needs are not sufficiently supported and how this could be resolved.

Aziz et al. (2004) describe how semantic web, web services and agent technologies in a mobile environment can improve construction collaboration. Because of the temporary, multi-organization structure of many construction projects where companies work together for a short period of time, the approach of loosely coupled web based platform is well suited for the construction industry (Aziz et al., 2004). One of the keys to realize fully ubiquitous mobile collaboration tools is to develop systems and applications that are adaptable and scalable to heterogeneous conditions of bandwidth availability and end user equipment capabilities (Johansson & Törlind, 2004).

4.5 *Integration of existing ICT systems*

Integration of existing information systems into a mobile computing platform is of critical importance. It is essential that mobile computing does not add another incompatible stand-alone ICT structure that fragments the construction process even more (Bowden & Thorpe, 2002). A mobile computing platform must be integrated with existing information systems and project collaboration tools in order to achieve a seamless flow of information throughout the whole construction process and to make use of the benefits of the information generated in earlier phases of the project. However, mobile computing differs a lot from traditional desktop computing, and an application that is designed for a fixed desktop-oriented platform may not deliver the same effective solution in a mobile environment (Rebolj et al., 2004). But still, merging existing information structures to create better integration and organization between design, planning and construction phases are imperative to increase productivity and improve the quality of the construction process (Stewart et al., 2002). Even though there is still a long way to go, the construction industry is trying to move towards a standardized exchange of data and fully integrated, digitalized product and process model oriented construction projects. If mobile wireless ICT technology can enable informal and intuitive utilization of existing formal information structures in critical problem solving situations, then mobile computing can be the link to bring an inclusive digital platform to the construction sites to enable increased integration and collaboration between the design phase and the building process (Rebolj et al, 2004).

4.6 *User devices and interface*

The mobile computing solution introduced at a construction site must meet the special demands on durability, user interface and be able to handle operation in harsh environments, otherwise the promised rationalization will be lost (Olofsson & Emborg, 2004). Overcoming the limitations of the user devices is a critical issue in this context. Although handheld computers are improving rapidly, they still suffer from small screen size, slow text input facilities, low bandwidth, small storage capacity, limited battery life, and slow CPU speed (Pilgrim et al., 2002). Of particular importance is the screen size and resolution. Small screens often have a negative effect on browsing related tasks because there is too much data and too little display area to present the information (Pilgrim et al., 2002). Data models in engineering applications tend to be complex and to designing the corresponding mobile device user interface is challenging. Also, compared to the design of desktop-oriented software there are relatively few guidelines available to aid the interface design of mobile computing devices (Pilgrim et al., 2002).

In recent years, wearable computers have gained interest by various mobile work organizations. Wearable computers are carried on the body, gener-

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ally on the head, arm, back or around the waist. But there are problems associated with the user interfaces of wearable computers. Baber et al. (1999) imply that head-mounted displays even with minimal weight can have negative impacts on user posture and performance. Head-mounted displays cause an increased range of head movements and reduce situational awareness by competing with environmental visual demands (Baber et al., 1999). Audio input and output that is often featured in wearable computers can be difficult to implement in mobile computing work environments (York & Pendharkar, 2004). Audio input and output is suitable in a low-noise environment, which is not the case at construction sites.

5 TOWARDS A RESEARCH FRAMEWORK

So, what is the next step for mobile computing in construction? As has been presented in this paper there are a lot of unresolved issues. This final section summarizes the described topics and attempts to outline a schematic research framework to approach these issues. The socio-technical perspective is central in this framework. Before incorporating new technology into the construction process, one must understand the complexity of use and implementation, survey the positive and negative effects of the technology on the existing work procedures, and know how to manage the technological and organizational changes in the processes. To accomplish effective mobile computing at construction sites, technology solutions need to be developed and implemented with a bottom-up approach recognizing end user and group needs and the separate issues of adoption strategy on different organizational levels. By mapping established research fields to the three organizational levels mentioned previously, a general socio-technical bottom-up research framework for collaborative mobile computing in construction can be outlined. Human-Computer Interaction (HCI) issues need further research at the individual/personal level. The research perspectives of Computer Supported Cooperative Work (CSCW) and Groupware have to be addressed at the project/group level. Methods concerning management of technology and innovation processes have to be developed at the corporate/industry level.

The remaining part of this section will explain the basic concepts and approach of this research framework.

5.1 *Human-computer interaction (HCI)*

The field of HCI is concerned with the design, evaluation and implementation of interactive computing systems for human use. Use and context of computers, human characteristics, computer systems and interface architecture, and the development process are four main areas of research in HCI (York & Pendharkar, 2004). An important issue in this context is the user acceptability of a system. A system that satisfies the needs and requirements of the users is an acceptable system and has a high level of "usefulness"; the system is capable of achieving the desired goal (Berg von Linde, 2001). Usefulness can be divided into utility, the level of functionality of the system, and usability, how well a user can utilize the functionality of a system (Berg von Linde, 2001). The usefulness perspective is crucial to be able to design suitable mobile computing systems with appropriate user interfaces that meet the user needs in a demanding and heterogeneous construction environment. One of the true challenges in this context is the limitations on the screen size and resolution of handheld computers. In the case of the construction site, graphical data such as maps and drawings are an essential part of the information flow in the work process. The question is how should this information be visualized on a handheld computer to be useful? More innovative forms of information visualization interfaces combined with development of user devices are needed for the mobile computing environment. Another HCI issue concerning mobile computing at construction sites is to design ubiquitous and "invisible" user applications and interfaces that enable the user to focus on their work at hand. Context aware forms of computing that makes interaction between a user and a computing machine less distracting are interesting concepts in this perspective (York & Pendharkar, 2004).

5.2 *Computer Supported Cooperative Work (CSCW) and Groupware*

Like HCI, the CSCW research field is socially oriented rather than technology driven. CSCW studies how people work together, and how computer and ICT related technologies affect group behavior. By looking at the way people interact and collaborate, technology can be developed that properly supports these collaborative activities (Larsson, 2002). The term CSCW is often associated with the term Groupware. Groupware are the computer-based systems that support group work to achieve a common task (Greenberg, 1991). Groupware systems assist both groups of people working together and also single individuals performing isolated tasks. CSCW relates to groupware in the sense that it defines the scientific discipline that motivates and validates groupware systems design (Greenberg, 1991). Groupware communication technologies can be divided into time and location of communication, distinguishing between synchronous (real-time) and asynchronous (different times) work, and between co-located (same place) and distributed (different places) settings (Larsson, 2002).

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The challenge for the CSCW and groupware perspective is to understand the socio-technical gap of what is required socially within a work group and what can be done technically. This is a critical issue to be successful in designing and implementing mobile computing at the group/project level. It is important to understand how people really work in groups and organizations so that the introduction of new ICT systems do not deteriorate and distort the collaboration process and social interaction. Before implementing collaborative mobile computing at construction sites, the culture, social structure, communities of practice and the tacit knowledgebase of the group/project level have to be understood. When these mechanisms are identified and the relationships between them are recognized, then a collaborative mobile computing platform can be designed to truly support the existing knowledge formation, develop and enhance organizational capabilities and improve collaboration and project communication in the construction process.

5.3 *Management of technology and process innovation*

The term "enabling technology" can be used to describe a technical solution that is introduced into an organization's production operations in order to enable productivity increase and to improve work procedures and organization. These improvements of an organization's production are often referred to as "process innovations". Process innovation can often be described as a discontinuous productivity advance because the enabling technology is making the production more efficient (Utterback, 1994). A major discontinuous change is usually followed by a number of small, incremental improvements. A collaborative mobile computing platform can be regarded as an enabling technology for the construction process. It is important point out that mobile computing is not that kind of enabling technology that creates process innovations that will change the physical construction process, i.e. the way buildings are built. Nevertheless, as this paper has described the contribution of mobile computing can enable radical innovations in the information and communication processes that surround the entire construction process, which can lead to significant productivity increase.

Process innovation is usually divided into technological and organizational process innovations. Technological and organizational processes often go hand in hand with many interdependencies between them. Introducing an inclusive mobile wireless ICT platform at a construction site is a technological process innovation, while the improvements in work procedures, organization, communication, information flow and project collaboration created by mobile computing are organizational process innovations. A socio-technical approach where technological innovation and implementation aspects interact with work practices and human factors is essential for successful management of technology and process innovation at the corporate/industry level. Therefore, the management of collaborative mobile computing in construction needs to be approached from two directions, where both technological and organizational innovation aspects have to be handled and developed in conjunction. When introducing new technology into the production operations of an organization, the first problems encountered will probably be of technological character. As the technological problems are solved, problems will be of a more organizational character related to the use and integration of the technology. Therefore, the focus of management will be different as technologies evolve (Drejer, 2002).

It is important to stress the process perspective and the enabling role of mobile computing. The technology management of mobile computing needs to be addressed as an enabler that should be integrated with the production process, instead of a process independent driver. This becomes evident when looking at the failing of ICT in many parts of the construction industry. While ICT solutions have been introduced through various professions, there has been a lack of focus on the integration and use of ICT to improve construction project collaboration process on a holistic level (Aouad et al., 1999). In this perspective the issues of Robert Solow's computer-productivity paradox is also important to address. Solow's famous statement "You can see the computer age everywhere but in the productivity statistics" (Solow in Triplett, 1999) raises a lot of questions concerning the implementation of collaborative mobile computing in the construction process; first of all, is there a computer-productivity paradox at all? What impact will the adoption of mobile computing have on productivity in the construction process? How should the productivity effects of mobile computing be measured? Can the effects of mobile computing on productivity be measured at all? In general, a continuous critical discussion of ICT solutions and what improvements they are supposed to bring to the construction process is needed to confront and manage the computer-productivity paradox and to avoid failures when introducing ICT in the construction industry.

The research framework for collaborative mobile computing in construction sketched above needs a lot of development. The purpose of this paper is only to outline the fundamental cornerstones in this framework. Nevertheless, the point is that a socio-technical bottom-up approach that recognizes end user and group needs is critical to able to effectively design, implement, use and manage collaborative mobile computing in a mobile distributed heterogeneous construction environment.

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6 CONCLUSIONS

Changes of plan, unanticipated events and temporary critical problems are inevitable at construction sites. The need for appropriate information-rich communication tools in this environment is not well addressed today. Informal communication plays an important role in handling unanticipated events and solving critical problems. Informal communication is also vital for improving project collaboration, social group relations and teambuilding processes. The problem today is that informal communication is poorly supported by information and communication technology. High level of mobility and awareness in ICT tools are important to be able to support efficient ICT-based group communication in distributed work environments. The rapid developments of wireless mobile computing technologies over the past decade have brought new opportunities to the information and communication issues at construction sites. These technologies have now the potential to provide a complete wireless mobile ICT platform (voice and data) that can enable improved support for informal communication and on-demand data at construction sites, which can result in improved project collaboration leading to increased efficiency and productivity in the construction process. Towards accomplishing this, valuable experience can be obtained from the example of the walkie-talkie and why this technology has become a powerful tool for verbal informal communication at construction sites. Likewise, the breakthrough and user acceptance of a mobile computing platform in the construction process depends much on whether such a system can be designed to deliver powerful applications with an interface as simple and intuitive as the "push to talk" feature that the walkie-talkie provides.

