

## **CASE STUDIES: EVALUATING BUILDING INFORMATION MODELING IMPACT ON UNITED STATES ARMY CORPS OF ENGINEERS CONSTRUCTION**

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### **ABSTRACT**

Highlighted as test bed Districts for BIM implementation in the “U.S. Army Corps of Engineers (USACE) Building Information Modeling (BIM) Road Map,” Seattle and Louisville accomplished in-house BIM designs in 2005, three years before any other of the 43 Districts across the United States transitioned to a BIM-centered approach in 2008. However, while perceived benefits of BIM used on these test bed jobs are driving Corps-wide changes on billions of dollars of construction, these BIM-based projects were never critically evaluated for their benefits in the construction phase, creating a need for further investigation. Therefore, this research addressed the need and assessed BIM impact on construction projects according to the U.S. Army Corps of Engineers (USACE) internal metrics, the Consolidated Command Guidance (CCGs) metrics for military construction. Information garnered in the survey phase prior to onsite research at the Districts was used to guide research methodology assessing BIM effects on construction projects in the USACE Seattle and Louisville Districts. This research documented both quantitative and qualitative evidence demonstrated in BIM-based projects in Seattle and Louisville compared to similar projects (by facility use category code) to determine a correlation between BIM-based design and construction.

### **KEYWORDS**

Building Information Modeling (BIM), Key Performance Indicator (KPI),  
United States Army Corps of Engineers (USACE), construction, metrics

### **1. INTRODUCTION**

Building Information Modeling (BIM) is an integral part of the design and construction process in the United States Army Corps of Engineers (USACE). This is primarily because of two events: 1) the promulgation of *MILCON Transformation* and its associated Centers of Standardization (COS) effort & 2) The publication of ERDC TR-06-10, or the Army’s “BIM Road Map.” Due in large part to two test bed BIM designs accomplished in-house in the summer of 2005 in the Seattle and Louisville Districts, BIM is now required for the 42 standard facility types described in the COS effort. However, as the authors of the BIM Road Map discuss within the document, their reasons for mandating a BIM approach are anecdotal and not based on metrics related to design or construction (USACE 2006).

The hypothesis for this research is that there is a positive correlation between a BIMbased approach and construction management productivity. Therefore, qualitative and quantitative data was collected to evaluate a BIM-based design’s impact on construction. In “Phase I,” surveys were administered to assess practitioners’ perceptions about BIM’s impact on construction in relation to researched Key Performance Indicators (KPIs) of documented value to the construction industry (Cox et al. 2003). In Phase II, embedded research was accomplished on-site in Seattle and Louisville to garner qualitative and quantitative data regarding BIM effects on construction through the USACE’s internal metrics, the Consolidated Command Guidance (CCG) program.

## 2. BACKGROUND

**Why BIM?** In 2004, the National Institute of Standards and Technology (NIST) published a report stating that poor interoperability and data management cost the construction industry approximately \$15.8 billion a year, or approximately 3-4% of the total industry (Gallaher et al. 2004). Since this report, many have labeled Building Information Modeling (BIM), an emerging technological information management process and product, as the answer to this problem. From the National BIM Standard (NBIMS) published in December 2007, a BIM (i.e. a single Building Information Model) is defined as “a digital representation of physical and functional characteristics of a facility.” Furthermore, a BIM represents “a shared knowledge resource, or process for sharing information about a facility, forming a reliable basis for decisions during a facility’s life-cycle from inception onward.” In the words of former NBIMS Executive Committee Leader and current Executive Director of the International Alliance for Interoperability (IAI) buildingSmart Initiative, Dana K. “Deke” Smith, FAIA., “A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder” (NBIMS 2007). In fact, in NBIMS Chapter 4.1 “Minimum BIM,” where it discusses what constitutes a “minimum BIM,” the basis for writing this section was the U.S. Army’s BIM Road Map – showing again the importance of the Army BIM Road Map.

**Construction Productivity** In a 2007 follow-up research effort to the NIST report from 2004, NIST’s Building and Fire Research Laboratory (BFRL) researcher, Robert Chapman, stated that, “Construction industry stakeholders need compelling metrics, tools, and data to support major investments in productivity enhancing technologies. The development of metrics, tools, and data is complicated because each measurement level (i.e., task, project, and industry) has many different analysis requirements.”

While there are large organizations engaged in benchmarking and creating metrics like those discussed by Chapman, organizations like the Construction Industry Institute (CII) have created metrics that are primarily **task-based** (Thomas 2002). At the other end of the spectrum, with large organizations like the Bureau of Labor Statistics (BLS) tracking metrics that are primarily **industry-based**, there are few, if any, metrics tracked on the project management level from the owner’s perspective. This research focused on two project-based sets of metrics from the perspectives of a contractor and from an owner.

**Metrics for Construction Productivity—The USACE Consolidated Command Guidance (CCG) Program** As it is well known in the construction industry and corroborated in Adrian’s book, *Construction Productivity: Measurement and Improvement*, “the success or failure of every construction project can be measured in terms of four variables: cost, time, quality, and safety” (Adrian 1995). Similarly, these are aligned with the primary metrics that USACE uses to evaluate its own competency is the CCG program. The USACE CCGs attempt to compare past or current performance to an expected norm. There are a myriad of CCG metrics used to evaluate every phase of USACE work from design to sustainability, but there are five specific CCGs primarily used to evaluate construction productivity. These five CCGs are found in the USACE construction administrator’s automated management application, called the Resident Management System (RMS) are metrics MP-6 through MP-10. From the RMS, geographically disparate construction managers or contract administrators can add data or query USACE databases for real-time status updates on any of the active or completed projects in the USACE. Status is reported back in the following, simplified fashion:

- Green: CCG metric has met or is meet the goal
- Amber: CCG metric has not met the goal by a slight margin
- Red: CCG metric has not been met and is not close to being met

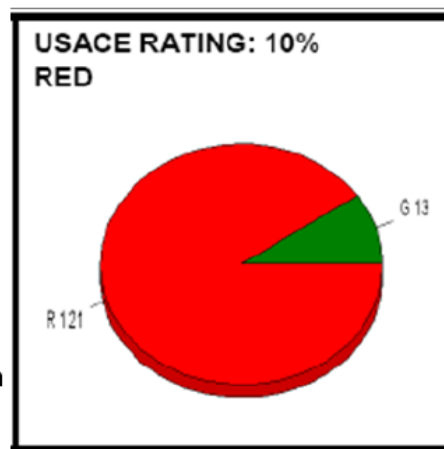
Below are a list of each specific metric and their accompanying goals, from the Honolulu District’s guidance (Won 2007):

- MP6: Construction Project Cost Growth
  - i. “Is the project’s current cost of construction within 5% of the awarded contract amount?”
- MP7: Construction Project Time Growth
  - i. “Is the project’s scheduled construction completion within 10% of the original contract duration?”
- MP8: Project Beneficial Occupancy Date Time Growth
  - i. “Is the project’s scheduled BOD within 10% of the original BOD?”

- MP9: Project Construction Timeline
  - i. “Is the project’s overall delivery schedule within the timeline guidelines based on the PA amount?”
- MP10: Project Financial Closeout
  - i. “Is the project’s scheduled fiscal closeout within 12/15 months of BOD?”

When evaluating construction projects individually, each project can only “meet” or “not meet” the goal. However, for the regional Districts, or their higher sub-regional headquarters called “Divisions” (which consist of multiple, subordinate “Districts”), the metric is “expressed as a percentage of the sum total of number of on-going projects in program years (PYs) 02-06 meeting the Cost Growth goal” (Strock 2006). Then the average sum total when dealing with an entire District or Division is broken out into the green, amber, red ratings. For each metric, the performance level and the windows of opportunity for achieving a “green” rating vary accordingly. For example, for MP-6 “Construction Project Cost Growth,” the goal is to “manage on-going MILCON Project construction through contract completion with no more than 5% total project cost growth” (Strock 2006). Therefore, for a single project to achieve a green rating would require that the project’s cost could grow no more than 5% for the “sum of all construction cost growth from Military Construction (MILCON) funded contracts executing a project” (Strock 2006). If it did not meet this goal, the project would simply be classified as “did not meet goal.” However, collectively, an amber rating would be achieved for 85-95% of the projects meeting the cost growth goal and a red rating would be applied for below 85% of the collective projects meeting the goal. Therefore, in the figure showing the CCG report from RMS querying all on-going projects for all Program Years, metrics MP-6 and MP-7 for the USACE are Amber with 89% for MP-6 and Red for MP-7 with a 68% rating.

- **MP6: Amber, 89%**
  - **Cost Growth**
- **MP7: Red, 68%**
  - **Project Time Growth**
- **MP8: Red, 72%**
  - **BOD Time Growth**
- **MP9: Red, 43%**
  - **Timeline (Duration) Growth**
- **MP10: Red, 10%**
  - **Financial Closeout**



*Note: Taken from CCG Report for all on-going projects as of 19 OCT 07 for all Program years*

Figure 1. USACE CCG Report, 19 OCT 07, showing range of 10%-89% meeting their metrics

As shown in Figure1, the Army is not meeting their goals. In fact, as of the date that report was queried on October 19, 2007, the USACE was red in four of the five metrics tracked in RMS, and, as shown in the figure above, only achieved an amber rating in the last remaining non-red metric. Clearly a change is needed and the army hopes to change this current level of performance.

## MILCON TRANSFORMATION

The USACE's FY 08 Military Construction budget was \$18.3 Billion. These projects included worldwide traditional MILCON projects such as Ranges, Barracks, Housing, and work on Host Nation Construction Management and Oversight in places like Germany, Japan and Korea (Temple 2007). With a construction budget this large, the USACE is one of the largest construction owners in the world. However, as seen in Figure 1, their current program execution needs improvement.

The strategic level program for ameliorating the current inefficiencies and meeting future challenges is called "MILCON Transformation." It is MILCON Transformation that drives the recent initiatives towards change in the Army Corps of Engineers. From former USACE HQ Commander and Chief of Engineers, Lieutenant General (LTG) Carl A. Strock, MILCON Transformation can be attributed to Deputy Assistant Secretary of the Army (Installations & Housing) Joseph W. Whitaker. In November 2004, Secretary Whitaker directed the Corps of Engineers to develop a strategy and implementation plan in support of Army Transformation to provide the Army the ability to establish, reuse/re-purpose facilities with minimum lead-time, leverage private industry standards and practices, and reduce acquisition/lifecycle costs. His direction recognized the urgent need for a massive, multi-year construction program to provide new facilities. The initiative developed in response to Mr. Whitaker's task assignment is now known as MILCON Transformation and is an important element of the Army's Business Transformation. This strategy was created in a partnership between the Corps of Engineers, the Office of the Assistant Chief of Staff for Installation Management, the Installation Management Agency, private industry and Mr. Whitaker's office. Key elements include standardization in acquisition processes, standardization of design of facilities and expanded opportunities for use of alternative construction methods such as manufactured building solutions (Strock 2007).

With the sheer size and massive budget for the work that the USACE oversees, MILCON Transformation is poised to have far reaching implications. MILCON Transformation includes a "disciplined emphasis on standardized facilities" and is designed to provide Soldiers with quality, sustainable facilities less expensively, in less time and on-time to allow the Army to meet its transformational schedules. Specifically, the USACE plans on 15% less cost on projects and 30% quicker time tables. With MILCON Transformation as the driver, the USACE has moved towards focusing on BIM as an answer. This comes from their formally promulgated mission and vision regarding BIM, in the Army BIM Road Map.

### **The Army BIM Road Map** ERDC TR-06-10, "Building Information Modeling (BIM):

*A Road Map for Implementation To Support MILCON Transformation and Civil Works Projects within the U.S. Army Corps of Engineers*" is simply known as the "USACE BIM Road Map." The BIM Road Map is a 96-page guide and requirements listing for successful BIM implementation in the Army Corps of Engineers. The USACE BIM Road Map is a product jointly executed by the CADD/GIS Technology Center, Construction Engineering Research Laboratory (CERL), and Engineering Research and Development Center (ERDC). While the BIM Road Map addresses many areas of possible contribution, the primary impetus for pursuing BIM, according to the authors, is to "drive down costs and delivery time" (2006). According to Seattle District CAD/BIM Manager, Van Woods who managed one of the real world BIM projects highlighted in the document, "driving down costs and delivery time" specifically meant that the USACE wanted to achieve economies of scale for repeatedly designing the same types of buildings, as well as reduce the average 18-month time from award to ground-breaking that the Corps was experiencing. As seen in the title, the BIM Road Map was an attempt to support "MILCON Transformation" within the USACE. The Army BIM road Map can be seen as the technological vehicle for making the logistic requirements of the COS initiative a reality (Woods and Solis 2007).

**The Centers of Standardization Initiative** Also support of MILCON Transformation, the Army published memorandum from now Major General (MG) Merdith W.B. Temple, the Director of Military Programs, on March 06, 2006 regarding "Realignment/Establishment of Centers of Standardization (COS), FY-06" (Temple 2006). In the COS memorandum, General Temple broke with the traditionally regionalized Division and District areas of expertise and established centers of standardization that would serve as design authorities for 42 different types of facilities in different Districts across the CONUS and even in Hawaii. The traditional model was for the Corps to focus on all MILCON and Civil Works projects within their region and contract



out 75% of the work to contractors while retaining 25% of the design work in house. Now, under the joint COS and USACE BIM Road Map guidance, the 42 facility types will be designed via a BIM approach and altered to fit site conditions at each District. More importantly, each COS will establish regional Indefinite Quantity (IDIQ) contracts that will administer “services associated with assigned facility types.” This means that firms who “win” the original design solicitations for the BIMs for these 42 jobs will in essence have a contractual lock on the design services EVERY time that building is modified and built in any USACE District in the United States, and that each District that serves as a COS will have an IDIQ to provide millions, and possibly billions, of dollars in services to construct these facilities across the United States. Quite simply, the impact is staggering.

However, the USACE BIM Road Map is a step towards alleviating those fears by clearly spelling out lessons learned and best practices for Districts to follow when formulating their in-house or contract-led BIM efforts. Based on design work accomplished in the Seattle and Louisville Districts, the USACE BIM Road Map discusses the strength of BIM, as well as how best to implement it through a discussion of requirements, and both short term and long term strategic goals. Possibly the most beneficial to the technical or tactical level BIM implementer are the Appendices which discuss the goals in depth, the specific implementation plan, “dataset evolution instructions” (file structure library recommendation), organizational recommendations, contract language, oversight and implementation guidance for working A-Es, personnel position descriptions, and other related roles and responsibilities. All in all the BIM Road Map would be beneficial to any BIM neophyte and is both concise and thorough in a way that most other documents of its kind have not achieved.

The USACE has created indicators that are both ambitious and realistic. By phasing their strategy, they have avoided the trap of “over promising” benefits that the technology cannot deliver. This also allows time for the culture within the USACE to change and to gradually phase in BIM in the best, most practical way in a traditional spiral fashion, indicative of other successful IT implementation initiatives. Appendix A outlines six “goals” that build on the four phases and seven milestones discussed above. Goal 1 reads, “Establish Metrics To Use for Measuring Process Improvement,” however no such metrics have been created since the document’s publication at the end of 2006 (USACE 2006).. This is the impetus for this research.

### 3. METHODOLOGY

#### USACE DISTRICT CASE STUDY INTERVIEWS

Research was conducted on-site in the Seattle and Louisville Districts in the summer of 2007. The following information summarizes the information gleaned in the interviews:

**Seattle District (NWS)** The pilot BIM project designed and managed by USACE-Seattle District was an enlisted unaccompanied personnel housing (UPH) barracks project at Fort Lewis, Wash. The project consisted of a total of seven barracks buildings, including two campus style barracks complexes designed to house 300 and 239 people, respectively.

Van Woods, CAD/BIM Manager, noted some missed opportunities when he lamented that Seattle’s estimators used neither the quantity take-off nor estimate from the model the designers provided. Instead, the estimators “trusted their experience over the BIM software.” When the traditional process yielded a significantly higher figure than the initial government estimate, the estimators returned to the designers for help. The explanation was that the estimators had included one kitchen arrangement (e.g. refrigerator, stove, sink, etc.) for every person in the barracks, when in reality there was only supposed to be one kitchen set for every two people. This problem could have been easily avoided had the estimating team used the virtual building model, which clearly indicated the correct quantities and provided an accurate estimate.

When talking to Mr. Bruce Hale, the lead architect, the primary theme was that, **“BIM provides a lot of promise, but that the cultural and training hurdles necessary for overcoming transition to the new process were more difficult than predicted.”** Due in large part to the lessons learned in Seattle and Louisville regarding training, the USACE and their BIM software partnered to establish a pedagogical approach to learning their BIM software that included 3-5 weeks of training, with a 1-week introduction to the

software followed by 2-4 weeks of intense training where designers work together to apply newfound BIM knowledge to an Army Center of Standardization (COS) standard facility type. Therefore, all eight geographically disparate COSs were trained by the end of FY07 with sound training plans that resulted in tangible benefits and real design drawings. A final challenge that Seattle uncovered was the lack of metric “assemblies” (or sample content) available in 2005. The design team was forced to convert or modify every assembly from imperial units to metric one-at-a-time, eliminating a benefit of BIM that is more prevalent today. Conversely, there are widely available project assembly data that can be used “off the shelf” in any project to rapidly advance the design phase.

Lastly, after interviewing Mr. John Herem, the Chief of Contract Administration for Seattle District, he said that aesthetically, the BIM design on this project was embraced by the user. But from a contractual standpoint, it was “as good as any other design” when it came to the quality of the construction documents. Ultimately, he wished that the contractor would’ve had the knowledge and training to work with the **virtual model** rather than just the construction drawings; but since this was not the case, the project suffered significant construction management issues caused by the contractor that could have been avoided. In particular, there were structural and mechanical issues and scheduling/phasing difficulties that could have been avoided if the contractor was more active in using the model to visualize, and in turn, manage a successful project. In the big picture, operating in a BIM environment leverages information to transform the building supply chain through open and interoperable information exchange, while contracts only stipulate legal minimums. In other words, “when you do things the way you always did them, you get what you always got.” Seattle found that operating in a BIM environment gave them an edge, but because of lack of buy-in, the contractor did not.

**Louisville District (LRL)** The pilot BIM project completed by USACE-Louisville District was a U.S. Army Reserve Center with an organizational maintenance shop built on land leased from North Carolina State University in Raleigh, N.C. The primary benefits noted in the Louisville District’s BIM project can best be summarized as “products, people and processes.”

**PRODUCTS.** The Louisville District’s roots in 3D, object-oriented design began in the late 1980s with its proprietary interface, the Modular Design System (MDS). This tool was used to design repetitive layouts and arrangements for the Support Team, Army Reserve (STAR) in Louisville on all Army Reserve projects. Whereas the Seattle District started with no library of data, the Louisville District’s transition to BIM began with importing and updating the knowledge base preserved in the MDS databases. This enabled the project team to overcome design challenges like those encountered by the Seattle District during its pilot project.

**PEOPLE.** The Louisville District also took great care in forming the team that would manage its first BIM-based project, hand-picking team members who were open to change and who possessed good communication skills. After initial attempts by individual design team members to achieve progress on their own proved ineffective in early 2005, the Louisville District transitioned to an approach it called the BIM Process Initiation Team (PIT), whereby all members of the design team received training that incorporated the project requiring design.

During the first week, members worked on real engineering and architectural requirements for the project. In the subsequent weeks, members were coached by the trainer and BIM manager to complete the design. Because of this accelerated, integrated design effort, the Raleigh project was designed and ready for solicitation approximately eight months before the STAR-imposed deadline.

**PROCESSES.** The Louisville District’s BIM team achieved success by standardizing their BIM-PIT workflow and data management. Much of its work serves as the basis for the *USACE BIM Roadmap* section discussing the BIM data workflow and management processes that will be used USACE-wide on approximately \$24 billion of military construction annually.

#### 4. CCG COMPARISON AND DISCUSSION

In order to collect the data on BIM-based projects versus non-BIM-based projects, the USACE Resident Management System (RMS) database administrators were contacted. They added a toggle box in the *Contract Description* area that allowed users to note whether or not a project was considered “Building Information Model (BIM) Compliant.” (Figure 2) In this way, known and future BIM projects could be easily differentiated for research purposes.

Figure 2. New “BIM Compliant” toggle box in Resident Management System (RMS) construction management database interface (Note non-compliance on this project)

Next, a data extraction was accomplished using the Consolidated RMS (C-RMS) database. In this query, projects with the barracks facility category code (72111) or Army/Armed Forces Reserve Center category code (17140/17141) were compared to the test bed BIM projects in Seattle and Louisville, respectively. Therefore, all completed projects of the aforementioned facility category codes and meeting the requirements necessary to appear in a CCG report were generated. This yielded 27 individual projects completed from 2002-2007 in various locations around the United States. Using the central limit theorem, the data was summarized and evaluated for 90% and 95% confidence intervals to describe the field of 27 projects.

Next, the two pilot BIM projects’ metrics from Seattle and Louisville were compared to the metrics from all the similar, completed projects from the past. Using the data from these two projects, their information was compared to the confidence interval data from the past completed projects. Results were accumulated individually by applying the same procedure to past projects CCG data and creating statistical norms through the Central Limit Theorem (CLT) approach. This included calculating the mean, standard deviation, standard error and then 90% and 95% confidence intervals for the data based off the 90% and 95% t values. Upon completion, the BIM-based projects were compared through simple, automated “IF” statements in the spreadsheet that labeled the result with one of three possible choices: “OUTSIDE (red or blue)” and “INSIDE (green).” If the result was INSIDE, then the BIM-based value was within the CI for the given metric. If the label was OUTSIDE, then the BIM-based project’s performance was either highly favorable or highly unfavorable and outside the CI.

In summary, the two pilot projects scores were very different. While the Louisville project never scored unfavorably outside the confidence intervals, it scored very favorably in cost, modification amount, time

growth, and duration. The Seattle BIM project scored very unfavorably in five of eight possible areas dealing with time growth and overall duration, but was inside the CI for cost and typical duration of actually completed projects. A summary of the percentage of each label can be seen in Figure 3.

|                   | CI         | OUTSIDE | INSIDE | OUTSIDE |
|-------------------|------------|---------|--------|---------|
| <b>Louisville</b> | <b>95%</b> | 0.00%   | 38.89% | 61.11%  |
|                   | <b>90%</b> | 0.00%   | 33.33% | 66.67%  |
| <b>Seattle</b>    | <b>95%</b> | 33.33%  | 55.56% | 11.11%  |
|                   | <b>90%</b> | 33.33%  | 55.56% | 11.11%  |

Figure 3. Summary Table of BIM-based projects results when compared to 90% and 95% Confidence Intervals (CI) of the control population of completed construction projects

#### DISCUSSION – LOUISVILLE PROJECT

When comparing the Louisville BIM-based project to the control population, it appeared to score very well. However, this could have been due to a relatively small project with an exaggerated timeline. This possibility became apparent when noticing that it met every CCG, sometimes even favorably outside the CCG CI, but actually did not meet the MP-9 metric for completing the project inside the administrative window for projects of its typical cost. In this way, the Louisville project no longer appears to have scored as well as some of the statistics would indicate.

#### DISCUSSION – SEATTLE BIM PROJECT

When comparing the Seattle BIM-based project to the control population, the words of the Contract Manager, John Herem, come to mind, “Seattle found that operating in a BIM environment gave them an edge, but because of lack of buy-in, the contractor did not.” The technological benefit of the BIM-based was never realized by the contractor, who faced many problems once on site including interferences as well as weather and mold delays due to their administration of the project and approach with the unusual material type of Heavy (Type V) Timber construction in the Pacific Northwest. Conversely, had they taken advantage of the virtual building model, it is likely that some of their problems could have been avoided.

#### 5. CONCLUSIONS

It was noted that overall the Louisville BIM-based project had statistically significant (when compared to the control population in this research) less modifications on their project than the typical barracks or reserve center facility projects. This information substantiates data collected in earlier surveys where practitioners responded that they thought “quality” was the biggest key performance indicator of the construction phase aided by BIM in the design phase. However, the Seattle-based BIM project, which demonstrated the stochastic nature of typical construction projects showed little impact from its technologically superior BIM design, due to common construction management problems like time growth due to HVAC interferences, weather, and mold.

However, the hypothesis for this research was that there is a positive correlation between a BIM-based approach and construction management productivity. Through qualitative means (interviews) and quantitative means, (statistical analysis) the BIM-based projects did, in fact, demonstrate varying levels of positive impact. However, with the limited sample size and scope of the control population, this data should only be used to establish correlation and not causation. As indicated by the Seattle project, more complex models would be required to account for the myriad of variables that exist in the design and construction facility lifecycle. In

addition, much more data would have to be collected in order to make any claims about BIM-based designs causing construction productivity gains.

However, the business case and argument for the USACE to adopt this approach is compelling. Currently, their internal metrics, the Consolidated Command Guidance (CCG) program has no way of determining if their innovation will yield any significant results on a portfolio-wide level in line with their goals. In the Corps' move to breakdown the geographic boundaries and focus on optimizing construction by facility type, they need an approach that establishes statistically sound confidence intervals to allow them to know what to expect, reward/emulate those projects that surpass their expectations, and evaluate/document those projects that fall short of their expectations.

It is recommended that the USACE adopt a procedure to allow for the use of their meticulously collected data for documenting benchmarks whereby similar projects of type, cost, and duration are compared. Administratively-driven metrics are of little value and fail to reward superior performance and only document the existence of inferior performance.

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## **CAD-BIM REQUERIMENTS FOR MASONRY DESIGN PROCESS OF CONCRETE BLOCKS**

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### **ABSTRACT**

The masonry constructive technique of concrete blocks is a practice that contributes for a high level of industrialization in construction in addition to achieve the rationalization in this sector. The achievement of these benefits demands some design features such as modular coordination, blocks rows details and well documented and precise specifications. One solution to meet these design features without causing agility reduction during the process is the use of CAD-BIM (Building Information Modeling), which applies modeling and visualization techniques already consolidated in other industry branches. Although the CAD-BIM brings improvements in the design process, it does not provide tools aimed directly to blocks masonry design, what can cause difficulties. The goal of this work is to identify these problems through a case study in a builder office sited in Curitiba, Parana state, Brazil, which is specialized in building design of concrete blocks masonry. Based on the results of data collected in the case study and in the literature available was possible to develop a list of CAD-BIM requirements more suitable for this kind of design.

### **KEYWORDS**

CAD, BIM, concrete blocks masonry.

### **1. INTRODUCTION: THE USE OF INFORMATION TECHNOLOGY IN THE PROCESS DESIGN**

The use of communications and information technologies in the building industry is creating new opportunities for collaboration, coordination, and information exchange among organizations that work on a construction project (Caldas e Soibeman, 2003). These aspects contribute for the design accuracy and consequently result on a proper building execution. Moreover, there are also technologies such as presented by Ganah *et al.* (2005), developed to assist design teams in communicating design details that may be problematic for construction teams. In the design phase, the CAD technology represents one of the most influential information technology innovations of the last four decades and offer resources for drafts and design automation, communication and design and data base exchange (Kale e Arditi, 2005). The new generation of CAD systems is recognized by “Building Information Modeling – BIM”, which can be described as the process of creating and managing building information in an interoperable and reusable way. Thus, BIM is a system that enables users to integrate and reuse building information and domain knowledge through the building lifecycle. Therefore, through a BIM model it is possible to encapsulate building knowledge in such a way that each object represented is able to hold an intelligent behavior in accordance with the context of their application (Lee *et al.* 2006).

Given these characteristics, the BIM approach is considered a proper solution for the development of specialized objects, which is able to represent the relevant characteristics of a masonry design. Thus, the design documentation could be automated in order to facilitate the representation of constructive details and as a consequence, contribute for the adequate construction in the site build. The objective of article is to take requirements stock for software based on the concept BIM appropriate for a masonry building of concrete blocks.

## 2. METHOD

The method adopted for this research was the literature research on the peculiarities of masonry process of concrete blocks and on the possibilities of implementing an object BIM for automatic extraction of design documentation. For this article, was chosen the way of implementation through an associated application. Thus, through this approach, and considering the possibilities offered by BIM model, was drawn up a list of proposed requirements. There this list of requirements, has proposed a model of processing data for representation of instances of BIM model.