An implementation strategy for collaborative mobile computing at construction sites must consider numerous issues regarding system capabilities, mobility, applications, services, integration of existing ICT systems, user interface and user devices to meet the requirements and behaviors of site workers. A socio-technical bottom-up approach is needed to able to improve the design, implementation, usage and management of collaborative mobile computing in a mobile distributed heterogeneous construction environment. Different viewpoints of technology implementation and adoption strategy are needed on different organizational levels. Human-Computer Interaction (HCI) issues need a lot of consideration and further research at the individual/personal level. Usefulness concerning utility and usability of system applications and user interfaces are important aspects to meet the specific needs and behaviors of construction site workers and to achieve high user acceptance of the mobile computing system. Computer Supported Cooperative Work (CSCW) and Groupware have to be addressed at the project/group level. The challenge of this perspective is to understand the socio-technical gap of what is required socially within a work group and what can be done technically with mobile computing. Understanding how people really work together, the culture, social and organizational structures, communities of practice and the tacit knowledgebase of a construction site is essential to be able to design a collaborative mobile computing platform that truly supports the existing knowledge formation, develops and enhances organizational capabilities and improves collaboration, social interaction and project communication in the construction process. Methods concerning management of technology and innovation processes have to be developed at the corporate/industry level. The management of collaborative mobile computing in construction needs to be approached from two directions, where both technological and organizational innovation processes have to be handled and developed as one integrated unit. It is critical to approach these management issues with a broad construction process perspective and accentuate the enabling technology role of mobile computing for improving collaboration and project communication throughout the whole construction process. This combined with a critical discussion of what effects mobile computing will have on work flows and productivity and how this should be measured, are key points to avoid impulsive and expensive ICT failures in the construction industry in the future.

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Professor Örjan Wikforss, Department of Industrial Economics and Management (INDEK), Royal Institute of Technology (KTH), Stockholm, Sweden

Professor Staffan Laestadius, Department of Industrial Economics and Management (INDEK), Royal Institute of Technology (KTH), Stockholm, Sweden

Associate Professor Per Andersson, Center for Information and Communication Research (CIC), Stockholm School of Economics, Stockholm, Sweden

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Using Voice over IP and a Wireless Network to aid Collaboration in the Construction Industry

S. Ahsan, A. El-Hamalawi & N. Bouchlaghem
CICE, Loughborough University, Leicestershire, UK

S. Ahmad
Myriad Vision, Leicester, UK

ABSTRACT: This paper looks at how the use of Voice over Internet can benefit the construction industry. The technology has advanced to enable the use of a wireless network allowing a custom wireless network to route communications on a construction site. The network on the construction site can be linked to a corporate network to allow seamless communications of both voice and data between the head quarters of a company and the construction site.
The paper looks at the technologies required to accomplish such a goal and identifies the potential benefits and barriers in the construction industry.

1 INTRODUCTION

Voice over Internet Protocol (VoIP) is a technology that has been under-utilised, and is seeing a resurgence of interest (AT&T, 2004). This interest lies in the advancement of network technology and the lowering costs of network equipment. The VoIP model is being adopted in favour of the traditional digital PBX systems within the office.

The Wireless network is also a new addition to most corporate networks. It allows mobility for the workforce to move around anywhere within the range of the antenna allowing them access to the network. The wireless technology has been proven to allow for greater data transfer rates and is constantly being improved to incorporate Quality of Service (QoS) (IEEE, 2004). What this means is that there is an opportunity to allow voice traffic to run over a wireless network which connects to the main fixed network. Running voice over a wireless setup can give the advantage of offering voice communication to remote workers piggy-backed on an existing IT infratructure, therefore seamlessly allowing them to communicate with the rest of the network as if they are sitting at their desk.

The construction industry is such that projects are sporadic, and run over several months, with different companies coming together to work for a specific goal. Communication between the different parties is crucial to the successful completion of the goal, and the most effective means of communication is the voice. Currently the mobile phone is the tool that is used most frequently when on site, but this can mean very costly communication bills for the company. Utilising a wireless network and tunnelling into their own corporate network, a mobile worker could utilise their wireless device to communicate with the rest of the team, and stakeholders in the project.

This paper will look at the feasibility of setting up such a system; the technology that is available today, and what future technology will help. The benefits will be explored as well as the potential for failure.

2 THE CONSTRUCTION PROJECT

The Construction industry is purely a project-based industry. The projects are worked on by, most often, multi-disciplinary groups. These groups consist of members from different companies, members from the supply chain, and customers, who all have an input into what is required for the completion of the project. Communication across team members is crucial to the success of the project. Increased collaboration between the different team members is often hindered by the fact that they are not all located under one roof. As they belong to different companies, they work in their own offices, which may not even be in the same country. Project methodologies have changed from the original over the fence type of project, where each department worked completely separate from the other, to a more involved project methodology in which all members of the team come together to plan, therefore cutting down the time and costs involved. This method is known as concurrent engineering, and it has stimulated a lot

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of interest. Concurrent Engineering embodies methodologies such as multi-disciplinary teams, parallel scheduling of activities and cross-functional problem solving (Anumba et al., 1997). Information Technology plays a crucial role in supporting this collaboration. The use of extranets is ever expanding with companies able to have a common location on the internet to meet and share information and documents. The different members of the project team can collaborate in the design process; discuss topics on a message board and share drawings as well as other crucial documents.

Information sharing specifically on the construction site is also of great importance. The UK construction industry has defects which cost at least £20 billion to repair or rebuild (BRE guidance). Poor communication on the construction site is the cause of some of these defects, with poorly detailed drawings, operatives being given incorrect instruction or technical information not being available. Access to project resources such as team members and project data is increasingly important to cut these losses.

3 COMMUNICATION TECHNOLOGIES ON THE CONSTRUCTION SITE

Different information needs have been identified on the construction site. The research identifies the typical information tasks taking place (De La Garza et al., 1998). Out of the tasks identified, the following were highlighted to have voice as the most important format for information transfer:

- Design and intent clarification
- Contract specification
- Work package information
- Means and methods questions
- Implementation problems

Many different wireless technologies have been tested on the construction site including different infrastructures and communication devices (Bowden, 2002, Meissner et al., 2001, Beyh et al., 2004 and de la Garza et al., 1998). The COSMOS and MICC projects tested various technologies on the construction site. The MICC project identified the DECT (Digital Enhanced Cordless Telecommunications) technology to be suitable for the construction sector due to its reliability. The DECT system, though does have problems with standards, and cannot match the bandwidth of other technologies such as the wireless LAN (Local Area Network).

When identifying the various communication methods available, researchers have identified certain characteristics which should be looked into (Beyh et al., 2004):

- Benefits in terms of the nature of information that need to be transmitted including voice, data, video, web collaboration, etc.
- Access to all members forming the project teams including site workers, gangers, and foremen
- Reliability, availability and quality of service
- Cost of service including network administration, maintenance and upgrade
- Availability of terminals and users' devices such as mobile handsets

Many of these technologies have been reviewed with an emphasis on data communications. Data communications that would occur on the construction site usually require less bandwidth than voice communications and are less demanding on network resources. The remit of this paper is to investigate the wireless LAN as it proves to be of relative simplicity and provides the correct infrastructure for carrying voice and even video. The impact of such a system is highlighted as it could allow access to information and contact with remote experts from a construction site (Miah et al, 1998).

3.1 Wireless networks in construction

The use of a data network on a construction site has gained momentum with the increased use of IT within construction. The move towards a paperless office has found its way onto the construction site, with a move towards a paperless job site

The wireless network has gained increased popularity as it provides the benefits of being connected to a network without the hassle of any wires, making the user mobile. The wireless network works with radio waves, and there currently exist three popular standards produced by the Institute of Electrical and Electronics Engineers (IEEE) which are in use today. The main difference in these three standards is the bandwidth they offer. The IEEE 802.11b was the first to have widespread adoption and offers a bandwidth of 11Mb/s. This has been updated with the IEEE 802.11g standard which manages to reach 54Mb/s at the same frequency of 2.4 GHz. Some vendors have managed to increase this bandwidth utilising their own propriety software. The IEEE 802.11a standard offers the 54Mb/s but at a higher frequency of 5 GHz. This has the advantage of a less crowded airspace providing a much more stable connection.

Figure 1 shows a sketch of three different networks that can be integrated together; the Hybrid network consists of LAN, WAN and 3G (cellular) networks (Xu, K. et al., 2005). The WLAN requires radio base stations (network access points) that manage the sending of data to and from the wireless clients. All these networks can be integrated, as they

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all utilise the common TCP/IP communication protocol.

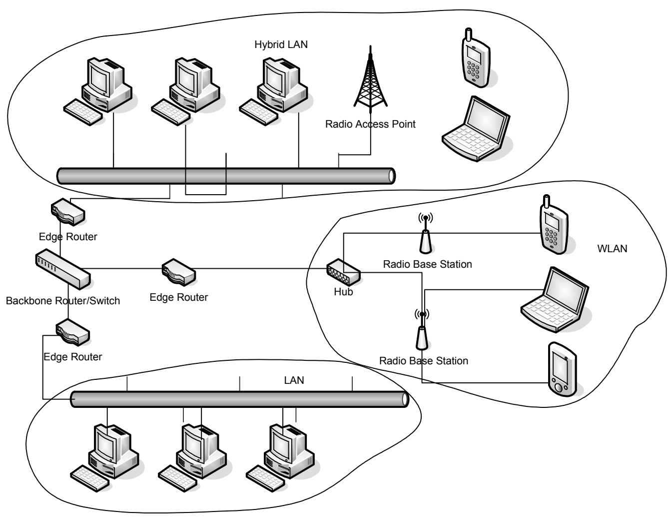

Figure 1 A sketch of integrated networks (K. Xu et al., 2005)

Wireless networks have been tested on construction sites primarily for data exchange. One such test ran with tablet PC's on a construction site connected as thin clients via a wireless network (Ward et al. 2004). The wireless network on a construction site can be set up relatively easily, and is scalable to cover large distances. The network can be set up to mimic the traditional cellular network, with access points marking the centre of each cell. This way, the network could be enlarged with an increased number of access points being 'daisy-chained' together as shown in figure 2 (De la Garza et al., 1998, Ward et al., 2004). Installing a wireless network on a construction site is very different to a traditional office. The outdoor environment is a great factor, with the effects of weather and dust which mean that the wireless technology should be rugged enough to cater for that.

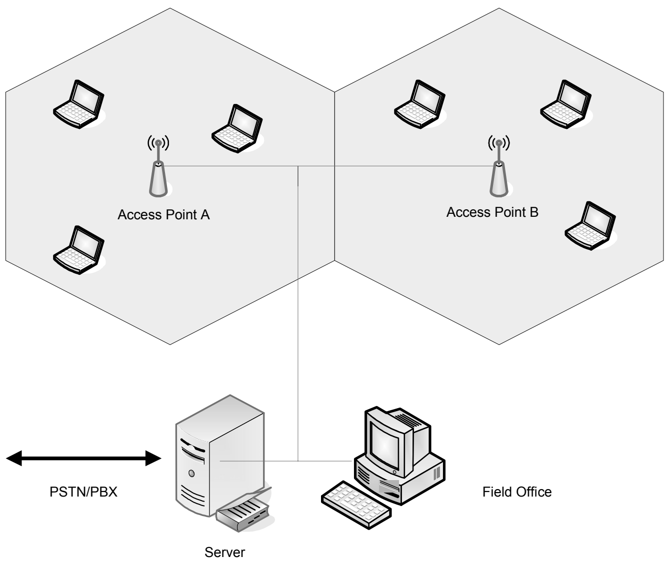

Figure 2 A WLAN network with access points (De la Garza et al., 1998)

With tests of wireless networks on construction sites, the researchers have used standard wireless equipment in rugged containers to keep them secure in the construction environment. Manufacturers of wireless equipment have developed systems specifically for the construction industry that are capable of withstanding the conditions on site. Theses systems can be installed and daisy-chained like ordinary wireless systems which have been identified. Figure 3 shows an example of such equipment. This specific device works with the 802.11b standard with a maximum throughout of 22Mb/s and a claimed range of up to 10 miles (CII).