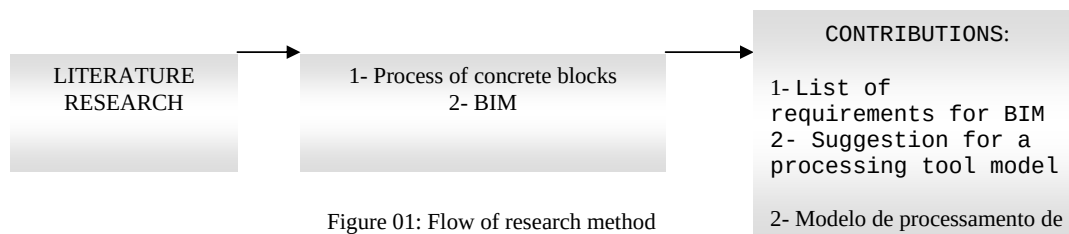


Figure 01: Flow of research method

## 3. APPROACHES FOR THE DESIGN DOCUMENTATION AUTOMATION

The development of a tool to automate the design documentation could basically follow two directions: an independent application or an associate application, which could be a plug-in to a BIM CAD. The advantages and disadvantages of each approach are described below:

**Independent application:** this approach would demand the development of a tool completely independent of others BIM CADs, although it could be used together. The key element of this approach is the reading of a file which holds the virtual model, preferable in IFC (Industry Foundation Classes) format. In such a way, the building model can be read by the main BIM CAD. The major advantage of this approach is the flexibility offered by the independency of proprietary formats that interact in the BIM process. Among the disadvantages is the enormous effort required to develop function and interfaces already available in BIM CADs: even applications specifically developed to defined process design stages, such as Tekla (Tekla, 2008) or the Ecotect (Square One, 2008) demand basic functions of object creation. Other disadvantage is the instability of IFC model, which still present some conversion problems between different applications.

**Associate application:** in this case, it would be developed a tool which could act from the main interface of the BIM CAD available in the market. This approach uses the basic functions already available in BIM CADs and focus in the automation of the masonry design documentation. The main disadvantage is in lack of flexibility, which would demand a new programming for each BIM CAD and also for each version of BIM CAD.

This article focuses on the second approach and demonstrates the key situations to be faced by a tool regarding to the automation of design documentation for masonry construction. This choice was due to the fact that a complete implementation (first approach) would only demand solutions to interfaces and basic functions, which are already described by the guides of major BIM CADs (Graphisoft, 2008; Autodesk, 2008; Nemetscheck, 2008; Bentley, 2008).

One of the BIM CADs principles, regardless of the manufacture, is the automated extraction of information from a model composed of objects that represent constructive elements of the designed building. Therefore, among the functions there are routines responsible for automating much of design documentation such as sections views, elevations, perspectives, layouts and quantities take-off (Ibrahim *et al.*, 2004; Tse *et al.*, 2005; Moum, 2006; Mao *et al.*, 2007; Campbell, 2007). These routines are important agents for improving the design process, but usually they only correspond to generic situations. In such a way, the specific characteristics of the constructive system are designed by the project team without the BIM CAD support. This aspect is in part result of the business strategy adopted by the BIM CADs manufactures, which invest primarily in the improvement of basic interfaces and in the more generic features to make the product adaptable to the largest number of consumers in the worldwide. To compensate this lack of detail about the constructive systems or specific regions, the manufactures advice the possibility of improving the basic functions of their applications. Below are described the main ways to do it with the focus in a tool to automate the design documentation for masonry construction.

**Configuration of native parametric objects:** the objects called “wall” in BIM CADs can be modified to behave as compositions of blocks or bricks. It only demands the configuration of the filling material, to represent blocks or bricks in sections views, and the external textures to represent their faces in the views and perspectives. This configuration is the easiest way to automate the masonry design documentation, and if it were implemented in a suitable way, can support the level of information required for this constructive system. However, this approach demands the management of all designers involved in order to verify the correct representation of the filling material in sections and the block faces textures in views. Moreover, the use of generic textures in the wall faces, although represent visually the course, do not embody intelligence in the object. It is not possible to, for instance, indicate the insertion of special blocks for modular adjustment or for facilities.

**Templates:** packages containing standards of graphic representation and rules for the creation of parametric objects which will represent the constructive elements. These patterns are consistent with the local regulations or with the standard guides of architectural offices and their use may prevent the designer to create elements that were not pre-defined. The templates assume great importance for the masonry design documentation because they hold options for blocks, course and coatings.

**Special parametric objects:** they are more detailed and flexible representation of constructive element created separately from the building model and later inserted. In previous experiences of this research group, parametric objects to represent concrete brick walls shown to be very useful for automation of design documentation.

**Scripts and macros:** tools that automate processes through algorithms composed of sequence of commands which trigger BIM CAD functions. Like the special parametric objects, they shown great useful in previous experiences, where scripts were created to automate the objects replication of concrete blocks in order to compose a complete wall. The limitation of their functionality is directly related with the scope limitation of the programming language used to generate the algorithms. In the ArchiCAD, for example, the programming language used in the scripts is not able to access all data of the building model, and the contextual intelligence of the object can be compromised.

**Association with auxiliary data bases:** function that allows associating the specific parameters of each parametric object (e. g. wall area) with generic data, inserted in auxiliary data bases (e. g. number of blocks per square meter). The data bases can be created from the BIM CAD or external to it. This is a very flexible approach to the data extraction from the building model because it eliminates the need to create new parameters in the objects each time that new information is required. Although it is a excellent alternative for quantities take-off, this approach do not solve the graphical representation of the composition of masonry wall: it is possible to know the number of blocks based on the area consuming index, but it is not possible to know the position of these blocks in the wall.

**API (Application programming interface):** are packages of functions and access rules to be inserted in new applications, which allow the communication with the application core of BIM CAD and their data structure. The main BIM CADs offer this alternative for software developers to permit the creation of new application



that is able to improve the basic processes. The applications developed with the APIs holds unrestricted access to the building model data, which make this approach the most powerful among all presented.

#### 4. FEATURES TO BE CONSIDERED IN THE AUTOMATION OF MASONRY DOCUMENTATION DESIGN

The following topics are related to the main features to be offered by a tool specialized in the automation of masonry design documentation through a BIM CAD.

**Top-down modeling:** During the early stages of a building design there is a great number of indeterminations related to the architectural spaces, constructive systems and materials to be used. In these phases, parametric objects should behave in a generic and abstract way, in order to permit the agile handle and successive updates. As the design process continues, the parametric objects must be able to store more detailed information and to behave in a more specific way (Lee *et al.*, 2006). One disadvantage of using excessively determinants and complex parametric objects in the early stages of building modeling is overloading the designer with information that will be determinate only in the later stages. Cheng (2006) advice for the fact that very complex parametric objects can damage the experimentation process that is inherent in the architectural conception.

**Behavior of objects:** parametric objects are the essential of BIM CADs. They associate the description of constructive elements to behaviors that define, among others possibilities, the way the object must be graphically represented in each design view (floor plan view, elevation, section and perspective). The tool must, therefore, generate behaviors to the parametric objects in order to automate the masonry wall representation in any view selected by the user. This ability would allow the automatic extraction of masonry course plan, sections views, wall elevation, including the blocks indication, and perspectives that support the understanding of assembling elements.

**Blocks and Bricks:** they are the masonry basic units and vary considerable in accordance with the geographic region. Therefore, the tool must support various unit types and should also be possible to create new ones from the descriptions provided by the user. Different types of block or brick can be used in the same building (e. g. external or internal walls). Hence, this feature should be a parameter of an object that represents the wall.

**Course:** they refer to the basic unit laying and vary considerable in accordance with the local (as the blocks and bricks) and also in accordance with the basic unit selected. Thus it should also be possible to create new ones through the description of its basic rules. Another critical aspect is the correct interpretation of the basic unit, regardless the laying position (e.g. header, stretcher, brick-on-edge or soldier courses).

**Modular coordination and neutral zones support:** based on the block and on the course selected, dimension updates in the object would be limited by multiple modules of the basic units. Dimensions that are not suitable for the modulation would be clearly shown to the designer (e.g. through hatches). In such a case, there should be at least two possibilities: insert automatically units or materials for the adjustment, in accordance with the bound rules; or advice the user about the constructive interferences in order to give the option for the user to do the modular adjustment or resize the problematic objects.

**Wall openings:** the tool should make the automatic shifting of the wall openings (or at least suggested it) which is not in accordance with the basic unit modulation. Furthermore, based on user definition, should be included automatically frames, window sill elements and lintels, etc.

**Wall interfaces:** the joint toothed intersection masonry demand elements which extend beyond the geometric limits of the objects. An example is the joints with intercalated courses (in which the blocks of odd and even courses are interposed in a way to transfer strengths between different plans); wire meshes and reinforced steel bar (Pfeifer *et al.*, 2001). The resolution of this situation depends on the object ability to recognize properly the context where it is inserted, adapting itself.

**Interfaces with other constructive elements:** the tool must automatically adjust the parametric object in situations where it meets other elements such as slabs, columns, beams, foundations etc., in a way to insert the necessary components. A typical example would be the automatic insertion of special blocks as channels blocks in the last wall course, if there is a parametric object above them to represent a slab.

**Gable walls:** wall plans sectioned diagonally present a special challenge. Their graphical representation must consider a wall as an irregular polygon (at least one trapeze), and there may be several different angles resulting from the section operations executed in the object. One very useful function would be the recommendation for user about the better section angle which would result in the fewer block waste, considering the setting of the courses selected.

**Facilities:** an essential function for the tool is the indication of the facilities position (electrical, hydraulic, logic, etc.) in a way to permit, from the rules settled by the user, the automatic identification of special blocks for the passage of tubes.

**Structural function:** defining a wall with structural function opens a new range of situations to be considered by the tool. Therefore, a tool should represent the horizontal reinforcement and columns, conformed by the masonry hollow blocks, and also the steel anchor of these elements. This situation should be addressed by an approach similar to the item “facilities”: through the identification of elements position by the user. A more advanced tool version should even insert the structural elements automatically, based on the gaps and loads defined by the user.

**Coatings:** in addition to represent the basic units which make up the masonry, a tool should be able to associate multiple layers of coatings, and also to quantify the components used in these layers. The tool should also be able to interpret the design context (design stage, scale, and view) to decide whether the coating should be represented or not. In the architectural design, for instance, visualize the masonry units is unfavorable to the correct data interpretation (unless it refers to a facing brickwork). In the masonry design execution, the visualization of coatings is unfavorable to the information understanding.

**Quantities take-off:** the object created by the tool should include information regarding the components consumption to permit the automatic material quantification, based on their coverage or volume. The tool should offer functions for automatic report extraction, based on the features presented in the major BIM CADs. A more advanced tool version, regarding this function, should also consider the model section (e.g. by stories) and the place for the material delivery.

**Standard guides:** in addition to automate the graphical representation of masonry elements, a tool should also automate the requirement description for construction. From the data insertion in the auxiliary data bases, the BIM CAD is able to automatically associate the descriptions and indications in the drawings and in schedules separately, when a specific object fit in particular criterion previous established. For example, to insert a tag with the text “Follow NBR 8798:1985” in all drawings that contain wall composed of hollow blocks structural masonry.

## 5. SUGGESTION FOR A PROCESSING TOOL MODEL

From the associate application approach of a BIM CAD and also from the features to be considered by the tool, a suggestion for a processing model was developed, which should be adopted by a tool addressed to automate the design documentation of masonry construction. Briefly, the processing executed by the tool would implement a set of basic objects to generate specific objects, which would contain necessary representations in order to automate the design documentation.

One possible solution to represent constructive detail of masonry wall would be the three-dimensional representation of each block that constitutes them. Although it is possible to automate this task, previous experiences of this research group showed that it would demand high processing capacity, besides to generate files which contain dozens of megabytes, even considering simple construction. To create three-dimensional objects to represent facing bricks may be a good option, but in many cases (perhaps most of them), the masonry will be coated and the view of position of each block is used only in the execution documentation.

Alternatively, the presented suggestion would be useful if a tool generated temporary two-dimensional representation, which could result in a more fast processing and suitable to the view required by the user. The main steps of the use of the tool are described below.

**Reference object creation:** the constructive representation of masonry wall detail would be executed automatically by specialized parametric objects, which are created from references extracted from native parametric objects (in this case, the “wall” object of BIM CAD). Using native objects as a reference, rather than modify them directly, has the advantage of maintaining the speed and facility of handle provided by the simplified characteristics of them. Changes in objects of reference would spread these modifications to the others specialized objects automatically, such as examples of existing tools, like a Wall Framing Tool, which converts native objects of walls in wood frame components (Cadimage, 2008).

**Facilities and structures definition:** from special interfaces, the user could launch information about complementary facilities and structures, as occurs in applications like Constructor (Vico Software, 2008). This information would result in auxiliary objects to represent the facilities.

**Selection of reference objects:** the user would select the native parametric objects which would like to obtain detailed representations, leaving all other walls in charge of the standard representation of BIM CAD.

**Masonry characteristics selection:** Among several options available, the user would choice the brick or block type, the bound rules for laying and the coating types on the walls. These options would be stored in relational data bases of the building model, which would be managed from specific interfaces. Keeping independent data base of the model would result in availability of the settings created for a specific design for all the others.

**Specialized parametric objects creation:** for each native object selected would be made a sweeping, seeking the spatial-geometric characteristics of the wall and the interferences between it and the objects that represent the complementary facilities. For each issue found, the tool would select the suitable block (for example, a special block for electrical box if it meets an outlet point) and would record their characteristics and their position in a data matrix. A specialized parametric object copy is created, containing the data matrix and the set of behaviors necessary to generate the graphical representations.

**Creation of the specialized parametric objects representation:** the processing in charge for the generation of graphical representation of specialized objects would be separated from the processing in charge for the object creation. It would occur because in a BIM CAD the different geometric representations are only objects instances and they are not new objects. For each new visualization required by the user (floor plans, sections, elevations and perspectives), the processing would be in charge to generate a new “object view”, composed of geometric elements which correspond to the new context. The geometric elements used (e.g. drawing of the block in section, indicative texts, textures) are stored in auxiliary data bases, allowing the automatic updates of the drawings.

**Quantitatives take-off and schedules:** from the same process of associate data bases, specific functions could generate notes of material list to be used in all derivative objects (obtained from the object data matrix reading). Besides, guidelines for construction carry out and instructions could also be generated automatically, based on the simple criterion association to descriptions inserted in the data bases.