Figure 3 Orinoco Outdoor Router

Issues identified with the wireless setup included obtaining power for the wireless access point. This was resolved by connecting the access point to a rig's power supply, therefore bypassing the need for a battery (Ward et al., 2004). Device battery life has been identified as a problem with measures to reduce battery consumption including placing the device on standby.

The placement of the wireless access points can also provide some difficulty on a construction site. An American construction company, Webcor, installed a wireless access point on the crane hovering over the construction site. This wireless network gave engineers and crew's access to blueprints and the ability to easily coordinate projects (Shim, 2004).

4 VOIP IN CONSTRUCTION

Voice over the Internet Protocol is the process of sending voice traffic over the data network, therefore combining the data and telecoms network into one. Industries around the world have seen an increased adoption rate of VoIP systems. They represent cost savings with a greater feature set. Construction firms have also begun implementing the VoIP solutions within their offices. One such company is Facchina Construction who deployed an IP-PBX system. With the installation of VoIP within their offices, companies such as Facchina Construction are identifying the construction site as further uses of the technology (Hagendorf Follet, 2004). The costs of setting up both a data line and telecoms line is reduced with the removal of the telephone

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line. In addition on an IP based system, a user would carry the same number from site to site, therefore simplifying the communications process.

Transmitting voice over a wireless network, although a very new technology, has had success in the indoor market. Companies such as Vocera are supplying the hospitals in America allowing for hands free instant communication amongst hospital staff. The Vocera network utilises the 802.11b standard for the wireless network. This setup is unique as the company has produced specific communication devices which allow for one touch calling (Vocera, 2004). The Vocera solution also encompasses voice recognition. This is necessary for the one touch dialling, whereby the user asks for a particular person or job role, the server then interprets this and connects to the resulting person. This technology could be applied in the construction field, although the one touch dialling may prove to be difficult to work with on a noisy construction site. Figure 4 shows the network structure with the Vocera solution. The diagram highlights the ability to link the voice solution with other applications, as all data is run over the same network using common standards. This is the case with any VoIP solution. The power of the VoIP solution is therefore enhanced with the ability to converge it with other applications to enhance collaboration.

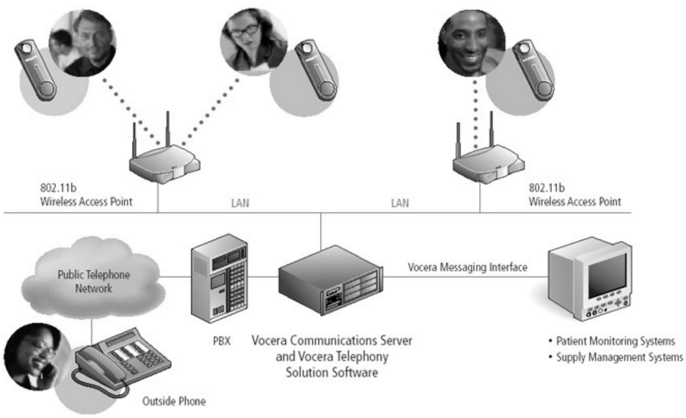

Figure 4 Vocera Networks Solution (Vocera, 2004)

5 ENABLERS AND BARRIERS

Many issues pertaining to the use of these new technologies on the construction site have been investigated by various authors. There have been frameworks identified to enable the construction industry identity their readiness to accept this technology. One such framework is the IPTCS framework (Beyh et al., 2004). The IPTCS framework suggests a methodology to help the increase in adoption of VoIP in construction. These include

– Users' involvement and education
– Existing telecommunication means assessment
– IP Telephony technology assessment and benchmarking, and
– Technological alternatives

Tackling the issues identified in the framework would prove to reduce the barriers from within the construction industry in adopting this and any other new technology.

The main advantage of implementing a VoIP solution in the construction site is that of cost savings. The WLAN setup is unlike others which have been reviewed as it does not require any on going fees (De La Garza et al., 1998, Beyh et al., 2004). The WLAN is set up and managed by the client, not a third party operator. The level of control can be considered as both an advantage and also a barrier to the WLAN. The level of control is a benefit as the network can be tailored from site to site, although this tailoring requires skilled personnel which would be an extra cost on the project. The ability to move the setup from one site to the next provides cost advantages for the industry. A large amount of investment on the technology is not required, as the same equipment can be used from one project to another.

Research investigating the time taken to communicate information on a construction site highlights the cost savings achieved in terms of productivity and time from switching to a wireless network compared with traditional communication methods (De La Garza et al., 1998). The research highlights the benefits of the WLAN for data transfer, which alone would argue a successful case for the implementation. Using this new infrastructure for voice would therefore not add an extra cost, as the infrastructure setup for data transmission would be used.

In terms of barriers that exist in the construction industry, research has shown four categories, which include technical, financial, cultural and organisational (Beyh et al., 2004). These barriers coincide with barriers that would exist in many other industries, but are exacerbated by the lack of the construction sector to adopt innovation, the large scale and scope of the construction industry, and the difficulty of introducing technology into areas which are not the optimum conditions for its use.

6 VOWIFI TECHNOLOGY CONSIDERATIONS

6.1 Reliability

The wireless network initially started off offering low bandwidth rates, but as technology has progressed, the bandwidth offered has increased to those comparable to the wired LAN. Research into the use of the wireless network has shown that although the wireless network is capable of handling the data rates, packet loss and congestion can occur,

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causing delays in the information being sent (Barberis, A. et al., Xu, K. et al., 2005). This delay in sending information could lead to extensive delays in a voice call over the network. With the total latency of a voice call recommended to not exceed 150 milliseconds by the International Telecommunications Union, this could lead to a very poor service for a user.

The method to minimise the disruption is to effectively manage the loss. This issue was addressed on the wired networks with the development of new algorithms to pass data. These new algorithms would provide more efficient ways to signal a problem and correct it. Solutions such as variable vocoding depending on network conditions, Adaptive VoIP (AVoIP) have been proposed to manage the traffic on the network (Berberis, A. et al., 2001). Other solutions attempt to manage the amount of data on the network by selectively sending data. This solution would only send data when a user spoke, or the volume of the sound exceeded a certain level.

Packet loss on a wireless network can occur for a number of different reasons above and beyond the traditional reason of congestion. The wireless network has to cope with hand-offs, fading channels, congestion and transient random errors to name a few (Tsaoussidis, V. et al., 2002). The management of these different issues calls for a method of identifying the actual problem, rather than assuming it is one type and attempting to apply a solution. These issues have been addressed and novel solutions which identify and manage the problems have been introduced. The only drawback is that the different manufacturers are building their own solutions in their own hardware as no set standard in dealing with these issues exist. This poses a problem for the consumer as the choice of hardware is limited as different hardware would be utilising different methodologies in handling errors, deeming these error handling features useless. Standards are to be released attempting to resolve many of these issues which, when included, would make the task of choosing equipment a less daunting one.

6.1.1 Quality of Service

Quality of Service is a general term given to a host of different methods to achieve this aim. The key aim is to keep the network reliable. For each issue that arises, different tactics can be used to solve the problem. Some problems require use of the bits that are sent over the network, and the fact that these bits are being used for error checking rather than actual data can have an adverse effect.

With the use of Quality of Service, which uses more bandwidth to make sure that the packets reach their destination, the reliability of VoIP is comparable to the traditional PBX system. Packet labelling through Multi-Protocol Label Switching allows the network to identify data packets from voice and video packets, therefore granting higher priority to these packets. (AT&T, 2004) This will guarantee the throughput of the voice traffic on the network making sure there are no interruptions of the voice call.

The wireless network IEEE 802.11e standard is set to introduce QoS as one of its standards. Many vendors who supply wireless technology for VoIP have implemented their own solutions, but as soon as the IEEE 802.11e standard is ratified, this will be implemented on all of the available hardware.

6.1.1.1 TCP Schemes

Standard TCP does not contain any sophisticated congestion control system. As highlighted earlier, this can cause problems on a wireless network, as all packet losses cannot be associated to one problem, and the problem is usually not related to the types of problems occurring on the wired network. By not identifying the problem the most effective algorithm to correct it cannot be applied.

Many different TCP schemes exist that attempt to manage packet loss situations on the networks. Newer schemes such as TCP New Jersey, one of the new proposals, have been shown to improve the level of packet loss utilising a number of methods (K. Xu et al., 2005). The important point to note is that the wireless network and networking technology in general has not been stagnant. All these issues which arise from utilising the wireless network for more than just data are having an impact, and resolutions are being created.

6.1.1.2 Roaming

When a user moves from one access point to another, it has to re-authenticate itself to the network. This can take well over 100 milliseconds, exceeding the recommended levels immediately (Greene, Tim. 2004). This issue has been looked at by many of the vendors and is also being looked at by the IEEE standards working group. The different vendors have created bespoke solutions for the problem, each one managing to work well, but limiting the choice for the customer to choose different setups. The different solutions vary from a centralised authentication server to a pre-authentication method on all access points when a user is authenticated on one (Cohen, B. 2004). The IEEE 802.11r working group is working on a standard method to solve this problem, but this may take some time. For now, one of the available solutions would have to be employed to create a successful voice over wireless setup.

6.1.1.3 SIP

The only way for different systems to recognise the traffic as voice traffic is for the industry to utilise

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standards. The standard that is being adopted by most of the VoIP industry is called Session Initiation Protocol (SIP). SIP is a signalling protocol designed to establish sessions on the internet for multimedia and voice communication. The use of standards gives the benefit to the consumer to purchase whatever equipment he/she desires and all should work together seamlessly. The lack of the available standards causes many problems and means that more hardware will have to be replaced to adopt the new standard. There may be issues with some networks, in trying to get the voice traffic past a firewall, and there may also be problems with some routes that utilise Network Address Translation (NAT). This is because with NAT IP addresses are masked, and different ports utilised, therefore making it difficult for the voice traffic to reach its destination (Higgins, Tim. 2004).

Some of the key advantages of SIP are as follows (Melinat & Kelly, 2002):

- SIP is an Internet Protocol, it can facilitate the integration of communication applications with other web-based applications.
- SIP does not rely on any type of network.
- Using SIP, new applications can be easily added without the need to rely on one specific vendor.

6.1.2 Wireless Device

The wireless device that is used for placing this call would for the time it is connected and making this call be using a lot of battery life. Specific Wi-Fi phones have been created that have an improved battery life, but power usage becomes more complex if a PDA is used, as the device is not used specifically for voice calls, but other applications, which use up power. The solution to this is improved battery technology, lower consumption chips, and also the network technology. A Wi-Fi device need not always be connected to the wireless network, as the user may not require the use of the network at all times, therefore switches with power management facilities have been produced by vendors to manage this. Specific firmware is required on the client device to allow for connections to be made, but it effectively reduces the power used on the client device (Griffith, E. 2004).

6.2 Security

Security is a fundamental issue when dealing with VoIP. This issue is of greater significance with the wireless network. The wireless network is inherently insecure as anyone with a wireless network card can attempt to connect to the network when they are in range.
Existing wireless devices may only utilise the Wireless Encryption Protocol (WEP) along with MAC address authentication. There is still a security vulnerability though, as static WEP security is weak, and if a MAC address is cloned, a new device can connect on the network and cause disruption (Griffith, E. 2004).

These issues are constantly being improved upon, with WPA (Wi-Fi Protected Access) and the newer WPA2 (Wi-Fi Protected Access 2) standards being incorporated into the IEEE 802.11i standard offering a greater level of security. The WPA2 standard is relatively new and is being incorporated on the newer access points which are being released.

Security of the voice packets being relayed from sender to receiver can also be achieved through extra encryption algorithms. This process can be achieved fundamentally because the data is sent as packets on the network which can be manipulated in the same way as traditional data. Therefore when the voice data has gone through the vocoding process, it can run through further encryption algorithms to prevent unwanted tapping of the voice communication. Of course, the receiver would require a decryption algorithm to decode the voice packets.

6.3 Specialist Hardware

In order to utilise a wireless network for voice calling, the specific hardware to establish a wireless connection is required. Different types of hardware may be required to achieve the set of reliability and security needed for the call to be achieved with acceptable quality. There are two options in terms of device hardware that can be taken. The first uses a generic solution, with a wireless enabled device such as a PDA or Wi-fi enabled laptop can be used, the second is using specifically built wireless VoIP handsets, such as the Vocera solution identified earlier.

6.3.1 PDA

The Personal Digital Assistant (PDA) has been introduced into the construction industry as a data device. Its speed, memory capacity, communication possibilities, reliability, small size and long power independence, as well as its level of hardware and software standardisation, gives the PDA a powerful potential in the information chain of a construction project (Cus-Babic et al., 2000).

The PDA connected to the wireless network can work as a ‘soft phone’. All the functions that would take place on a desktop VoIP phone would have to be programmed in software for the PDA to manage before it passes on the data. Companies such as Skype have already produced software for the PDA, but that utilises the internet to establish the call via their gateway.

The advantage of using a PDA, or generic wi-fi device is that the one device can be used for much more than voice. All communications can be unified

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through one device. The PDA is a versatile piece of equipment, with selected add-ons it can be used as a video recorder, as a bar-code scanner and as a diary. This presents a powerful opportunity for a mobile or field worker, as no longer would they have to use several devices, and carry them around; the one device will suffice.

6.3.2 VoWLAN Phone

Special Wi-Fi handsets have entered the market, which have all the hardware necessary to process a call in-built. The advantage of this sort of phone is with the hardware. The hardware would have been specifically designed for the task of establishing a voice call. The PDA software would attempt to mimic what the hardware would be doing, but having specific hardware results in a much more powerful device.

7 CONCLUSION

This paper identified that voice communication is essential for all the industries to operate and work effectively. There are many tools around which aid collaboration, such as the extranet and project discussion groups, but voice communication can never be replaced. What can be done, however, is that the voice communication can be improved to allow for reduced costs and increased collaboration.

VoIP was identified as a technology that could aid the construction industry which relies heavily on communication with different members of a team, and the different members of the supply chain. The reduction in cost is reason enough to move to VoIP, but there are a great many other advantages that can be realised with its implementation. There can be an increased capacity to collaborate as the different modes of communication can be converged in one location, giving rise to greater productivity.

VoWLAN was investigated with a view to be utilised on a construction site. The very nature of a wireless network lends itself to a construction site as no wiring is required, and one can be setup relatively quickly. The PDA can be utilised to act as a 'soft phone' allowing for communication of data and voice on a single device. Connecting a mobile device such as the PDA would give the user access to project information as well as project members whilst on the construction site. The PDA can be used as a multi-function device as it is now powerful enough to carry out most of the functions of a laptop.

The varying issues with regards to implementing a VoIP solution on a LAN and WLAN were investigated, with a view to look for solutions that have been implemented. Issues regarding security are becoming less of an issue as new standards become available which introduce higher security levels. Issues of service quality were investigated, and again these issues are being tackled with the standards bodies. VoIP is not 100% perfect, and there is still room for improvements, but despite the complexities in introducing such a system, most companies have found the move to be beneficial.

The VoWLAN setup can be effectively utilised on a construction site, or even within an office to allow for communication on the move or in remote locations for a relatively minimum charge. The VoWLAN has been implemented in many other industries, but not tried in construction, and there is no reason why it shouldn't. In fact it is something that would give great benefit to the construction industry. What remains is for the construction industry to adopt it and find more applications that can merge with the voice communication to further enhance the collaboration process.

8 FURTHER RESEARCH

Further investigations into the various technologies would prove beneficial to the construction industry. Identifying the feature sets which are most suitable for the industry and also identifying areas where VoIP can be merged with other applications to further enhance the collaboration process.

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Provisions for proficient Construction Project Extranet Protocols to facilitate Collaborative Extranet Working

S.G. Yeomans, N.M. Bouchlaghem & A. El-Hamalawi
Centre for Innovative Construction Engineering, Loughborough University, Leicestershire, UK.

ABSTRACT: Construction teams within the industry are recurrently adopting Construction Project Extranet (CPE) systems to facilitate project integration and collaboration. When deciding to adopt a CPE, it is important to support their use with a clearly defined Construction Project Extranet Protocol (CPEP). Prior investigations found that the principal cause of their inefficient use was associated with missing, or poorly developed protocols. Project teams also cited the lack of a generic industry standard as the main reason for not being able to produce practicable CPEPs. This paper reports on the findings of a study, to establish the main requirements for development of a proficient CPEP and investigate the need for a generic toolkit to aid project teams. It identifies the key issues to be considered, along with the findings of a survey on current CPEPs. The paper concludes by proposing a set of recommendations for improving the way in which CPEP are produced.

1 INTRODUCTION

Construction teams within today's AEC industry are becoming increasingly reliant on the deployment of Construction Project Extranets to facilitate project information exchange and collaboration; whilst individual organisations endeavour to use them as a tool for generating improvements in quality, competitiveness, profitability and client satisfaction. A survey conducted in the UK by *The IT Construction Forum* (2004) affirms that the use of extranets is growing rapidly, with nearly half of all respondents indicating they had used a project extranet to collaborate online (43% of the 373 responding firms).

Within the context of this paper, the term Construction Project Extranet (CPE) refers to an extranet system, which is supplied by an Application Service Provider (ASP) and is subscribed to by a project team for a fee, either on monthly, yearly or project-to-project basis. Project members utilise the Internet and web browser technologies to securely exchange and store project information via the ASP's central repository. This is now the most commonly adopted method of implementing a CPE on a project, as systems are available 'off the shelf', can be setup within a short time frame and costs relatively little (when compared to the option of developing an ad-hoc system, which requires a great deal of expertise, resources, time and money).

The use of the web and associated technologies in such instances has now been widely acknowledged by practitioners (Nitithamyong & Skibniewski 2004) and is also described by various designations including: Project Specific Web Sites (Thorpe & Mead 2001); Project Collaborative Extranets (Hamilton 2002a); Web-enabled Project Management (Alshawi & Ingirige 2003); Online Project Management and Collaboration Tools (Unger 2003); Web-enabled Project Management Systems (Nitithamyong & Skibniewski 2004); Web-based Project Information Management (Stewart & Mohamed 2004) and Construction Project Extranets (Murphy 2001). A detailed précis on the evolution of CPEs along with an examination of their ever-increasing adoption within the USA is offered by Becerik (2004).

Within the UK, prior investigations primarily focused on understanding the impact of working with multiple CPEs within a single organisation, found that the principal cause of ineffective or inefficient use of CPEs stemmed from missing or poorly developed protocols (Yeomans et al. 2005). 20% of projects surveyed (with a total value of £342m) were found to have instigated the use of an extranet without a supporting protocol, despite many project members having to perform their duties in new ways. Additionally, although the remaining 80% of projects (with a total industry project value of £2.1 billion) had introduced some form of protocol, users reported that they were usually

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ad-hoc and inadequate; as they focused exclusively on how to use the designated extranet system and provided little or no consideration of the other essential issues such as how to attain effective integration and collaboration. Project teams cited the apparent lack of both a generic industry standard along with comprehensive guidance notes on how to undertake extranet working, as the main reasons for not being able to produce practicable protocols.

The remainder of this paper aims to contribute to the growing knowledge base on the subject of CPEs by providing the key findings of additional new studies, undertaken to evaluate the importance of a protocol in facilitating efficient Collaborative Extranet Working (CEW).

2 RESEARCH AIMS AND OBJECTIVES

The main aims of the research were: to investigate the need to develop a generic industry recognised and accepted protocol, to aid clients and construction teams in the production of their own; and to establish which material construction teams deem most crucial for inclusion within the proposed development of a generic protocol. This was achieved through:

- Surveying 48 projects, where 22 different CPE systems were deployed.
- Examining eleven different protocols that were already employed by project teams.
- Surveying CPE administrators and users who worked by existing protocols.
- Participating in the development and review stages of five different protocols.

3 METHODOLOGY

This research was conducted as partial fulfilment of an Engineering Doctorate in Collaborative Working Methodologies at Loughborough University. It applied both quantitative and qualitative methods of research to facilitate a comprehensive study on understanding the main issues surrounding current development and use of protocols, whilst also determining which issues are crucial to the development of a generic industry protocol. A descriptive questionnaire was used to survey CPE managers, administrators and document controllers to facilitate collection of factual evidence on the realities of working to existing protocols. A series of project studies and observations along with meetings with senior manages, ASPs, and other CPE experts were used to accomplish investigative research into how projects currently approach the development of protocols. To aid the acquisition of subject knowledge, the Research Engineer (RE) also conducted a literature review, participated in the development of five protocols, conducted collaborative extranet working trials whilst managing a CPE system (Buzzsaw Standard) with three live projects over the past 18 months. Other activities included: attending UK industry conferences *Project Extranets IV & V* (PE 2003, 2004); attending extranet vendor presentations; undertaken training on four different systems; and administrator training on two. These activities have proven invaluable as a means of attaining firsthand experience and knowledge of the issues surrounding working with extranets and developing protocols.

4 OBSERVATIONS ON CONSTRUCTION PROJECT EXTRANET PROTOCOLS (CPEP)

The following section provides a précis of the key issues derived from an amalgamation of literature review findings, project observations and experience gained whilst participating in the process of developing Construction Project Extranet Protocols.

4.1 *Varying levels of complexity in CPEPs*

Project teams utilise CPEs in one of three main ways (see Fig. 1), either as a simple means of transferring files between parties (Hamilton 2002b), as a comprehensive Electronic Data Management (EDM) tool, or as an means to achieve project collaboration (Hannay 2004). Yeomans et al. (2005) refers to the last of these options as Collaborative Extranet Working (CEW).

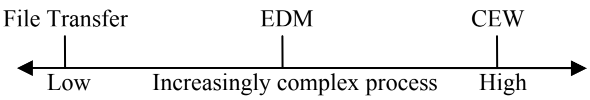

Figure 1. The three levels of CPE operation and the increase in complexity of each process (adapted from Hannay 2004).