The processing tool model data flow can be seen in figure 01 and the graphical instances of specialized objects can be seen in figure 02:

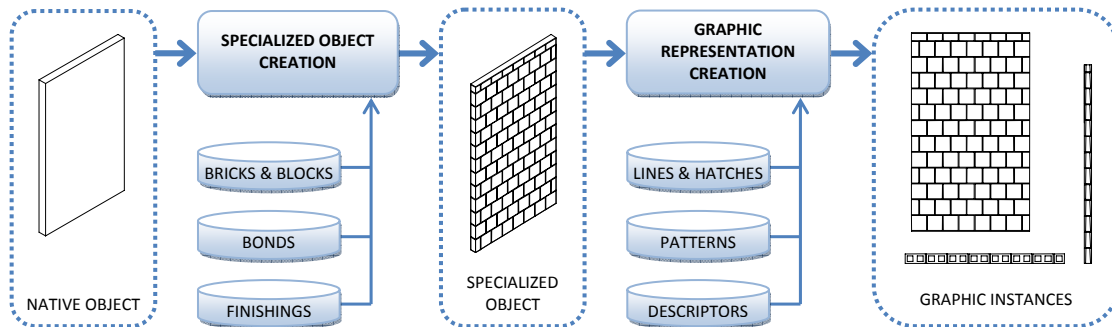


Figure 02: Processing tool model data flow

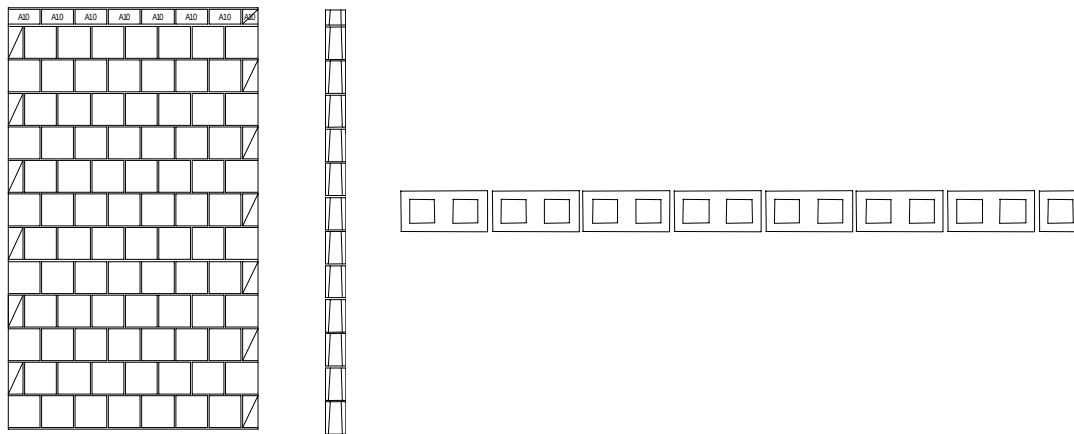


Figure 03: Graphical instances of specialized objects

## 6. CONCLUSION

In previous work conducted by this research group and also in experiences reported by the literature of the area demonstrated that through the parametric modeling capacity, provided by architectural BIM CAD, the automatic extraction of much of design documentation is feasible to be done. The features in charge for this task are those that distinguish this new CAD generation from the previous one: the use of parametric objects, the semantic interpretation of objects relationships which constitute the building model and the storage of this model in a data base format, from which information can be extracted automatically.

These experiments showed that is possible to automate the design documentation required to guide masonry construction, with high level of construction detail. A tool addressed to assist this task will demand several routines to analyze the context and to define the suitable behavior for the parametric objects, but much of the programming effort can be eliminated when basic features and interfaces available in BIM CADs are used. The proposed model aims to assist the source code generation necessary to develop such a tool, based on the assumptions which guide the BIM.

The automation of design documentation provide great potential for improvements in the quality design, adding value to it, besides to improve the communications among stakeholders. All these aspects contribute for the better quality of final products.

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## A BETTER BIM: IDEAS FROM OTHER INDUSTRIES

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### ABSTRACT

The architecture, engineering, construction and facility management (A/E/C-FM) industries have the opportunity to interoperate with software tools which utilise the IFC standard building information model (BIM). However, within the companies and projects which are currently using this standard there have been a number of issues raised with an impact on achievable interoperability. At the time that the IFC specifiers look at approaches to address these interoperability issues it is worth looking at other industries, who also have complex models and high reliability requirements, to see how whether there are lessons which can be learnt. In this paper the healthcare and manufacturing domains are surveyed in regards to their interoperability, conformance and certification approaches and novel ideas from these industries are presented for consideration of the A/E/C-FM industries and the developers of the IFC. A number of these approaches would argue for a restructuring of responsibilities between standards setting and certification, and others propose further development of freely available resources for all in the industry.

KEYWORDS: BIM; Interoperability; Survey.

### 1. INTRODUCTION

A range of recent papers have documented issues with the current BIM approach utilised in the A/E/C-FM industries (Kiviniemi 2007, Amor et al. 2007, Lipman 2006, Pazlar and Turk 2006). The issues identified in these papers show that current approaches to the management of BIM data are not sufficient to guarantee the level of interoperability which is expected by the industry. This has been acknowledged by the major developer of BIM standards for A/E/C-FM, the International Alliance for Interoperability (IAI), who develop the IFC data model utilised by the majority of major CAD tools and which is being mandated for use in several countries around the world. The IAI are looking at making changes to their certification processes to address the concerns raised, though it is unclear at this point how successful that approach may be.

It is clear that interoperability is a major requirement for the A/E/C-FM industries to gain further efficiencies and to support new business processes. A BIM, that describes all the major components of a designed building, the relationships between components, important attributes of the components, and the process to deliver the building, is central to being able to support interoperability between tools with different needs for building information. The development of the IFC standard for BIM and its incorporation into the major CAD tools in the industry, as well as a swathe of related simulation and information management tools, also argues for the willingness of industry to move in this direction. There is also evidence from major surveys of the industry, most recently the NIST report on interoperability (NIST 2004) which indicated that the cost of inadequate interoperability in the capital facilities industry was \$15.8 billion per annum in the U.S. alone, that the performance of the industry can improve significantly with the acceptance of this approach.

In relation to software tools it is also clear that testing of these tools is often not at the level which is really required to ensure the overall quality of the delivered software. The NIST (2002a) report on 'The economic impacts of inadequate infrastructure for software testing' noted likely impacts to be \$59.5 billion in the U.S. alone, with the potential for cost reduction of \$22.2 billion from feasible infrastructure improvements. In particular they recommended:

*"standardized testing tools, suites, scripts, reference data, reference implementations, and metrics that have undergone a rigorous certification process would have a large impact on the inadequacies listed above"* (pg ES-6, NIST 2002a)

When NIST surveyed the impact of STEP in transportation equipment industries (NIST 2002b) they identified that for the benefits of STEP to be realised, further resources have to be invested into:

- *“software developers’ costs associated with the standards development and demonstration (referred to as R&D); and expenditures to integrate STEP functionality into commercial products; and*
- *end users’ costs associated with the standards development, demonstration, and implementation of STEP.”* (pg ES-3, NIST 2002b)

These reports argue for further consideration of the approaches to interoperability and to tackle the issues inherent in interoperability between software products within A/E/C-FM. To help address these issues Section 2 looks at approaches to supporting the development and testing of interoperability in other domains. Section 3 then puts forward a smaller set of recommendations as to changes which would be beneficial for A/E/C-FM.

## **2. APPROACHES IN OTHER DOMAINS**

It is clear that other domains face information model issues of the same magnitude at A/E/C-FM, and in many cases their approaches to information model development share the same pathways. For example, the ISO-STEP standards (ISO 10303, which is well established for aerospace, systems engineering and design, manufacturing, ship building, and electromechanical industries) developed the specification languages (EXPRESS and EXPRESS-G) and the data transport mechanisms (STEP Physical File – ISO 10303:21, etc) which were utilised by the IAI. For these industries to interoperate they have to overcome the same data model and data transport issues as would be seen in the use of IFC as an interoperable standard. It is also clear that the models developed for these domains will be of a similar magnitude and complexity to A/E/C-FM models (e.g., ship modelling covers almost the same set of sub-professions as is found in a large building project). It is also clear that the impact of interoperability errors in these domains will have consequences at least as serious as in building projects. For example, cost of a ship or jet-liner is at least that of a major building and the impact of poor interoperability in the healthcare industries has the potential to cause injury or death to patients.

In the following sub-sections there is a summary of the different approaches to interoperability which can be seen in these industries, and which may have a beneficial impact on interoperability in A/E/C-FM.

### **2.1 INDEPENDENCE**

A striking aspect of the review of approaches to interoperability conformance in other industries is the separation between the standards setting body and the standards testing bodies for the domain.

For example, for ISO-STEP related standards there was the U.S. Product Data Association (USPRO 2006) which had been approved by ANSI as a body to certify processors for STEP. USPRO was a non-profit membership organisation established in 1992 and which worked through to the end of 2006 providing a range of standards-related services to U.S. government and industries. In the late 90's USPRO developed the STEP Certification Testing Programme to certify compliance of STEP-based software products. Similarly, the CAx Implementers Forum (CAx 2008), which was established in 1995, draws together a wide range of CAD vendors and third-party software developers in a less formal testing environment for ISO-STEP standards.

In the healthcare standards domain there is a similar independence between the standards development and publication (e.g., Health Level Seven (HL7 2008)), and organisations which provide conformance testing. For example, the Certification Commission for Healthcare Information Technology (CCHIT 2008) is a private non-profit initiative to act as a certification body for healthcare software system interoperability. CCHIT was formed by leading industry associations within the domain (American Health Information Management Association, Healthcare Information and Management Systems Society, and the National Alliance for Health Information Technology) and finds funding from major beneficiaries of healthcare software systems as well as the U.S. government.

These models are quite distinct from that operated by IAI, where it is both the developer and publisher of the standard, as well as the software certification body. The potential issue in the IAI structure is a perception of

conflict of interest in a body which strives to develop and publish a standard which they wish to be widely used by industry and then certifies those industry software products as being conformant. It is clear from the organisations which exist in these other domains that conformance testing requires significant resources and expertise. Expertise and resources which can exist in external companies (e.g., Solibri Inc who develop a model checker for IFC-based BIM) and with business models which enable an organisation to exist purely for the purposes of certification of software tools.

## 2.2 CONFORMANCE CLASSES

Strikingly similar to the IAI approach to certification is that all other industries also support the notion of subsets of the total standard which form a business case that can be tested against. There is a common recognition that a total standard covers concepts not required for every data transfer, and for many tools there is a distinct subset of the model which encompasses the data required for their business and place in the market.

For example, in the healthcare industries, the labs who test conformance to HL7 (2008) provide this service against a range of subset schema. AHML (2008) allow their clients to define a specification against which conformance can be checked, resulting in a number of publicly available specifications for large clients. IHE (2008) define a range of profiles which model a particular business process and against which data can be checked in a 'connectathon', a meeting of vendors similar in nature to the IAI open days. CIS/2 (CIMsteel 2000) define a range of conformance classes and follow the ISO-STEP methodology for conformance testing.

## 2.3 SUPPORT FOR CONFORMANCE TESTING

Different industries provide a range of tools and information approaches which ease the process of gaining conformance certification or checking for conformance. While there is no commonality across the different domains, a number of these approaches provide benefit to the community and are worth consideration for A/E/C-FM. Approaches include:

- Free testing of data against a particular standard. For example, AHIL (2008) have a free message testing service running beside their certification process. Any developer or user can submit a data file to this service and gain a report detailing any non-conformance to the standard which was found in the file. The report breaks message problems down into three parts: errors; warnings; and alerts. However, as they note, this service does not rectify the problems, it merely documents where they exist. In A/E/C-FM the Solibri model checker performs a similar (though more comprehensive) service, but this tool is certainly not freely available, limiting the ability to check data files to those who can afford the purchase price of the tool.
- Provision of tools to identify differences between two versions of the same file. For example, the CADIQ tool (TranscenData 2008) identifies geometric differences in the data found in two versions of what should be the same model and provides graphical views to show the identified differences (see Figure 1). This tool works on data files from a range of CAD companies as well as from data in standard representations. This tool is used as part of the certification process for tools claiming compliance with ISO-STEP standards to ensure the translated geometry is maintained correctly.
- Provision of freely available comprehensive test suites for pre-certification testing. For example, CAx implementer forum (CAx 2008), CIMsteel (2000), and CCHIT (2008) provide a range of test suites for the different scenarios that tools may be tested against. CIMsteel also provide a range of worked examples showing how software vendors would proceed to gain conformance against a particular conformance class.
- Provision of recommended practices for implementers of standards and of scenarios within a standard (e.g., CAx implementer forum (CAx 2008)). These recommended practices provide for common practice which sits beyond the provisions of the standard, representing an industry consensus on how portions of the standard are, or are not, utilised.



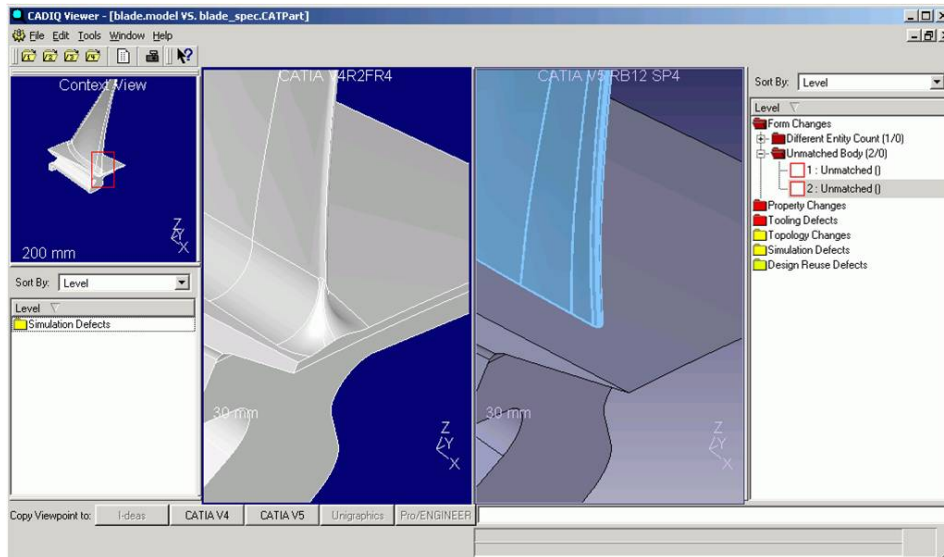


Figure 1: Comparison of geometry across representations (TranscenData 2008)

## 2.4 INTEROPERABILITY LAB

Within the healthcare industry there is a concept of a data interoperability lab which appears unique to this industry. These labs tend to be national in focus, for example, in New Zealand there is the Health Data Interoperability Lab (NIHI 2007). A lab, such as in NIHI, serves two major functions. One is to allow for the testing of software conformance, performance, and usability in a vendor neutral environment. The second is to support a development environment and showcase for innovation that will appear in future tools. To achieve these goals the lab provides computer equipment, expert staff, and installed copies of software from the major vendors in the field against which new tools can be tested or demonstrated. Figure 2 shows the two main aspects (corners) of the lab, with the red corner providing ‘a replicant of major healthcare systems and disidentified healthcare data suitable for stress testing of systems’ (NIHI 2007) and the blue corner ‘prototype systems that demonstrate the future state of health information technology’ (NIHI 2007). Note that the listed organisations at the bottom of Figure 2 such as MoH, DHB, PHO, etc are users of this service and providers of data for testing.