In all cases, it is critical that an early decision is made from the outset of the project as to which electronic system is to be used and how it is to be controlled (ITCBP 2003a). Project teams should develop a set of procedures to assist workers in achieving effective use of the CPE and therefore ensure greater overall project efficiency. These procedures are often referred to as ‘extranet protocol’, ‘protocol document’ or a ‘Construction Project Extranet Protocol’ (CPEP). Attention to detail in the creation of procedures is vital (CPN 2001), although the scale of detail required, along with the amount of effort, resources and time expended should match the chosen level of CPE operation. Use of a CPE to conduct file transfers requires relatively simple procedures, whilst a protocol to aid EDM should be increasingly more detailed. A protocol for CEW will need to be substantially more detailed, as collaboration involves a high level of complexity (Austin et al. 2001) and is still not so fully developed that proper implementation planning

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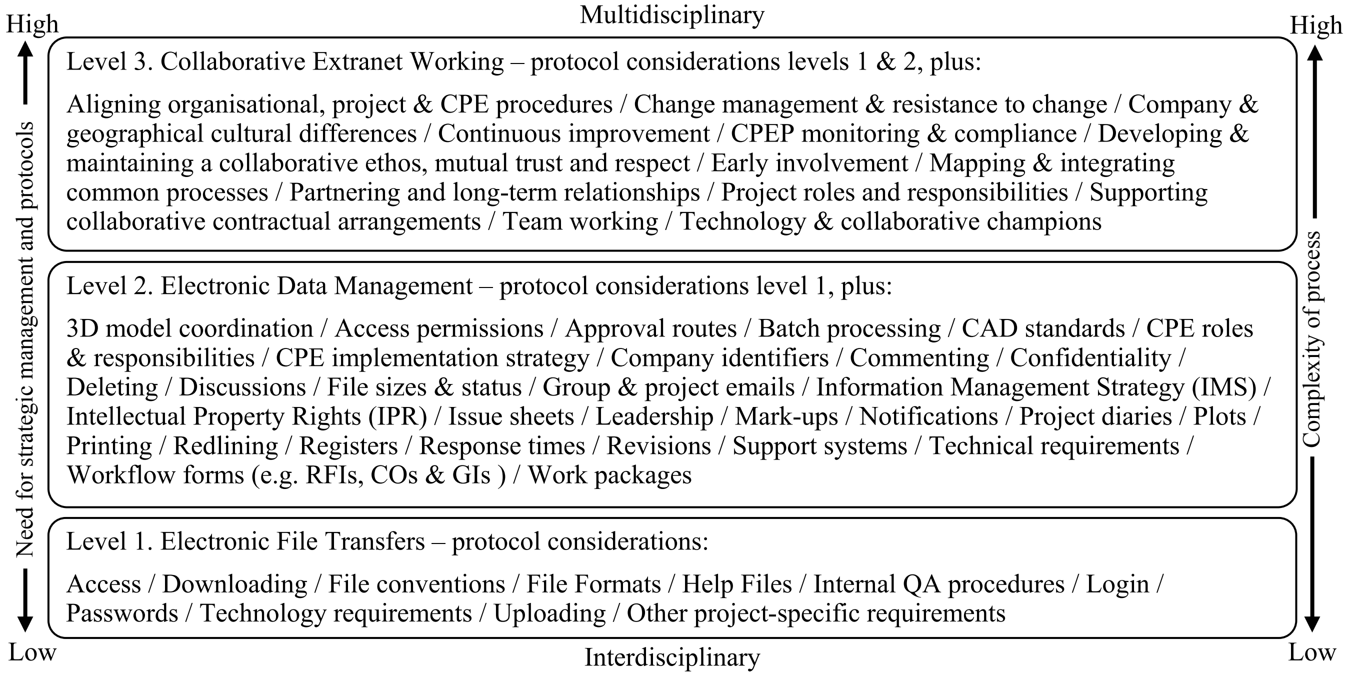

Figure 2. The levels of CPE operation and their respective protocol considerations

can be ignored; strategic support through the process is still required (CPN 2001).

4.2 *Main requirements of CPEPs*

In order to determine the main requirements of a generic protocol, as well as formulate a questionnaire about their availability in current CPEPs, the RE conducted a review of existing literature in addition to surveying 11 project protocols.

A considerable difference was noted between the contents of operational protocols, which concentrated on the 'nuts and bolts' of how to use the designated CPE system, and recommendations made by experts (CPN 2001, 2004a, 2004b, 2004c) along with issues raised by experienced CPE users (Yeomans et al. 2005). Issues include: monitoring protocol compliance, overcoming resistance to change, process management, continuous improvement, organisational cultural management, teamworking, collaboration, interoperability, data ownership, resource management, contractual arrangements and Quality Assurance (QA).

Figure 2, provides a comprehensive list of those items and issues a proficient CPEP should consider, whilst categorising them in accordance to the levels of operation for a CPE. In the case of CEW, all three levels would need to be taken into account. Examination of the working protocols and experience gained from the development process found all CPEPs to include the majority of the items listed in levels 1 and/or 2, but none of those contained in level 3 (see Fig. 2). Therefore, it is appropriate to argue that CPEPs are not proficiently developed to foster true project integration and CEW; despite clients and project teams indicating these as reasons for adopting the use of a CPE. To enable understanding of the reasons why protocols were not being adeptly formed, it was necessary to examine the role of ASPs in the initial stages of CPE adoption.

4.3 *Influence of ASPs on CPEP development*

Only one out of the eleven protocol documents reviewed, was not primarily developed and supplied by an ASP. In this case, the project team decided to develop an ad-hoc, in-house extranet solution, which meant no ASP was present in the process. All remaining CPEPs originated from generic documents produced by an ASP. This was attributed to project teams inexperience of CEW, their lack of understanding as to the requirements and the relationship between the adopters of the CPE and the ASP. The way in which relationships are formed depends largely on one of the following sets of circumstances happening:

1. A client has previous experience of working with CPEs and specifies use.
2. A client (who has no previous experience of CPEs, but is knowledgeable about the benefits) requests that the project team investigates and recommends a suitable system.
3. An individual team member has experience of, or understands the benefits of CPEs and suggests/persuades the rest of the project team to adopt the use of a CPE.
4. The Main Constructor (MC), who has an arrangement with a particular ASP to service all of their projects, specifies use as part of their contractual arrangements.

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As those within the first three instances were found to have relatively little or no long-term exposure to working with CPEs and lacked the necessary experience and expertise to understand how to implement and utilise a CPE to best suit their project needs, they would:

- Rely heavily on ASPs to provide the necessary expertise to setup and manage use of the system; due to their expertise in the use of the respective systems.
- Allow ASP administrators to provide generic protocol templates (formulated from use of their own system on past projects) and supervise project teams whilst revising them to suit current project needs.
- Believe that adopting a CPE and allowing the ASP to support the implementation of the system would naturally result in effective use of the CPE and lead to collaborative working (as the ASPs are selling tools to foster collaboration).

In the fourth instance, the main contractor has usually developed more experience both of working with extranets and with ASPs, due to the nature of the long-term arrangement between the two parties. As a result, protocols on these projects were more detailed and had considered a wider spectrum of issues; although they still did not include those specified for CEW (level 3, Fig. 2). Additionally, they were still based upon generic templates developed in the first instance by ASPs. It is therefore proffered that in cases where a rented CPE solution has been sought, ASPs are required to become the main drivers and facilitators of the CPEP development process; although in all probability that they are no more suited to delivering a proficient protocol. ASPs are adept at delivering protocols to assist users work on their particular systems, as they are experts in developing electronic systems. However, they are not experts in delivering efficient collaborative working based upon a collaborative contract and continuous improvement. This argument is corroborated by Bercerik (2004) who found systems to be very document-orientated; which has led the industry to move towards shuffling electronic paper rather electronic collaboration.

4.4 *Development and implementation of CPEPs*

The following describes the archetypal approach to development and implementation of a CPEP on large construction projects. It is by no means indicative of all cases.

Parties responsible for purchasing a CPE will normally work with the ASP (as shown by the options 1, 2 & 3 Fig. 3) to further develop the ASPs generic template into an appropriate form for the current project. This may be completed through a series of meetings, workshops or 'postings' (placing the document on the extranet for review). Once the main members issues and project requirements have been addressed, those responsible for developing the CPEP may follow one of two courses of action. Either invite all other parties (currently contracted to the project) to read and comment on the proposed protocol; notifying the document administrator of any issues or specific needs e.g. exclusive folder for photos. Or, conversely, publish the guide without consultation and request all other parties to work to

KEY:

ASP	= Application Service provider	CPE	= Construction Project Extranet	DC	= Document Controller
ASPA	= ASP Administrator	CEA	= Company Extranet Administrator	E	= Employee
FM	= Facilities Management	QS	= Quantity Surveyors	PM	= Project Manager

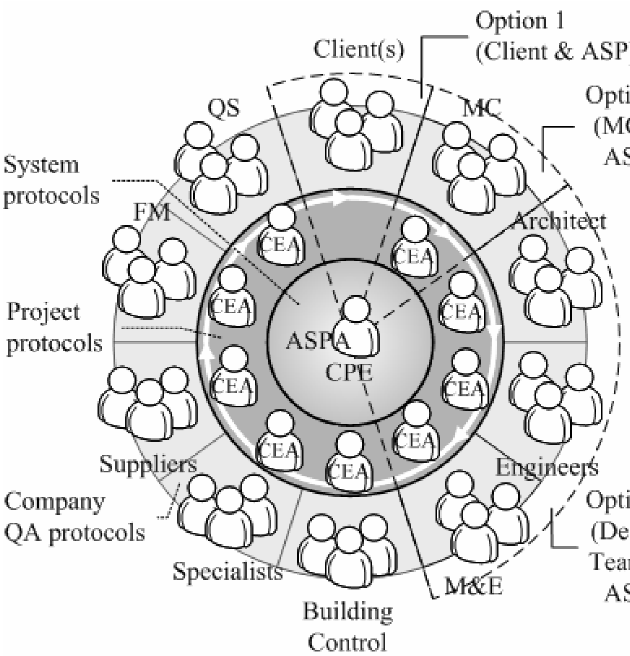

Figure 3. CPEP development and implementation options

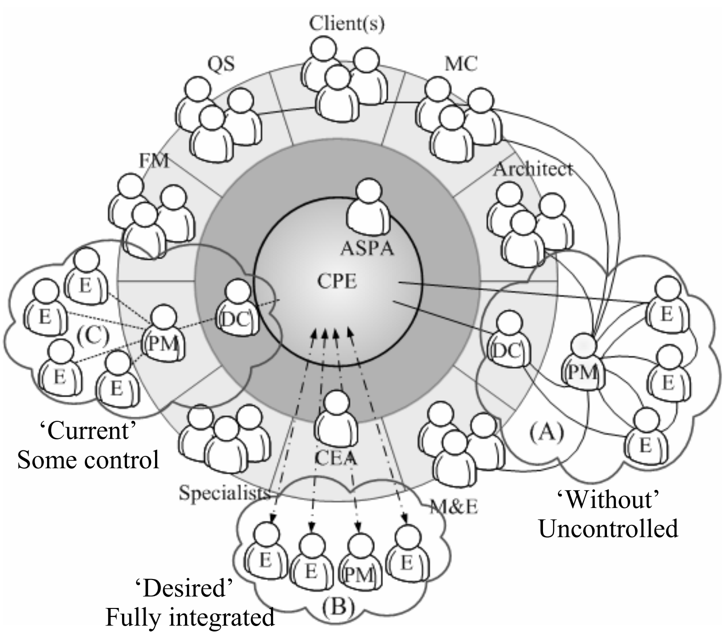

Figure 4. Realities of working with or without current CPEPs

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the procedures. The ITCBP (2003b) stipulates protocols must be agreed from the beginning by all - it is a partnering process.

The ASP maintains an active role throughout, mainly to provide advice, setup the system and deliver training. Nevertheless, they will also ensure that procedures being included within the CPEP document are consistent with their systems abilities and protocols (e.g. inherent electronic workflow procedures). Perhaps the most difficult task facing any protocol development team is deriving a solution that satisfies each members project requirements, whilst still being acceptable to all others. This was never achieved on a single one of the projects surveyed, as a large number of the parties who were to work on the CPE, were not represented at the development stage, and therefore their needs were not accounted for.

A good protocol must also provide equal consideration of individual company QA procedures, project procedures and the inherent protocols of the specified extranet system (as shown in Fig. 3). At present, this does not happen and company procedures are usually sacrificed at the expense of the other two. As a result, many organisations struggle to understand the benefits of working on a CPE due to them having to duplicate work in order to satisfy both in-house procedures and those of the project. This sometimes created resentment, both towards the CPE and those championing its use. It also led to various organisations:

– Refusing to adopt the CPEP and reverting to old methods of working e.g. company email and issuing paper copies (option A, Fig 4);
– Wrongly interpreting the CPEP and developing and/or adopting inefficient modes of working; or
– Bypassing the CPE's audit system by using a single person to interface with the CPE (option C, Fig. 4).

If any of the above problems transpire, the CPEP should be determined as failing in its primary objective, to have everyone working in the same, integrated and efficient manner (option B, Fig. 4).

5 CPEP QUESTIONNAIRE SURVEY RESULTS

A electronic questionnaire was sent to 159 individual CPE managers and administrators throughout the industry to question them about current CPEPs, to:

– Determine those issues currently being included within the protocol document;
– Gauge opinions on the success rates of CPEPs;
– Ascertain if additional issues were required for inclusion;
– Assess reaction to the planned development of a generic industry protocol and best practice guide.

23 people responded to the survey, providing a response rate of 14%. CPE managers (seven) and administrators (seven) were the largest responding groups, followed by CPE document controllers (five). Between all of the respondents, they had gained experience of working on 211 different projects where a CPE was used. 123 (59%) of these had developed and implemented some form of CPEP.

5.1 *Findings on Current CPEPs*

Table 1, demonstrates that current CPEPs focus most often on the use of the system and its tools, and sometimes covers issues such as EDM and electronic workflow. The majority of respondents also indicated that other crucial issues were not likely to be included; substantiating arguments made in section 4.2.

Table 1. Frequency of procedures within current CPEPs.

Procedures required for effective CEW	How often (No. of people)			
	Never	Seldom	Often	Always
Use CPE tools and system		6	11^{x}	6
Conducting EDM	4	12^{x}	6	1
3D model coordination	18^{x}	5		
Conducting collaboration	13^{x}	7	1	2
Managing online relationships	11^{x}	8	4	
Collaborative contract duties	15^{x}	7	1	
Align QA & project procedures	16^{x}	4	3	
Managing online workflow	6	13^{x}	3	1
Continuous improvement	16^{x}	5	2	
Change Management	16^{x}	4	3	
Data and software compatibility	8	10^{x}	4	1
CPEP compliance monitoring	12^{x}	9	2	
CPEP strategy	13^{x}	10		

* ^{x} used to facilitate easy identification of largest response.

When questioned about the ability of current CPEPs to helping project members work more efficiently on project extranets, and therefore bring about savings in time and project costs through effective CEW, nine people indicated that they felt protocols had been partly unsuccessful, eight people felt they had been partially successful, whilst 6 people felt they were very unsuccessful. Overall, the mean score found that CPEPs have been unsuccessful.

Respondents were also asked to specify how important it is to include information on the procedures outlined in section 4.2. None were determined as unimportant (Table 2), which signifies they all must be considered when developing a CPEP. Two additional items were also gained from a question asking if there were any additional items that should be addressed. These were:

– What to do when the CPE is unavailable and information requires publishing.
– Highlighting the impact of failing to follow protocols.

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Table 2. Respondents' views on the importance of containing various procedures within a CPEP.

Procedures	How important (No. of people) 1	2	3
Use CPE tools and system	16 x	7	
Conducting EDM	17 x	6	
3D model coordination	10 x	8	5
Conducting collaboration	15 x	7	1
Managing online relationships	11 x	10	2
Collaborative contract duties	9	11 x	3
Align QA & project procedures	6	15 x	2
Managing online workflow	10 x	13	
Continuous improvement	4	15 x	4
Change Management	9	9	5
Data and software compatibility	11 x	11 x	1
CPEP compliance monitoring	6	15 x	2
CPEP strategy	7	16	
Strategy for CPE use	14 x	8	1
Project roles & responsibilities	14 x	9	
CPE roles & responsibilities	18 x	5	
Training provisions	13 x	9	1
Flow charts for procedures	6	13 x	4
Technical requirements	10	11 x	2
Technical support	10	10 x	3
Intellectual property rights (IPR)	12 x	11	

* x used to facilitate easy identification of largest response.
1 = very important, 2 = important and 3 = not important.

Both are important issues, and although they were not originally identified by the author as requiring individual recognition, it is recommended they form an integral part of any CPE strategy.

Finally, CPE users were asked how important is a good protocol to the successful application of an extranet system on a project. Fifteen (65%) responded by ticking 'very important'. All but one of the remaining group said that it was 'important', with the single individual stating they were 'neutral'.

5.2 *Developing CPEPs*

Ten respondents had been involved in the course of helping project teams form a CPEP. All indicated that undertaking the task for the first time proved to be either a difficult or very difficult process. Two common themes were apparent throughout all of the reasons (provided in supporting statements) why respondents had encountered such an experience. Firstly, that the most problematic part of the process was *trying to get people to agree and work together*, (collaborate). The second was *not enough guidance and a lack of expertise* (best practice experience).

When asked to rank four given barriers to the successful creation of an extranet protocol, they were positioned in the following order:

1. A lack of best practice guidance, generic templates and guidance notes.
2. Relying on the extranet system vendor to facilitate the process.
3. Adapting an ad-hoc template from another project.
4. A lack of necessary expertise to call upon.

When asked to rank four known issues that hamper efforts to create a successful CPEP, respondents placed them in the following order:

1. A lack of expertise and experience within those responsible for development.
2. Not having all project team members involved in the process.
3. Having to rush the process as the CPE was already being used.
4. A lack of commitment to the process from project team members.

Responses to this section suggest that there is a lack of participation in the process from professionals who are well versed at the 'art of collaboration'. Furthermore, projects teams wanted to seek additional assistance or expertise, but were not sure what was available or where to obtain it.

5.3 *Requirements for a CPEP toolkit*

To appreciate what assistance project teams require in developing a CPEP, they were asked to indicate in which one of four services they would most likely use, if they were available. These were, in order:

1. A best practice guidance document (explaining how to develop an extranet protocol).
2. A generic extranet protocol (template document that can be adapted to individual projects)
3. Specialist designated software (step-by-step guide with input boxes to complete).
4. Professional extranet coordination services (employing consultants to facilitate the process)

The survey then asked which format would respondents most like to see a CPEP toolkit presented in. Sixteen (70%) people chose a web-based guide with generic document that could be completed online.

5.4 *Respondents opinions to key research findings*

The final section of the electronic survey asked respondents to indicate their reactions to five statements, formulated from key findings of the overall research project. The statements were:

1. The use of poorly developed extranet protocols, or non use of them, leads to the ineffective and inefficient use of construction project extranets
2. Current extranet protocols are ad-hoc, project-specific and inadequate, as they focus on how to use the designated extranet system but provided little or no consideration of other critical issues such as integration and collaboration.
3. The lack of an industry generic extranet protocol and guidance documentation, make it difficult for project teams to develop practicable extranet protocols.

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4. Project teams would benefit greatly from the availability of an industry approved, generic extranet protocol toolkit.
5. The availability of a generic industry extranet protocol would facilitate more efficient collaborative extranet working.

Table 3. Reactions to five key statements formulated from key research findings.

Statement	Response (number of people)				
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1	8	14	1		
2	7	11	4	1	
3	5	11	3	4	
4	6	11	4	2	
5	5	15	1	2	

As shown in Table 3, the majority of respondents agreed, or strongly agreed with all five statements. Whilst the low survey response means these statistics cannot be used to demonstrate an industry wide opinion, a strong grouping of responses to the five statements can be seen to validate the findings of the research.

6 CONCLUSION

Application Service Providers (ASP) lease-based Construction Project Extranet (CPE) systems are increasingly deployed on construction projects as a means to facilitate project information exchange, integration and collaboration. However, existing research shows that clients and project teams are failing to realise the full potential of such systems (in terms of project cost savings) due to missing or poorly developed Construction Project Extranet Protocols (CPEP). Additional research conducted by the authors on the subject of CPEPs, their importance in assisting Collaborative Extranet Working (CEW), and the proposed subsequent development of a generic CPEP toolkit reached the following conclusions.

There are three levels of CPE operation, simple file transfers, Electronic Data Management (EDM) or CEW. Regardless of the level chosen, the project team will need to develop a set of procedures (a CPEP) to help workers achieve effective use of the system; therefore ensuring greater overall project efficiency. The CPEP must also be tailored to suit the chosen level of operation. As the need increases for the CPE to facilitate collaborative working, so to does the need for greater strategic management and a more proficient CPEP; to ensure successful application of the system. The issues that an adept protocol should consider, in accordance with the CPEs level of operation, has been complied and included within Figure 2 (page 3). The relevance of these issues along with the importance of their inclusion within a CPEP was authenticated by the survey response.

All protocols must provide equal reflection of company, project and extranet system procedures. At present, company procedures are usually sacrificed at the expense of the others.

The most difficult task facing a team trying to develop a CPEP is ascertainment of a document that satisfies the individual's requirements, whilst still being acceptable to all others. Respondents who had participated in the protocol development process substantiated this. All indicated that undertaking the task for the first time proved to be difficult and most supporting statements mentioned the main issues were: *trying to get people to agree and work together* (collaborate), and the *lack of available guidance.*

Current protocols were found to partially unsuccessful at achieving effective working and delivering savings in project costs. They include the majority of items identified for undertaking EDM, but none of those listed for achieving CEW. Therefore, they are not sufficiently developed to foster true collaboration. This was attributed to the teams lack of experience in understanding what was required, along with their subsequent reliance on ASPs to manage the process.

ASPs deliver protocols that mainly assist users to work with their particular systems, but lack consideration of other crucial issues. This has seen them contribute to the industry's move towards shuffling electronic paper rather than helping to achieve electronic collaboration.

Whilst a detailed listing of the main barriers, that hamper creation and implementation of a successful, can be found in Section 5.2, the two main issues identified by the survey were:

- A lack of expertise and experience within those responsible for development; and
- A lack of best practice guidance, generic templates and guidance notes.

When questioned about how project teams felt they could best be assisted in the process of developing a CPEP, the majority (16) stated that they would want a best practice guidance document (explaining how to develop an extranet protocol). They also indicated that a web-based guide with generic documents that could be completed online, would be the most desirable form of media.

The general consensus between those CPE managers, administrators and document controllers (who responded to the survey) agreed with the following statements formulated from the research:

- Poor CPEPs lead to inefficient use of CPEs.
- Current CPEPs are inadequate.
- The lack of a generic template and guidance documentation makes it difficult to develop practicable extranet protocols.

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– Projects would benefit greatly from the availability of an industry approved, generic CPEP.
– The availability of such a document would lead to more efficient CEW.

7 RECOMMENDATIONS

Based upon the above findings, the following recommendations are submitted for consideration by the construction industry and where applicable, future work:

– Clients, project teams and ASPs must develop and implement CPEP on all projects, where a CPE is to be used.
– Appropriate time and effort should be expended in the development of CPEPs, and at the earliest feasible time. Doing so will encourage greater successful adoption of the system.
– Teams responsible for developing a CPEP should identify which of the three levels of operation is required and ensure consideration of the appropriate items (as outlined in Fig. 2).
– Protocols must provide equal reflection of companies, projects and extranet system procedures and not sacrifice one at the expense of the others.
– Clients and project teams would benefit from adopting external expert assistance on how to ascertain efficient collaborative working.
– ASPs should provide greater consideration of other critical issues surrounding the use of the system on a project, not just efficient use of their system. When selling a collaborative solution, it should 'do exactly what it says on the tin'.
– The need exists to develop a best practice toolkit, which aids development and implementation of practicable CPEPs on projects. This should be presented to the industry in the form of a web-accessible application.

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Agent-facilitated Trust Building in the SEEM Infrastructure

Z. Ren, T.M. Hassan, C.D. Carter & C. J. Anumba
Department of Civil and Building Engineering, Loughborough University, Loughborough, UK

ABSTRACT: This paper presents an agent-based trust building approach developed for the Single Electronic European Market (SEEM). Intelligent agents, embedded in the distributed SEEM registry and repository nodes, SEEM Certification Authority (SCA), Trust Third Parties (TTPs) and external Certification Authorities (CAs) are adopted to collaboratively seek the trust related information of a potential partner such as user certificate and conformance information, as well as registry information.