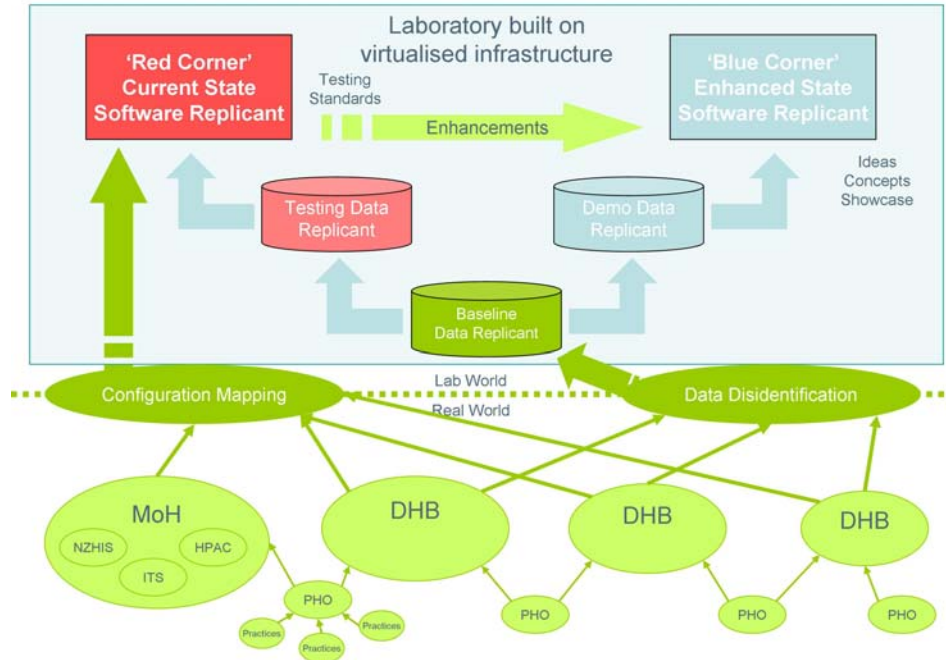


Figure 2: NIHI data interoperability lab concept (NIHI 2007).

### 3. RECOMMENDATIONS FOR A/E/C-FM

Reviewing the approaches taken in other domains the author would suggest the following for A/E/C-FM:

- Establish a body independent of the IAI to manage conformance testing and certification against the IFC standard. This removes the potential for a perception of conflict of interest between the standards setting and promotion body and the certification body. Evidence from other domains is that a non-profit organisation is feasible in this role and develops a very strong expertise and customer focus for certification.
- Reduce the barriers to conformance testing in the domain. A tool which freely checks a file for conformance would be of enormous benefit to all in the industry, whether they represent a software developer looking to determine the strength of their approach, or users of tools who look for reassurance of the conformance for a particular data file of their building model. Making available a larger and more representative set of standard test suites would also encourage stronger translators in software tools prior to embarking upon the formal certification process.
- Encourage companies within the ISO-STEP community to repurpose the tools developed there for model checking and comparison within A/E/C-FM. Of special interest would be tools which are able to compare geometry across the various CAD systems and their translations of standards-based data models.
- Investigate the possibility of a data interoperability lab for software vendors in the major software development regions (e.g., North America, Europe, and Asia). Such a lab provides a vendor neutral meeting point at which conformance testing can be undertaken at any time of the year (not just during a certification meeting) and where all the major software is available along with expertise to run and test the software.

#### 4. CONCLUSIONS

There are many industries who face similar issues as found in A/E/C-FM in the development of interoperability for their community. While the makeup of these domains is quite different from A/E/C-FM, there are lessons which can be learnt from their approaches to interoperability and ensuring conformance of software tools developed for their standards. This paper identifies a number of approaches which are applicable to A/E/C-FM and recommends that further investigation of approaches be undertaken. Some proposals would have a serious impact on the industry, such as devolving certification away from the standards setting body, but the evidence from other domains is that they are feasible and provide benefit to the industry as a whole.

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## A CONTEXT-ADAPTIVE BUILDING INFORMATION MODEL FOR REAL-TIME STRUCTURAL ANALYSIS IN A DISASTER MANAGEMENT SYSTEM

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### ABSTRACT

In case of disasters in urban areas it is important to immediately gain precise information about the constructional environment in order to react appropriately. Information can be gathered from Computer Aided Facility Management (CAFM)-, Computer Aided Design (CAD)- and Geographic Information Systems (GIS)-Applications but their effectiveness depends on the preparation of the data for the special needs in extraordinary situations. A major challenge is the integration of real-time data from sensors in the building and from the equipment used by the rescue forces on site.

At the Institute of Building Informatics a Computer Aided Disaster Management System (CADMS) is under development which is based on an enlarged ifcXML model. The system allows for the interaction of building data with static and mobile sensors, and can be used for indoor positioning of the rescue forces. A simplified, real-time adaptive static model will be used to estimate the danger of structural collapse. The rescue forces will be equipped with head-mounted displays (HMDs) and be able to interact with the application by voice. The tracking of the rescue forces is performed by inertial and magnetic sensors. These sensors are constantly calibrated according to the surrounding "intelligent" building data.

### KEYWORDS

building model, sensors, real-time structural analysis, indoor positioning, speech enabled user interface

### 1. INTRODUCTION

Today information about buildings is usually gained from traditional floor plans and maps which are part of CAFM-, CAD- or GIS-Systems. The first one is state-of-the-art for today's large real estates. Their databases need to be prepared for the special requirements in extraordinary situations to increase their effectiveness. In particular the ability to integrate data from sensors and data added by the user (i.e. rescue forces) is an [essential enhancement](#) for the [serviceability](#) of the plans in case of emergency situations.

During situations like fires, floods or terrorist attacks various information is collected by the rescue forces. With this information, the difficulties of overviewing the scene as a whole can be reduced and therefor appropriate response strategies can be developed. Furthermore an efficient coordination of the whole rescue operation can be developed upon these data. Most of those information concern the location of objects (like exits, stairways) but any other semantic information (destroyed fire extinguishers, hazardous areas, structural element collapse) can be included as well.

Especially in public large buildings like shopping malls or underground railway stations precise information about the structural behaviour is important. This is essential for decisions like whether or not to evacuate an area within the building. Though common rescue forces are experts with lots of experience in their field of profession, they usually do not have enough knowledge as well as information to carry out a structural analysis.

Therefore a context-sensitive Building Information Model (BIM) has been developed and its data will be linked with a finite element program enabling an immediate, real-time verification of the structural

behaviour. This BIM is a new approach to integrating structural data for a real-time analysis in an emergency command system. This system is based on a CAFM-database and an IFC-based architectural model. Further, dynamic data are added to the system. These data are gained by either sensors within buildings or mounted on persons or that are “manually” provided by the on-site staff. With this BIM, the impact of changes concerning the structural elements of a building can be estimated and it can therefore contribute to reducing the risks in case of extraordinary incidents.

Though the project is still under development this paper shows the up-to-date outlines of the CADMS with a focus on the BIM, the real-time structural analysis and the approaches to designing a voice operated user interface for this application. Further, first implementations will be presented and the challenges for future work will be discussed.

## **2. GENERAL SYSTEM ARCHITECTURE**

This paper focuses on some specific parts of the system used during a case of emergency. The system itself consists of five components: the building model, the position estimation, the position verification and correction, the user interface and the communication. All those parts are shortly illustrated in this paragraph.

The system requires floor plans supplemented with additional data that include transitions between rooms and floors as well as room boundaries for example. Augmenting floor plans with information on semantics are created using a commercial Computer Aided Facility Management (CAFM) system. The floor plans are tagged with additional information and converted into an XML document. This XML document is locally stored on every device allowing for autonomous navigation and fast data access.

In our system real-time data is gathered by inertial navigation and positioning based on Inertial Measurement Units (IMUs). They work without fix or temporary infrastructure. The position determination is based on a position defined as starting point and ongoing movement measurements [Glanzer 2007]. On device start-up the current location has to be determined. Since the results of the inertial navigation are not accurate enough for indoor positioning in extraordinary situations [Beauregard and Haas 2006], a novel approach is used for the position determination. To accomplish this task, information on semantics like the exact position of the entrances to the building, doors, fire extinguishers is used. Once initialised a verification and correction module permanently corrects the position with information about landmarks included in the BIM. This assures the correctness of the position data.

The position estimation reads raw sensor data and therewith computes the position coordinates. Once computed, a position is verified and corrected if necessary. Each instance of raw position information is examined and checked against information about the building. The verification and correction process is based on the tagged floor plans and is designed to require as little user interaction as possible. By exploiting information on semantics, physically impossible measurement results can be detected and partly corrected.

By comparing consecutive data and knowing the location of room transitions, the position of on-site staff entering neighbouring rooms through walls can be corrected (Fig. 1). Thus, re-positioning can be carried out automatically without asking the user for interaction, if the information about the building is dense enough and the measurement inaccuracy is not too high. Otherwise, the user has to communicate his current position to the CADMS. It is possible for the user to define his position by giving information related to his current position, like closely located fire extinguisher or similar. This information is analysed by the system and the position can be corrected.

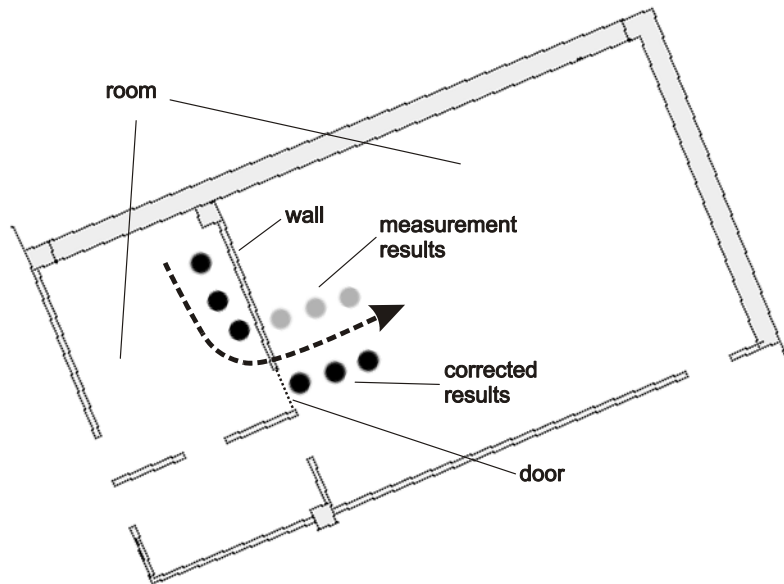


Figure 1: Correction of imprecise position measurement results exploiting information from the BIM

The output of the verification and correction procedure is comprised of the corrected position data which is transmitted to other network nodes. To communicate the location of the mobile units among themselves and to the control room, special mechanisms based on the IEEE-802.11 Standard (Wi-Fi) are fused to build up an optimised communication network.

The BIM-data is linked with a finite element (FE) program. With the support of an implemented algorithm all detected critical changes concerning structural elements automatically initiate an analysis of the structural behaviour. This enables the rescue forces to develop operation strategies like distributing alert messages to other teams or initiating the evacuation of the building.

Finally there are two user interfaces. A conventional one to be used on computer terminals equipped with a screen and a pointing device (mouse, touch screen) and one to be used on head mounted displays with speech enabled controls for the staff on-site.

### **3. GAINING INFORMATION FOR A BUILDING INFORMATION MODEL**

The BIM data for the CADMS are stored in the XML format and can be gained either by extracting them from a CAFM system or by converting traditional CAD or GIS data. Therefore the graphic input module of the CAFM system in use has been enlarged to add context-sensitive information interactively, for example for rooms, doors, staircases and structural analysis. BIM data could be also gathered from an enlarged ifcXML model. The Industry Foundation Classes (IFC) data model is a neutral and open specification and it is the state of the art modelling language for BIM.

Unfortunately, the IFC-standard has not yet been widely introduced in practice, especially in the building documentation. This will not change in the near future because of the large effort needed for redefining the 3D-models of older buildings. In fact, 3D-data are not really necessary in disaster management. A 2½D overview of the situation is more suitable for the command and deployment of rescue forces. It requires floor plans with their proper orientation in space and the ability to position several of them at the same time on the command console or the HMD of the rescuers.

A special challenge poses the integration of sensor data and building information model data. Modern buildings are equipped with multiple real-time systems such as fire protection, admission control, building automation systems. Important information can be gained from these sources as long as they are still in working order. Unfortunately these systems are usually based on own building models and are directly visible for real-time evaluations and rarely in CAFM systems. CADMS gathers current building-sensor data over interfaces and represents them as space attributes in the data base of the BIM. Additional real-time data are those gathered from the IMUs and the building's status information collected by the emergency forces. These data is combined with those mentioned before in the BIM as well, as shown in Fig. 2. Thus, the CADMS can handle status information collected by the action forces and immediately highlight blocked routes, the location of hazardous substances, areas with trapped people inside, smoke or gas alarm or leakage of dangerous goods in the floor plans.

Our proposed building information model is context-adaptive, which means that the model can be adapted during the deployment according to possible influences from the environment. Due to its hierarchical and object-oriented design it is not complicated to change the attributes of the elements in the model. If the rescuer on-site faces an impassable, door he can communicate this observation to the CADMS, which immediately changes the settings in the BIM and the structural analysis data set if necessary. From this time on, all the functions of the CADMS will work with the adapted model.

### **4. REAL-TIME STRUCTURAL ANALYSIS IN DISASTER MANAGEMENT**

Creating a structural model from an IFC-based architectural model is described in the paper of Deng and Chang (2006) and the primary prerequisite is a 3D architectural model. As mentioned before, such data models are currently not widely available in building documentation.