1 INTRODUCTION

The EU sponsored SEEMseed project (Study, Evaluate, and Explore in the Domain of the Single Electronic European Market, IST-1-502515-STP, URL1) is undertaking policy orientated research within the field of the Single Electronic European Market (SEEM), with a focus on registries and repositories. A major objective of the project is to develop an experimental infrastructure for the SEEM that can be used throughout Europe (and beyond) and is compatible with other similar initiatives. The core infrastructure focus is an intelligent and distributed registry service that is able to provide all the necessary information to set up, run and terminate eBusiness interoperations along pan-European supply chains.

By definition, SEEM should offer a collaborative model to implement the exchange of information between its actors. Typical services of the SEEM Registry and Repository (RR) includes:

- company information support;
- person information support;
- product and service information support;
- business process monitoring support;
- business messages support;
- document specification support;
- business agreements support; and
- technical agreement support.

According to the SEEM user requirements report (D2.1), security and trust are two key aspects of the SEEM framework. The following three points illustrate these issues from the SEEMseed perspective, with further details available in D2.2.

- Firstly, in an open and dynamic environment, trust is a fundamental issue to enable companies to conduct commerce and collaboration. This requires various types of information that can be part of the trust profile of a company, and this information may vary depending on the type of relationship. Two kinds of information are essential: 1) basic user information: name, address (e.g. address types, country and region), company identifiers, contacts, means of contact, banking account and dealing, tax scheme information, legal registration information, currency information, categorisation of the company, description of the activities of the company, preferred language, relationships between companies. Such information is essential to identify an individual user; 2) user conformance information: attitude, expertise, quality of service, previous projects, client satisfaction, etc. Such information is used to address a user's service or professional performance for trust building.
- Secondly, the SEEM Registry and Repository Network (SRRN) should be able to store – in a secure and trustworthy way – all users' information; because it has to be digitally signed, users will consider it to be valid. The access policies of the SRRN will allow users to gain access to specific information, and can even specify the period of time that they are allowed to access it.
- Thirdly, to obtain more specific information about a company, it will sometimes be necessary for a trusted third party to evaluate the information and recommend or oppose the use of

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services from a certain company. The SRRN will provide an algorithm to facilitate the information access from the SEEM registry to the trusted third party actors.

To adhere to the SEEM principles, the registry and repository possesses the following features and benefits:

– *No central control*: Users are left to their own devices, but have the support of trusted third parties when needed;
– *Open confidence*: The SRRN is secure and can be trusted, yet is open enough for all to participate in it freely at the layer they require;
– *Accountability*: The establishment of secured checksums, access control and authentication means that all parties are full accountable;
– *Privacy of Content*: The content, where required, continues to be private between relevant parties: and
– *Enhanced Reliability* – for example, the use of notification services on the registry allows participants to actively monitor the status of any process. If necessary the content can be replicated (whilst still secure and identified) to prevent any down time issues.

This paper presents a conceptual model in which multi-agent systems are used to facilitate trust building in the SRRN services.[1] Although these agents are designed to facilitate the complete trust-building lifecycle – from initial trust building, to monitoring of the collaboration process and finally reputation building and evaluation – this paper focuses on the agents' role in initial trust building through ensuring the credibility of the SEEM users in the distributed RR nodes, SEEM Credibility Authority (SCA) and TTPs.

2 THE SEEM INFRASTRUCTURE

2.1 *The SEEM RR Infrastructure*

To fulfil the needs of the SEEMseed project, and the realisation of the registry and the interfaces, the infrastructure has been divided into five different layers: user layer, application layer, registry and repository (RR) service layer, core registry layer and core repository layer (Figure 1). Of these, the RR service, core registry and core repository layers are the critical focus of the SEEMseed project. These generic components are referred to as the SEEM Registry and Repository Network and their focus is to serve and be served by information content, which can be stored and indexed.

[1] This paper is a tentative research study based on the SEEMseed infrastructure rather than fully comply with the infrastructure.

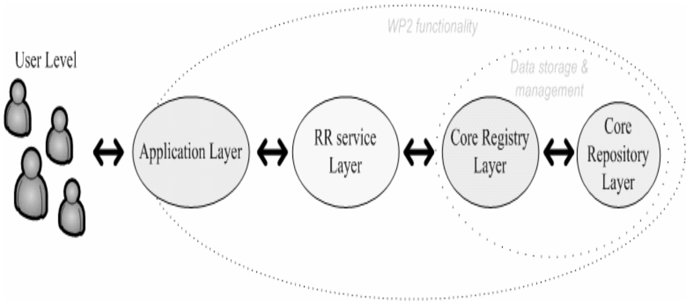

Figure 1. The layered structure of the SEEM (D2.1)

1) *User and Application Layer*

The user layer is a representation of all SEEMseed Users. The application layer contains applications and user interfaces to allow users to communication with the RR services layer. This can be an application running on a mobile device or a web site to enable access to the SEEM. From the RR service point of view, the high-level functions of this layer are:

– Formulate queries for company information and document retrieval;
– Receive and interpret information; and
– Formulate commands to store company information and documents.

2) *Registry and Repository Service Layer*

This layer is responsible for managing all kinds of registry logic, such as managing notifications and document types. It is an interface that allows the applications to access the information registered and stored in the registry in a homogeneous way. The scope of the functionality of the Registry Services Layer is constrained by the possibilities that the Core Registry Layer offers to it, and by the information model offered by the core itself. The functionality of the Services Layer has to be independent of any specific business framework specification. The RR services layer offers the external applications a high-level interface to access the contents of the registry and repository in order to:

– Query the SRRN for desired information;
– Manage information in a secure way, and make it available to authorised users;
– Allow users to specify 'alarms' that inform them when the information changes;
– Add, update, delete, and edit information on the registry;
– Categorise and associate the data in the registry so that users can find and use it; and
– Log the operations made at the registry.

3) *Core Registry Layer*

This layer is strongly connected to the Core Repository Layer. These layers are the key components of the SEEM's data storage and management system. The Core Registry Layer manages data distribution and access. It works as an access point to the global

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registry network and offers functionalities to quickly find stored information, which can be located in different repositories distributed over the Internet. This layer therefore implements an indexing system and offers some basic queries to retrieve stored data by forwarding queries to repositories and other registries. This layer is content neutral. Once receiving a query from the RR Services Layer, the registry layer will forward it to the Repositories, connected to the Core Registry Layer, which will perform a search based on the query.

One of the main issues of the registry layer is the distribution of the registry. It takes care of the knowledge base for all repositories in the network and their suitability for specific kinds of information storage or retrieval. A core registry node needs to connect to other SEEM registry nodes and queries them as well. Those registry nodes might have more nodes that they are connected to. All core registry nodes are connected in a peer-to-peer arrangement. Each SEEM core registry layer instance (peer) has a list of other instances. Once a query is received, it is forwarded to all known peers, which will then forward the query to the peers that they are connected to. They then collects the search results (if there are any) and sends them back to the peer that originally sent out the query. If there are no results this information is also returned, thereby reducing the timeout effects.

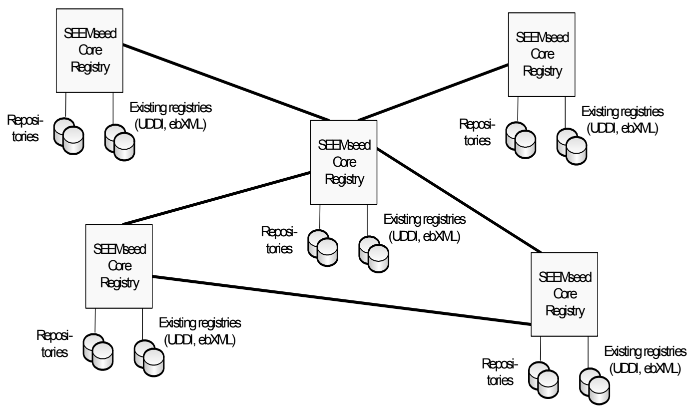

Figure 2. Connection of multiple SEEM core registries

4) *Core Repository Layer*

The core repository layer is responsible for storing documents and other entries and for retrieving them by performing queries received by the core registry layer. The primary goal of Repository Layer is to provide the storage functionality for the SEEM registry infrastructure. The high-level functionalities are:

– Store and serve all information used in the SEEM environment (e.g. schema, templates and instances of company information, business processes and documents, technical profiles, agreements, services, product information, etc.);
– Support different taxonomies and classifications;
– Store and serve metadata information;
– Support data versioning; and
– Security – providing access control and information privacy.

By implication, the layered structure implies a sequential flow of information from the user to the core repository layer. Each layer will thus receive requests, process them, possibly issue and wait for requests to be processed from the next layer, and ultimately return information to the calling layer.

2.2 *Distributed Registry and Repository Nodes*

Each SEEM implementation is a series of single components that are joined together in a serial manner. However, the reality is that there will be many instances realised of each layer, and each layers may use or know about only certain other layers. In other words, each layer should not be perceived as a single application, which can be implemented as many nodes with similar functionality. These nodes could be hosted by different service providers. The nodes can be linked and work together.

In addition, nodes in the same layer could be content or service specific. For example:

– There may be core repositories A,B,C…, of which A and B are generic (hosting any kind of information), whilst C only hosts company information,
– A core registry instance X may only know about A and B directly, but may be linked to another core registry instance Y, which may know about A and C, but not B;
– A RR Service instance P is implemented such that it only ‘cares’ about company related searches. It interfaces to registry X and another registry Z, which also knows about A and C but not B.

The distributed registry and repository nodes create a very flexible and comprehensive system in terms of how users are registered and how information is accessed and stored. However, with flexibility comes complexity. How to obtain users’ information for trust building efficiently is a major technical problem.

3 TRUST FRAMEWORK IN THE SEEM

3.1 *Theoretical Background*

Trust building in the SEEM involves many different aspects. Although the SEEM trust building should consider the overall lifecycle of eBusiness conducted in the e-market, the SEEMseed project mainly focuses on the initial trust building. A trust building framework has been developed (Figure 3).

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McKnight and Chervany (1996) identified three major trust types: dispositional, institutional and trusting beliefs. Trusting beliefs means that 'one believes that the other party has one or more characteristics beneficial to oneself'. It reflects the idea that interactions between people, and cognitive-emotional reactions to such interactions, determine behaviour.

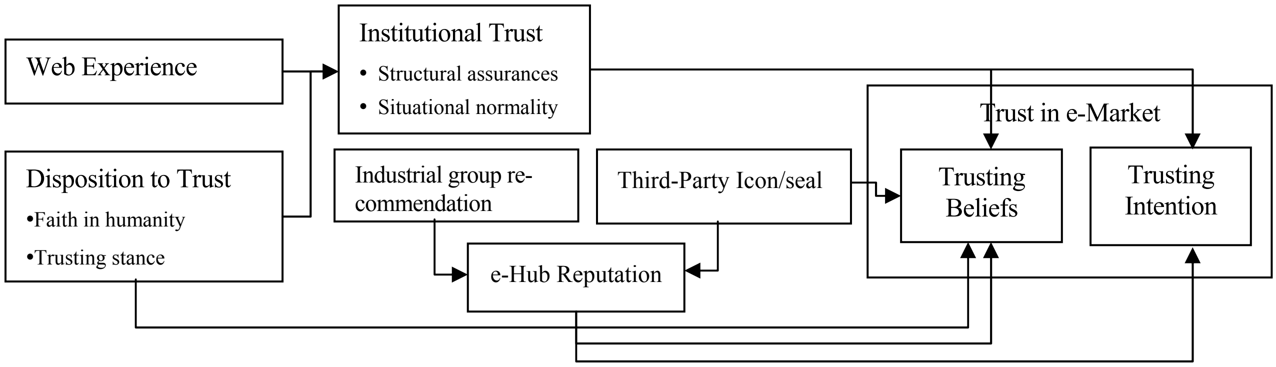

Figure 3. Conceptual trust building model for exploration stage (adapted from McKnight *et al.*, 1998)

There are four types of trusting beliefs:

– *Competence* means that one believes that the other party has the ability or power to do for one what one needs done.
– *Benevolence* means that one believes that the other party cares about one and is motivated to act in one's interest.
– *Integrity* means that one believes that the other party makes good-faith agreements, tells the truth, acts ethically and fulfils promises.
– *Predictability* means that one believes the other party's actions are consistent enough that one can forecast them in a given situation.