A direct extraction of a finite element model from an IFC-based architectural model is not suitable for other reasons as well. The aggregation with structural data not included in the architectural model, like loads, load superposition and design rules, is necessary. Automatically derived models do not correlate very well with the real load bearing behaviour. Furthermore automated detection and correct modelling of structural elements like hinges, elastic supports is very difficult.

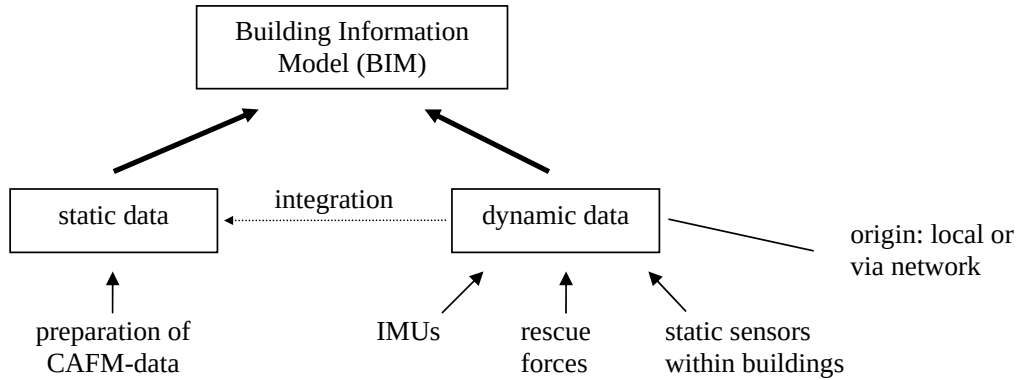


FIGURE 2: COMBINING CAFM AND REAL-TIME DATA FOR INDOOR POSITIONING

Structural models as described in [Romberg et al. 2004] composed completely of 3D-volume elements are not useful either. The computations last too long and the results are difficult to interpret. In case of an interrupt in communication between the command centre and a deployed team, the structural analysis will have to be performed on the local mobile device with limited computing power and data storage capacity. Therefore in the CADMS it is intended to store a simplified static model with all the necessary information on sections, materials, loads and load superposition in the format of a commonly used finite element program (Fig. 3). At the moment the program FLASH [Walder 1979] is used.

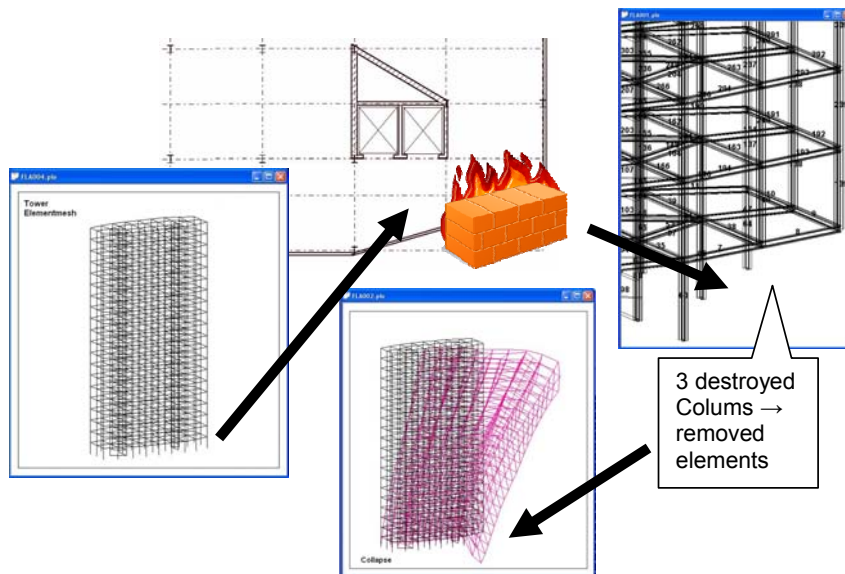


Figure 3: Simplified collapse model with removed elements



In addition to an interactive graphical input FLASH offers a format free input language based on a philosophy quite similar to XML. The structural bearing elements can be modelled by beam, plate and shell elements. Well-defined numbers are linked as XML-elements to the corresponding elements in the BIM. This solution can be realised with almost every FE-program providing numerical input. Though this procedure requires a large effort in redefining or at least linking an existing static model to the BIM, but it should be taken into account especially for high-risk buildings.

When rescue teams or local sensors detect the collapse of a bearing element, the structural model is immediately adapted and recalculated. This is realised by the implementation of a decision tree. It is started automatically every time a change of the structural model within the BIM occurs. In each case this algorithm decides whether or not to start a structural analysis. Furthermore it can update the BIM in other parts of the system if necessary. A simple scenario where more than one attribute is affected by a new input, is the notification of a collapsed wall. Logically this initially affects the accessibility (potential new way to enter neighbouring rooms) and the structural model. Though, as shown in Fig. 4, not only these attributes are affected. If the wall was a supporting one, a structural analysis has to be performed which could lead to changes in the accessibility as well as the representation model.

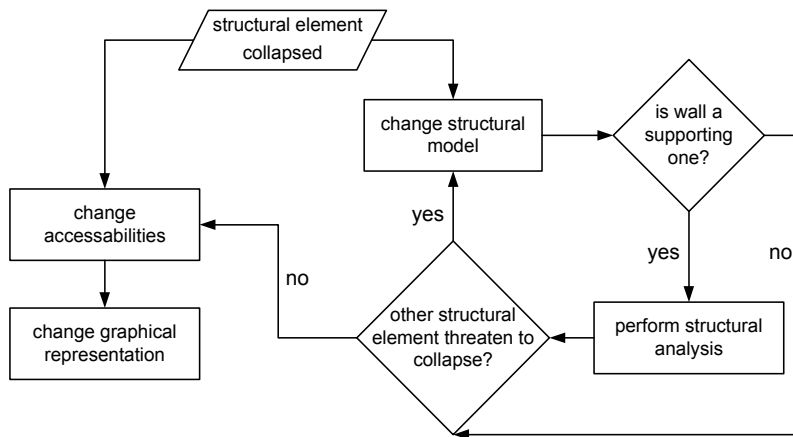


Figure 4: Sequence of actions in the system triggered by the knowledge of a collapsed element

Fig. 5 shows the implementation of a beam in BIM data by means of ifcXML [Nisbet and Liebich 2007] and the reference to the corresponding entity in the finite element program.

## 5. USER INTERACTION

The traditional user interface of the CADMS provides a conventional desktop layout with menu items to navigate on floor plans to view the position of different emergency crews, enter alarm messages to be distributed, and command and control functions.

The interface used by the forces on-site is more challenging. It has to be tailored for the visualisation on HMDs and operation by voice commands as it must not interfere on the one hand but make information easily available for the on-site staff on the other hand. An

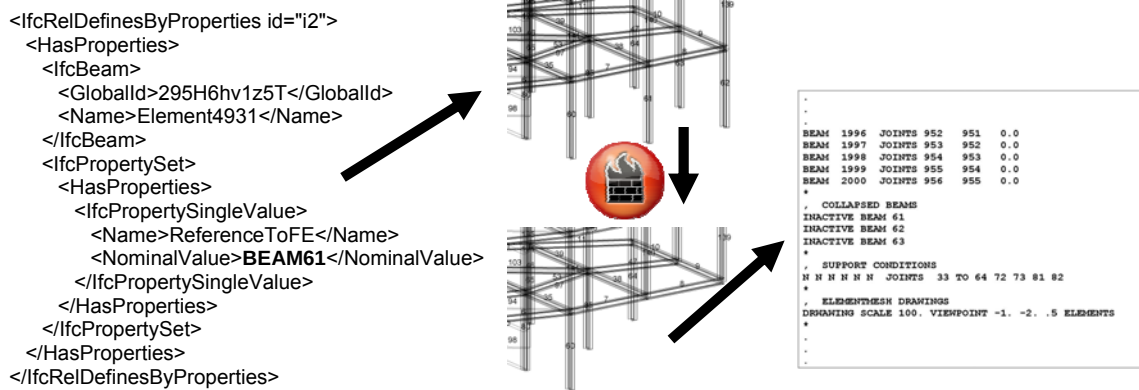


Figure 5: Automated adaption of the Finite Element input from BIM data

HMD with see-through functionality ensures that the additional equipment does not interfere with the activities of the rescue teams. Another factor to avoid distraction is information clarity. Context adaptive information visualisation is used to optimise the trade-off between information density and clarity. The graphic display only shows the information stored in the BIM that is necessary for a specified situation or that is requested by the user.

As the user interface of the mobile devices is based on voice instead of well known pointing devices, the hierarchy of the possible commands must be carefully designed and is supposed to be as narrow as possible [Schütz et al. 2007]. Furthermore the most accurate level of service concerning the [reliability](#) of the speech recognition engine is required. The need for corrections of the verbal system input must be as minimal as possible. Currently the framework “Sphinx 4” [Walker et al. 2004] is used. The results of first tests lead to acceptable recognition rates for a user-supporting user interface, even though only a simple low-tech consumer microphone was used. The general applicability for such speech based user interaction has been shown by Kondratova (2004). Thus, not only in special emergency situations but also in daily routine work in the AEC-business hands-free operation is deployable.

Correcting positions is initiated by the verification and correction module. This module is based on the BIM-data described above in more detail. Nevertheless as it can hardly be fail-proof, a possibility of overruling that module or manually initiating a position correction is mandatory. Designing such a speech driven repositioning procedure remains a challenging task as it has to be fast and simple.

Fig. 6 shows a screenshot of the users’ guidance method in case of a manual initiated repositioning. The current room is highlighted in blue colour and possible room transitions are displayed in green. The information is based on the semantic data in the BIM and displayed using filled polygons. The fading red points represent a possible measured route of the person wearing the IMU.

When asserting that oneself is not drifting towards the wall but going straight ahead in the middle of the room, a “positioning grid” can be activated in the display. This grid shows a 3x3 rectangular polygon matrix with every field having a number attached excluding of the one in the middle. This field, as the centre of the whole grid, is placed in a way to fit around the last

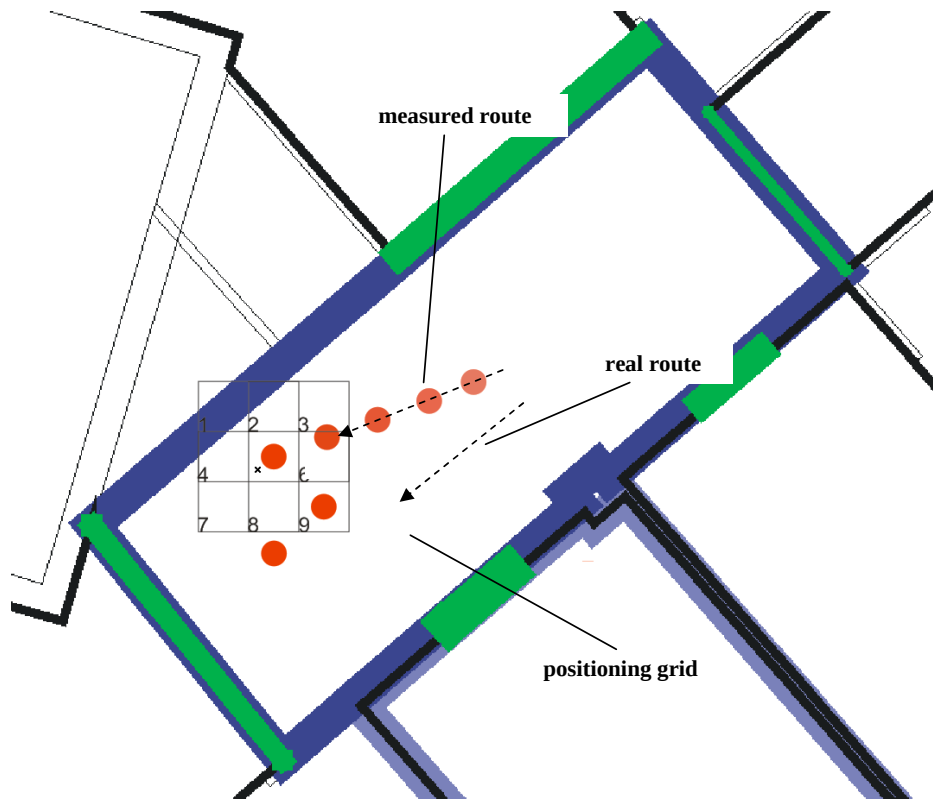


Figure 6: Repositioning grid for manual correction of the position

measured position of the person. The initial edge lengths of the fields are all the same and depends on the factors of scale and zoom used. The grid itself is also zoomable.

By selecting one of the numbers 1 to 9, the red point representing the location is translocated to the according field in the grid. This position is used as the new starting point for the indoor positioning. In that way, a simple two-step voice commanded repositioning procedure was implemented to increase the accuracy of the indoor positioning. Future work will include the modelling of more sophisticated interactions, especially of interrelations with real-time data.

## 6. CONCLUSIONS AND FUTURE WORK

Although techniques for positioning, the database-oriented modelling of buildings and speech-based human-machine interaction are available, there is no functioning system that combines them into a tool assisting the process of commanding emergency crews within buildings. The proposed CADMS uses existing IMUs and integrates their results with information on semantics about buildings exported by CAFM applications. This approach leads to a significant improvement in accuracy. Ongoing fast developments within the market, like the ones for small mobile computers and HMDs, are used wherever possible.

Future work will concentrate on standardising static modelling for the special requirements in emergencies and the refinement of the combination of real-time and CAFM-data to further improve the accuracy of positioning and its validation. Field tests with a local fire department will investigate the most useful way of

supplying the rescuers by the means of an “intelligent” user interface. The most appropriate communication protocol for data exchange between rescue teams and the control centre will be evaluated.

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## **BUILDING INFORMATION MODELLING DEMYSTIFIED: DOES IT MAKE BUSINESS SENSE TO ADOPT BIM?**

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### **ABSTRACT**

Building Information Modeling (BIM) offers a revolutionising way to design, document and procure buildings. BIM promises to become a new international benchmark for building design and documentation across industry on the basis of improved efficiencies and collaboration capabilities. However, BIM requires rethinking current practices and process thus it calls for a paradigm shift in the way we procure, design and operate buildings. There seems no question that BIM methodologies are to become the norm in the long term but more factual evidence is required today to provide guidance to industry. This paper investigates current business drivers for BIM adoption by architecture and building engineering consultants.

BIM needs to compete against well-ingrained methods to deliver projects in a fragmented and rather traditional industry. This paper investigates 47 value propositions for the adoption of BIM under a multiple case study investigation carried out in Australia and Hong Kong (Aranda-Mena et. al 2008). The selected case study projects included a range of public (1) and private (4) sector building developments of small and large scale. Findings were coded, interpreted and synthesised in order to identify the challenges and business drivers, and the paper focuses mainly on challenges and benefits for architectural and engineering consultants, contractors and steel fabricators. As a condition for the selection criteria all case studies had to be collaborating by sharing BIM data between two or more consultants / stakeholders. As practices cannot afford to ignore BIM this paper aims to identify those immediate business drivers as to provoke debate amongst the professional and academic community.

### **1. INTRODUCTION**

Current problems with design and construction quality and efficiencies are clear calls for action to improve an industry that remains behind any other in its attempt to become more competitive and provide a better service to clients and society as a whole - to reduce disputes and to share risks and move the industry forward into the 21<sup>st</sup> century. A well known finding by the NIST (2004) states that over US\$15.8 billion is lost every year due to the lack of interoperability in the capital facilities in the US alone, while a more recent response is the mandate of the General Services Administration (GSA) to require new building documentation be prepared in a BIM technological software.

The aim of the paper is to report on findings on business drivers for Building Information Modelling (BIM) and to provoke wider debate on the speed of adoption. The paper draws upon five case studies originally set to *demytify* myths surrounding 'Business Drivers for BIM' (Aranda-Mena et.al 2008). Froese et al. (2008) provides a detailed description of the structured study, data analysis and alignment with the Val IT business framework (ITGI 2006). On the other hand Crawford et. al (2008) presents a concise summary of Business Drivers for BIM. Both papers were intended to disseminate findings and value propositions to property owners, operators, contractors and consultants. This paper focuses on specific findings to consulting practices in architecture and engineering.

Taking the premise that practices cannot afford NOT to invest in BIM technologies this paper was set to investigate *business drivers for BIM*. The paper is based on a larger investigation sponsored by the CRC for

Construction Innovation representing a number of private and public sector architectural and construction organisations ([www.crcci.info](http://www.crcci.info)). The investigation was carried out during 2007 by researchers from RMIT University, Melbourne and QUT University, Brisbane, whereby the overall investigation was set as a project to identify *factual* evidence on business drivers for BIM as a response to the plethora of myths and misconceptions currently surrounding BIM.

## 1.1 WHAT IS BIM?

One might think that BIM needs no introduction but it should come as no surprise that currently BIM is an ambiguous term that means different things to different professionals. This was also confirmed by empirical results found by this study indicating that BIM is not only defined in various ways according to particular professions but that there is also confusion at three different levels; for some, BIM is a software application (1); for others it is a process (2) for designing and documenting building information; for others it is a whole new approach to practise and advancing the profession which requires the implementation of new policies (3), contracts and relationships amongst project stakeholders.

There are a number of views in industry and academia as to what constitutes BIM. An abundance of definitions related to BIM have emerged with terms including object-oriented modelling, project modelling, virtual design and construction, virtual prototyping, integrated project databases and the more recent term Building Information Modelling.

Amor (2001) identified a number of definitions including:

- Gann et al. (1996) ‘a single project database as an electronic data model to which all participants refer throughout the process of design, construction, operation and maintenance’.
- Björk and Penttilä (1989) ‘project models are conceptual structures specifying what kind of information is used to describe buildings and how such information is structured’.
- Fisher et al. (1997) ‘project modelling is object modelling applied to a project and including more information than just geometry’

Synonyms of BIM include terms such as *nD modelling* employed by Salford University:

- “An **nD model** is an extension of the building information model, which incorporates multi-aspects of design information required at each stage of the lifecycle of a building facility”  
Construct IT, University of Salford, UK, 2003

The term Building Information Modelling (BIM) as such was originally popularised by Jerry Laiserin, referring to the ability to use, reuse and exchange information, of which electronic documents are just a single component:

- BIM is much more than 3D rendering or transferring electronic versions of paper documents. By implementing BIM *“risk is reduced, design intent is maintained, quality control is streamlined, communication is clearer, and higher analytic tools are more accessible”*

AIA 2005 website.

More recent material offers several BIM definitions. However, they all seem to agree that BIM is a digital representation of the building. Following are two alternatives that encompass views of two of the leading organisations in the field.

- “A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward.”  
BuildingSMART website.

Complementing the architectural domain the American General Contractors defines BIM as:

- ***“Building Information Modeling is the development and use of a computer software model to simulate the construction and operation of a facility. The resulting model, a **Building Information Model**, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users’ needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility. The process of using BIM models to improve the planning, design and construction process is increasingly being referred to as Virtual Design and Construction (VDC).”***

The Contractors’ Guide to BIM (AGC 2006)

Succar et. al (2007) defined BIM as “a set of interacting policies, processes and technologies producing a *methodology* to manage the essential building design and project data in digital format throughout the building’s life-cycle”. They argued that BIM is an emerging technological and procedural shift affecting all stakeholders within the Architecture, Engineering and Construction industry with the resulting problems of semantics and a variety of connotations to those engaged with it.

Empirical results of this particular study align with those BIM problems of meaning and interpretation. It is expected that as BIM becomes a mainstream methodology the formal definition will be less of an issue as professionals start to understand the inherent attributes and characteristics. Discussions with professional bodies have started as to usage of wording and terminology linking geography and context.

## 2. CASE STUDIES

This section describes five in-depth case studies where small, medium and large architectural and engineering practices were involved. The study identified current and future issues related to business drivers and inhibitors towards the uptake of BIM. All selected case studies had some level of BIM data exchange with at least one other discipline - including architectural, design documentation and structural engineering. The research design and case study protocol was informed by Yin’s (1994) methodology.

This paper takes the premise that BIM is not an option but the emerging order for architectural, building engineering consultants. Practices cannot afford not to adopt BIM and thus it is paramount to identify the right timing when to start the transitional shift for practices that want to adopt it. This paper evaluates such change management process against a business model (refer to Aranda-Mena et.al 2008).

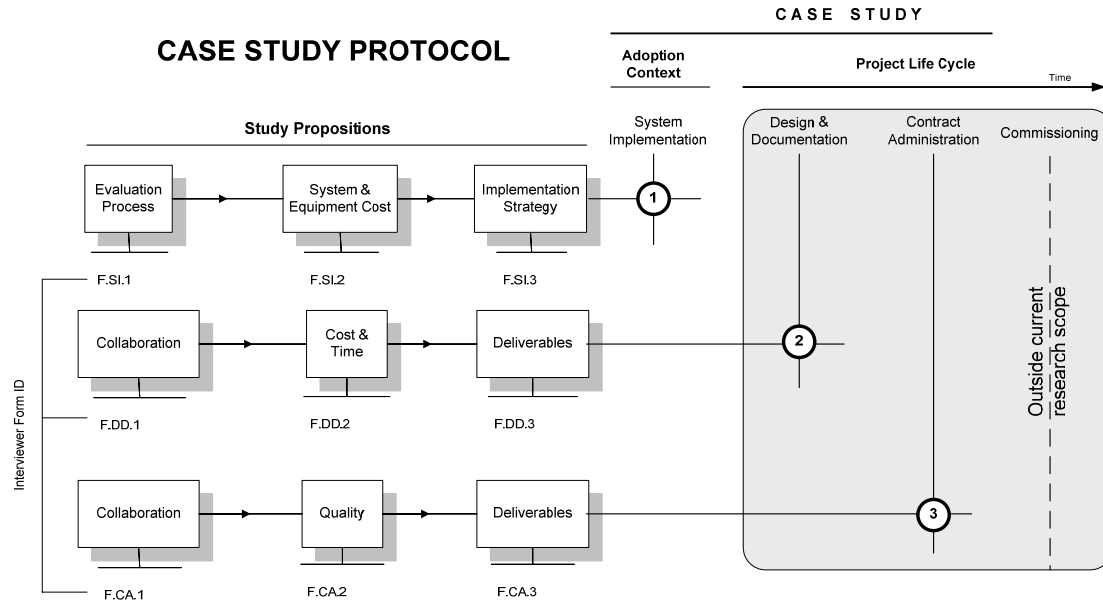


Figure 1. Case Studies: propositions within context and project life cycle

The research protocol (Figure 1) ensures that an acceptable level of data collection rigour takes place across all five case studies. The research protocol summarises all aspects investigated in each case study including 'organisational level' (node 1): BIM system 'evaluation', 'equipment cost', and 'implementation' strategies. At 'project level' (nodes 2 and 3) areas of investigation included 'project life cycle' especially aspects of 'design', 'documentation' and 'contract administration'. Case studies also targeted respondents at three organisational levels including (1) *junior designer/draftsman*, (2) *project designer/manager* and (3) *CEO/Executive*. A total of three pilot interviews and 18 full investigation interviews were conducted (refer to Table 1).

Case studies were selected based on the following criteria:

- BIM adopters:** The first criteria for selecting a project as case study was that it must have been done using at least one of the BIM systems as previously identified in the literature review by at least one party, in this case the architect. Case Studies where BIM collaboration between consultants occurred were preferred.
- Project Life Cycle:** The selected project needed to have at least commenced, or just about to start, construction. This would allow the study to evaluate the performance of BIM during this critical stage (e.g. reduction in RFI's, generation of "as-builts"). Refer to Figure 1.
- Variety of BIM authoring software:** Since the research does not aim to study, or promote, any particular BIM application, it was intended that case studies should use different systems. However, most of the suitable case studies were using Revit and ArchiCAD software. One case study used Digital Project (from Gehry Technologies based on CATIA) and another involved the partial use of Bentley's software.
- Variety of company / project size:** In order to allow readers to identify with a particular case study, or between two of them, an array of different size projects was preferred.



**Table 1.** Case Studies Undertaken

|                                               | Cas<br>e<br>Stud<br>y_1                                                                                                                                              | CS_<br>2                                                                                            | CS_<br>3                                                                                                      | CS_<br>4                                                                                                                 | CS_<br>5                                                                                                         |
|-----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| <b>Majo<br/>r<br/>stake-<br/>holde<br/>rs</b> | archi<br>tects<br>str.<br>engi<br>neer<br>s<br>mec<br>h<br>engi<br>n'rs<br>quan<br>tity<br>surv<br>eyor<br>deve<br>loper<br>meta<br>l<br>fabri<br>c'r<br>buil<br>der | archi<br>tects<br>str.<br>engi<br>neers<br>mec<br>h<br>engi<br>n'rs<br>deve<br>loper<br>buil<br>der | archi<br>tects<br>inter<br>ior<br>archi<br>tects<br>str.<br>engi<br>neer<br>s<br>deve<br>loper<br>buil<br>der | archi<br>tects<br>str.<br>engi<br>neers<br>mec<br>h<br>engi<br>n'rs<br>IT<br>man<br>ag't<br>deve<br>loper<br>build<br>er | archi<br>tects<br>str.<br>engi<br>neers<br>mec<br>h<br>engi<br>n'rs<br>deve<br>loper<br>(gov<br>)<br>build<br>er |
| <b>Est'd<br/>cost</b>                         | \$300<br>M                                                                                                                                                           | \$4M                                                                                                | \$280<br>M                                                                                                    | \$300<br>M                                                                                                               | \$10<br>M                                                                                                        |
| <b>Timef<br/>rame</b>                         | 2<br>year<br>s                                                                                                                                                       | 6<br>mont<br>hs                                                                                     | 18<br>mon<br>ths                                                                                              | 3<br>years                                                                                                               | 12<br>mont<br>hs                                                                                                 |
| <b>Locat<br/>ion</b>                          | centr<br>al<br>city                                                                                                                                                  | inner<br>urba<br>n                                                                                  | centr<br>al<br>city                                                                                           | inner<br>urba<br>n                                                                                                       | rural<br>town                                                                                                    |
| <b>BIM<br/>autho<br/>ring<br/>tool(s)</b>     | Arch<br>icad                                                                                                                                                         | Arch<br>icad                                                                                        | Arch<br>icad<br>Revi<br>t<br>Bent<br>ley                                                                      | Digit<br>al<br>Proje<br>ct                                                                                               | Arch<br>icad<br>Revi<br>t                                                                                        |
| <b>Interv<br/>iews</b>                        | 3                                                                                                                                                                    | 3                                                                                                   | 6                                                                                                             | 3                                                                                                                        | 3                                                                                                                |

| Extent of data exchange | Case Study 1                                                           | CS_2                       | CS_3                           | CS_4                                                                          | CS_5                                                                             |
|-------------------------|------------------------------------------------------------------------|----------------------------|--------------------------------|-------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
|                         | architects with str. Engineers (electronic data flow was one-way only) | architects, str. engineers | architects with str. engineers | architects, str. engineers mechanical engineering IT group, developer builder | architects, str. engineers mechanical engineering developer (government) builder |

The above Table 1 outlines five case studies and a brief description of size, cost and other characteristics such as BIM authoring tools and data exchanges. Note that there are a number of BIM related tools and code checkers such as NavisWorks or Solibri clash checkers. BIM authoring tools were the main focus of investigation rather than other types of BIM “*behavioural analysis*” software.

## 2.1 FINDINGS: CATEGORISATION CRITERIA

Nine cluster categories were taken to code each of the interviews. The categories were originally highlighted by reference to the Val IT approach (ITGI 2006) and used in the overall investigation to align responses to a business model.

The Fact registry is a tabulation of all of the relevant facts that make up the business case analysis, and the ValIT Business case format decomposes the wide range of issues along several key dimensions. While these dimensions could be considered in any order, we have organised them into the following hierarchy to provide a specific sequence to the analysis. Not all items at all levels are required, but should be included in the fact registry as appropriate.

- **Level 1: Analysis Components**

At the top level, the information is organised according to the overall flow of the analysis, as follows:

- ❖ Initiatives: The business, process, people, technology, and organisational actions/projects undertaken to achieve the outcomes. Also, the contributions of each initiative to individual outcomes (where appropriate). Specific action items associated with the BIM implementation.
- ❖ Alignment Issues: The degree to which the program aligns with existing systems and practices, regulations, policies, and business strategies. Issues relating to the alignment of the BIM implementation program with existing systems and procedures
- ❖ Efficiency: Improvements to the efficiency of designing and managing building projects.
- ❖ Design Functionality: Issues that lead to better building designs.
- ❖ Collaboration: Improved support for collaboration among project participants.
- ❖ Other benefits: Other project and corporate benefits.
- ❖ Resources/expenses: Resource requirements for delivering the program, and Expenses incurred to provide the necessary resources, from reduced efficiencies, etc. The resource requirements for BIM, and the corresponding costs.
- ❖ Risks: Critical risks facing a program, including risk quantification and mitigation information. Major risks associated with a BIM implementation.
- ❖ Assumptions/Constraints/Conditions: Issues describing assumed preconditions or constraints for BIM implementations

- **Level 2: Capability Layers**

The analytical components can be applied at each of three layers of business scope/focus:

- ❖ Technical Capability  
The specific technological capabilities delivered by the program.
- ❖ Operational Capability  
The operational capabilities that are supported by the technological capabilities.
- ❖ Business Capability  
The overall business capabilities enabled by the operational capabilities.