These four aspects are essential for initial trust building. Ren *et al.* (2005) discuss the SEEM trust building in terms of technological, business and social infrastructure. This paper focuses on the users' trust relevant information during the registration process.

3.2 Trust Information in SEEM Registry

In any environment where a degree of conformance is required, and especially for those that are based on trust mechanisms, there are a series of requirements placed upon the parties and a series of expectations if these requirements are not fulfilled. SEEM works as an 'open club' or a 'community', where there are no onerous membership conditions, but users are expected to know and fulfil the rules and statues; otherwise it impacts the benefits of the club for the other members. Two kinds of information essential for trust building in the SEEM registry process are:

– *Identification of parties*: Identity can be proven through PKI techniques, but these still rely on the correct identification of a party in the first place. A digital certificate is required for each SEEM user to identify each participant. A digital certificate is an electronic piece of information proving the ownership of a public key by the entity. This identification will allow access control at every level. Additional registry information allows service personalisation and thus more efficient configuration and adaptation of services.
  The SEEM Certification Authority (SCA) could issue, revoke and manage certificates to be used by SEEM users. It also issues web server certificates and publishes Certificate Revocation Lists. Since many users also have non-SEEM identification, it is particularly important for the SEEM infrastructure to cope with this. In the case of accepting certificates from other TTPs or CAs, in order to be identified by the SEEM infrastructure, the attributes of the certificate should satisfy the requirements of the SEEM. TTPs or CAs can issue certificates if they follow the rules identified and authorised by SEEM authorities. Those certificates include the SEEM Identification Number (SID), which is used to authorise users and is directly connected to the security profile of each user. Each registry and repository must keep a list of all the certificate authorities it recognises.
  The SEEM infrastructure treats the certificates issued by the SCA, external CAs and TTPs differently. They are classified in different trust levels. Normally, a user with a certificate issued by a TTP is normally regarded as more trustworthy, because TTPs may specifically evaluate the various aspects/capability/behaviour of a company, whilst the users with certificates issued by the SCA and external CAs are regarded as being of 'normal trust level' (for details, see the SEEM trust infrastructure[2]).
– *High Level Conformance*: During the establishment of electronic trading relationships, it is often considered essential to perform high-level conformance checking. This includes a check on

[2] To be published in May, 2005.

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system conformance – to ensure the integrity of the system and processes – and users' business behaviour – to ensure that participants are trustworthy in terms of their capabilities and good will. The conformance could be tested directly, or proven by reputation and comments left by partners, or through certificates issued by the SCA. In some cases, the issue of certificates could be undertaken by third parties that test conformance. This functionality therefore has to be supported within SEEM.

4 AGENT-FACILITATED TRUST BUILDING FRAMEWORK

Previous studies (Zacharia *et al*., 2000; Maarof & Krishna, 1999; Moukas *et al*., 2000) demonstrate that the personalised, autonomous, adaptive and proactive nature of agents provides for the high level of interactivity and expressiveness needed for an effective and fulfilling customer experience, leading to a trusting relationship with the business. Recently, Chihiro *et al*. (URL2) and Hu (2002) have attempted to use agents as facilitators to build trust in eBusiness.

4.1 The Role of Trust Building Agents

Unlike previous studies, this project embeds multi-agent systems within the distributed SRRN and credibility authorities to facilitate the search for, and storage of, trust relevant information in the user registry process.

In this framework, there is an agent in each of the registry and repository nodes, as well as within the SCA and TTPs/CAs. These agents collaborate with each other to help a registered user find a trusted partner, based on its certificate and conformance information. To do that, agents work in three aspects:

1) Firstly, a registry agent contacts other registry nodes (agents) to check whether a potential partner (either customer or supplier) has registered with these registry nodes. The registry agent also contacts repository nodes (agents) to check whether a node contains the specific information about the potential supplier/customer.

2) Secondly, the registry agent searches for the potential supplier/customer's certificate. In such a case, the agent will first contact the SCA agent. If it cannot find the certificate, the SCA agent will then contact its neighbouring TTPs to see whether they have the certificate of the partner. If not, the related TTP agents will further contact their nearby TTPs or CAs. Since each TTP can only link to a number of neighbouring TTPs, an algorithm has been developed for agents to seek and negotiate the certificate.

3) Similar to the process for seeking the certificate, the registry agent also needs to contact different registry nodes (agents) or repository nodes (agents) and SCA agents to explore the possible conformance information.

4.2 Attribute Definition

Accordingly, a number of attributes have been designed for the agents to specify a SEEM user such as:

– Certificate: The subject field identifies the entity associated with the public key stored in the subject public key field. The entity is a combination of Relative Distinguished Names (RDN), which comprise several attributes.

Table 1. Essential attributes of user certificate

Attribute	Object Identifier	Description
CountryName	{ 2 5 4 6 }	Abbreviation for country
CommonName	{ 2 5 4 3 }	Combination of subject's surname and given Name.
OrganisationName	{ 2 5 4 10 }	An informative unique name of the subject's organisation
OrganisationalUnitName	{ 2 5 4 11 }	An informative unique department name of the subject's organisation
SerialNumber	{2 5 4 5}	The SEEM Identification Number (SID)

In addition, there is extended information in the certificate such as the communication approach, bank account, business scope, decipherment, signature, certificate signing, etc.

– Conformance: This field specifies a user's performance related information. For example, for a customer, the following information needs to be addressed: rank by the SEEM ranking system, initial information provision, requirement description, payment, communication capability, response to change management, etc.; for a service provider, rank by the SEEM ranking system, the information to be addressed includes: expertise, product, resources, quality of service, communication effectiveness, response to change management, etc.

4.3 Scenario

The developed conceptual model will be implemented in the SEEMseed waste disposal scenario (WP3). In this scenario, a waste disposer (i.e. the customer) tries to find a specialist transportation company (i.e. the service provider) to dispose of the waste. The cus-

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tomer registers at a registry node, the registry agent receives the user request through the application layer and RR service layer (for details, see the SEEM trust framework). Following the request from the user, the agent starts to seek potential waste transportation companies (WTC) that are qualified to offer the service through the SEEM network.

The registry agent searches for three kinds of trust relevant information with other peer agents: the possible registry information of waste transportation companies, the certificate information of the companies and the conformance information if available. Figure 4 illustrates the simple process described below:

1) The registry node A agent first sends an enquiry to registry node agents B and C. The enquiry form is based on the SEEM generic partner requirement template;
2) Neither B nor C finds any registered waste transportation company in their records;
3) Agent B then forwards the enquiry to registry Agent D, E, F, whilst Agent C forwards the enquiry to Agent G and H;
4) After the search through the SEEM registry nodes, no agent finds any waste transportation company registered (for the case that there are registered transportation companies, please see the SEEMseed trust infrastructure report);
5) The search result then feeds back to Agent A;
6) Agent A then sends the enquiry and information to the SCA. The SCA agent sends the enquiry to TTP2 agent;
7) TTP2 agent has not found any required company, then forwards the enquiry to TTP1 and TTP3;
8) This process continues until TTPn finds a waste transportation company, which has a valid certificate; and
9) The relevant certificate and conformance information (if any) is then fed back to Agent A from TTPn agent through the peer agents.

5 CONCLUSION

As a Europe-wide electronic market, the SEEM should provide a mechanism to foster the trust building between customers and suppliers, particularly when dealing with complex engineering services. Current studies in trust building mainly focus on the online security, business perspectives (e.g. initial trust building, trust building and distrust building factors, reputation system and disputes resolution) and social legal framework. The SEEMseed project not only considers these aspects, but also develops a trust building agent-based system for the SEEM infrastructure.

An important characteristics of the SEEM is the distributed registry and repository systems, as well as the TTPs/CAs. Therefore, tracing the information related to user registration and credibility is important for trust building. Multi-agent systems provide an effective approach to tracing this information, and will help users to find trustworthy partners.

As this model is still immature, much work still needs to be done, and several specific issues need to be addressed, including:

– The principles of agent behaviour in each node, particularly those related to security. In fact, trust among agents themselves is an issue. When agent systems are used to facilitate trust building, particularly when dealing with confidential information, careful system design is required.
– There are many problems affecting the implementation of agent systems in the SEEM infrastructure. This is mainly because agent-building toolkits are not yet mature. Therefore, additional work is required.
– It is expected that agents could also facilitate the lifecycle trust building. The mechanism of how agents could be involved in monitoring and evaluating users' behaviour in the SEEM will be another interesting area of investigation.

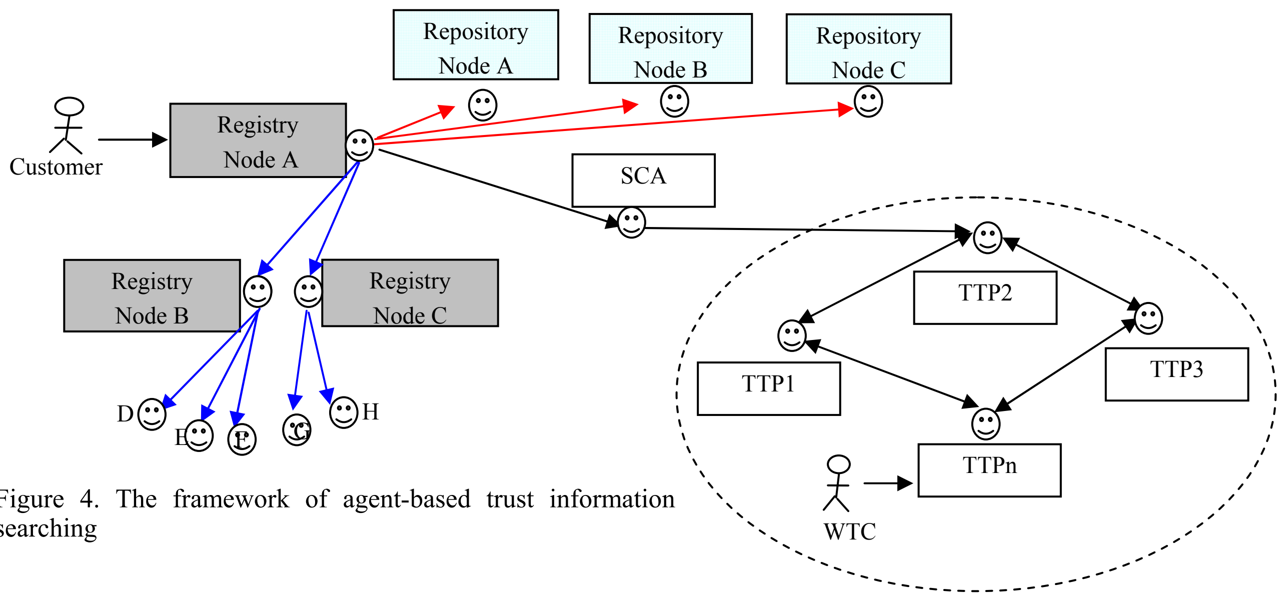

Figure 4. The framework of agent-based trust information searching

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