- **Level 3: Life cycle phases**

The analysis information can be organised according to the life cycle phases required to build/create, implement/deploy, operate, and retire the program.

- ❖ Build
- ❖ Implement
- ❖ Operate
- ❖ Retire

- **Level 4: Stakeholder**

Building projects involve large scale collaborations of stakeholders from many different organisations, and since collaboration issues are central to BIM technologies, the business case inevitably involves multiple stakeholders. The value propositions become considerably more complex since the parties that reap the benefits may differ from those that incur the expenses and risks. Thus, although not considered in the ValIT framework, it may often be relevant to define specific stakeholders' interests in each element of the program.

- **Level 5: Outcome Range**

Often, the expected results of the program cannot be forecast with very much precision, but can be described in terms of the best case and worst case extremes from a range of probable outcomes.

- ❖ Best case
- ❖ Worst case

Overall cumulative analysis of:

- Financial benefits
- Financial costs
- Non-financial benefits/alignment
- Risk Analysis
- Change impact
- The impact (positive and negative outcomes) of not doing the program. Including the opportunity costs - i.e., the net cost of foregoing the next best/status quo alternative.

## 2.2 FINDINGS: CODING AND ANALYSIS

*"We had infused a very precise discipline into the whole design process where architects, engineering consultants, structural engineers, all had to design to the same precise vocabulary. I think it has been an incredible process of intuitive collaboration. It is all about project certainty. We know what we're designing, we know how much it's going to cost, we know how it's going to be built, and for us as a developer that is paramount to total success."*  
(Managing Director CS4)

This section describes assertions identified from respondents including issues that arose most often in discussions (i.e. had the greatest "weight of evidence") with the various respondents for each of the case studies, and are detailed below. Note: a full account of the project is beyond the scope of this paper, refer to Aranda-Mena et. al (2008) for detailed results analysis and interpretation.

### 2.2.1 CASE STUDY CS1

*A multistorey office tower (with several basement levels) development located in a Central Business District of a major Australian city. The initial tower has recently been completed (2007) as one part (estimated construction value AU\$300 million) of a proposed two-stage project for the site.*

Based on the interviews and discussions held with staff from various stakeholders, there was consistent agreement in Case Study CS1 with the propositions that BIM:

- Improves information management/flow/sharing — associated with the category of Collaboration,
- Requires specialised software with certain characteristics — associated with Resources and Expenses
- Improves evaluation of design scenarios — associated with Design Functionality
- Improves efficiency — associated with Efficiency
- Success is dependant upon selecting the correct software — associated with Initiatives

- Enhances confidence in the design outcomes — associated with Design Functionality
- Improves co-ordination between consultants — associated with Collaboration
- Requires a significant process re-structure (internal and external) — associated with Initiatives
- Adoption is hindered by legal frameworks — associated with Assumptions/Constraints

### 2.2.2 CASE STUDY CS2

*A four-storey mixed hospitality/office development located some four kilometres from a major city centre in a 'suburban shopping strip' at a prominent intersection - surrounded by a mixture of commercial and retail businesses and nearby residential dwellings. Estimated construction value AU\$3.5 Million. Project at tendering stage and expected to start construction in 2008.*

Based on the interviews and discussions held with a variety of staff from various stakeholders, there was consistent agreement in CS2 with the propositions that BIM:

- Improves information management/flow/sharing — associated with the category of Collaboration
- Improves efficiency — associated with Efficiency
- Introduces new issues regarding ownership of information, IP, payment of information, etc. — associated with Risks
- Enhances confidence in the design outcomes — associated with Design Functionality
- Improves buildability — associated with Design Functionality
- Improves co-ordination between some consultants — associated with Collaboration
- Improves design — again associated with Design Functionality
- Helps to align project stakeholders expectations — again associated with Collaboration

### 2.2.3 CASE STUDY CS3:

*A multistorey office tower development located at a waterside redevelopment close to the Central Business District of another major Australian city. A horizontal development rather than a high rise building, the scheme is designed blatantly to maximise floor space (33,000 sq m).*

Based on the interviews and discussions held with a variety of staff from various stakeholders, there was consistent agreement in CS3 with the propositions that BIM:

- Requires leadership within the company — associated with the category of Assumptions / Constraints
- Provides a foundation for FM processes — associated with Alignment
- Requires appropriate training — associated with Initiatives
- Improves design — associated with Design Functionality
- Trained people are scarce — associated with Risks
- Introduces new issues regarding ownership of information, IP, payment of information, etc. — associated with Risks

There was also consistent disagreement with the proposition that BIM requires a high economic investment — associated with Resources / Expenses

#### 2.2.4 CASE STUDY CS4

*A commercial office building located on Hong Kong Island comprising of two basement levels and seventy storeys. Valued at HK\$2 Billion (AU\$300 Million) the project is due for completion in 2008.*

Based on the interviews and discussions held with a range of staff from various stakeholders, there was generally steady agreement in CS4 with the propositions that BIM:

- Improves efficiency <sup>d</sup> — associated with the category of Efficiency
- Reduces rework <sup>d</sup> — also associated with Efficiency
- Requires interoperability standards — associated with Alignment
- Improves information management/flow/sharing — associated with Collaboration
- Capabilities must be understood by other stakeholders — associated with Assumptions/Constraints,

Note <sup>d</sup> denotes some level of disagreement.

There was also steady disagreement with the proposition that BIM :

- Does not improve documentation — associated with Assumptions/Constraints

Other propositions often mentioned included:

- Improves buildability — associated with the category Design Functionality
- Improves co-ordination between some consultants — associated with Collaboration
- Implementation and maintenance costs (including underlying IT) outweigh its usefulness — associated with Resources/Expenses. Note : disagreement here
- Requires specialised software — associated with Resources
- Requires leadership within the company — associated with Assumptions/Constraints

#### 2.2.5 CASE STUDY CS5

*A project comprising a Police Station and Watch House, located in regional Australia. The project is being executed through the commercial project management arm of a Government department responsible for the built environment. The estimated project value is AU\$ 10 million.*

Based on the interviews and discussions held with a range of staff from various stakeholders, there was generally steady agreement in Case Study CS5 with the propositions that BIM:

- requires interoperability standards — associated with Alignment
- Improves efficiency <sup>d</sup> — associated with the category of Efficiency
- Improves information management/flow/sharing — associated with Collaboration
- Requires appropriate training — associated with Initiatives
- Requires a significant process re-structure (internal and external)) — associated with Initiatives
- Must be clearly understood throughout the organization) — associated with Initiatives

Note <sup>d</sup> denotes some level of disagreement.

Other propositions often mentioned included:

- Requires all project stakeholders to exchange and use the information — associated with Alignment
- Requires a high economic investment — associated with Resources

- Is NOT more labour intensive in earlier stages of the project than 'traditional' systems — there is no consensus on this view.

### 3. CROSS CASE STUDY COMPARISON

The examination of these theoretical propositions in the cross-case-study analysis leads to the following overall conclusions regarding the business case for BIM:

Despite the wide variety of case-study characteristics previously described, analysis shows that the proposition that “BIM improves information management / flow / sharing” (Collaboration category) was one of the top four propositions most often mentioned across four of the five case studies, while equally strongly, the proposition that “BIM requires appropriate training” (Initiatives category) arose as a topic right across the whole range of five case studies.

Amongst CS1, CS2 and CS3 case studies, both the propositions that “BIM enhances confidence in the design outcomes”, and that “BIM improves design” (both aspects of Design Functionality category) were mentioned often, whereas in the CS4 and CS5 case studies there was less mention of either of these propositions.

However, the proposition that “BIM requires interoperability standards” (Alignment category) was mentioned more often in CS5 study and somewhat in CS2, CS3 and CS4, whilst in CS1 the issue of interoperability did not frequently appear. This may simply reflect the critical importance placed on this aspect of BIM by the initiators of the CS5 project, and by the involvement of more stakeholders actually exchanging data in the CS4 case study than in the other studies.

Similarly, the proposition that “BIM is more labour intensive in earlier stages of the project than 'traditional' systems” (Resources/Expenses category) was mentioned - and disagreed with - in responses from CS4, but appeared less often in the other case study responses, while the proposition that “BIM improves efficiency” (Efficiency category) was highly placed in discussions within CS2 and CS4, but less so in the other case studies.

Following is a summary of key business indicators (ValIT) found in the above-mentioned case studies – CS1 to CS5.

#### 3.1 INITIATIVES

Analysis of a cross-case-study kind showed that a need for “significant organisational restructure”, “clear understanding”, “appropriate training”, “software selection”, “co-ordination role”, and “process restructure” were all issues brought up in interviews, and agreed with in general (particularly training).

#### 3.2. ALIGNMENT ISSUES

In this category, “BIM requires interoperability standards” was an issue with some agreement, whereas there appeared strong levels of agreement and disagreement with the proposition regarding BIM as a foundation for FM. BIM as a prerequisite for government projects did not appear to raise much interest – apart from the CS5 case study (which, it should be noted, already had government involvement).

#### 3.3 EFFICIENCY

In particular, “BIM improves efficiency” was an issue often mentioned with agreement, whilst the “reduction of rework” proposition was also raised and agreed with. Whilst CS1, CS2 and CS3 showed mild evidence that BIM allows the small practitioner to participate in large projects, no comments were ventured from CS4 and CS5.

#### 3.4 DESIGN FUNCTIONALITY

“Design”, “buildability improvements”, and “confidence in design” were issues mentioned in discussions and with agreement (but less so in case-study CS3, compared with disagreement on the same topic in CS5).

### 3.5 COLLABORATION

“Improved information management” and “improved consultants co-ordination” were important issues mentioned in discussions and with agreement (but less so in case-study CS3 than in others).

### 3.6 OTHER BENEFITS

Little opinion was ventured on these propositions. However, some level of disagreement is evident as to whether BIM attracts innovative staff (CS1).

### 3.7 RESOURCES / EXPENSES

As could be expected, there appeared general agreement with “BIM requires specialised software”, while discussion of “BIM requires high economic investment”, and “costs outweigh usefulness” indicates that these were issues of disagreement often mentioned in interviews. However there was also some level of agreement with the “costly investment” proposition in two of the case-studies, indicating high cost may be a factor for some projects/stakeholders.

### 3.8 RISKS

“BIM and information ownership” was an issue often mentioned with agreement. However there was also some level of disagreement (CS4). In addition, there appeared differences of opinion between case-studies as to whether BIM is considered “sufficiently mature”, and whether “BIM reduces risk in the project”.

### 3.9 ASSUMPTIONS/CONSTRAINTS/CONDITIONS

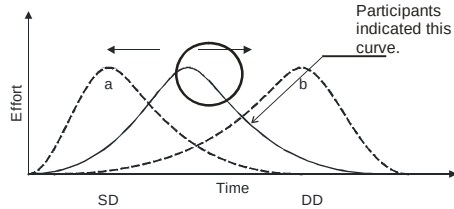
Analysis indicates that it is generally not agreed that “BIM is a short-lived trend”; that “BIM does not improve documentation”; or that “BIM is only a software approach”. The propositions that “BIM can be hindered by legal frameworks”; that its “capabilities must be understood by other stakeholders”; and that it “requires leadership within the implementing company” were generally agreed upon – right across the whole range of case-studies.

### 3.10 EFFORT DISTRIBUTION

A crucial aspect of BIM implementation relates to the perceived level of time-effort distribution curves described in the following Table 2. It was argued by a number of respondents that a clear understanding of this curve would have a direct implication on variations of fee structures. The table is a qualitative response to the perceived ‘*effort distribution*’ required to create BIM. Each diagram portrays a visual representation of apparent levels of effort as perceived by a number of respondents – no consensus was identified. The diagrams were elicited and discussed during each of the interviews.

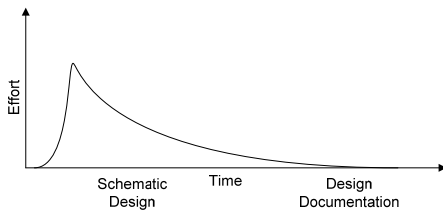


Table 2. Time-effort distribution curves: qualitative analysis.

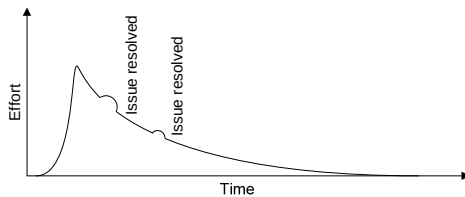


More commonly the effort distribution curve for traditional methods was identified as curve 'b'. Although some respondents believed that with traditional methods the effort was evenly distributed between the two phases but once BIM was implemented, the quicker the data could be put into the model the better (thus shifting the above curve to the left).

Once BIM is implemented, the distribution of effort is shifted to earlier stages of the project (curve a) - resulting in more of a straight line at the start of the project.



There were competing views amongst a number of CS2 respondents regarding the cash flow risk allocated by introducing BIM. For instance, the early input of effort could be seen as a cash-flow risk if hourly rates are being used; and over the whole life of the project BIM saved time, but not at the early stages. However, other stakeholders were of the opinion that with the same amount of effort more information was actually captured for use in the project.



Architects were of the view that substantial (but certainly not excessive) effort can be required quite early on in the project; but the effort quite rapidly declines until an issue needs clarification or resolution, and more detail is then needed. The issue results in a small increase of effort to resolve it, and the whole process is then repeated (with additional issues needing resolution and consequent effort) but always on a declining curve of effort versus time.

The method did not save the company time but risks have been reduced by eliminating

speculation; changes in 3D take  
less time than in traditional  
documentation.

The following heading aims to translate the above '*Cross Case Study Comparison*' results into operational business model(s). The overall project was initially preparing to identify a single business model to adopt BIM however as the research project progressed it became evident that a single business model was not plausible. On the other hand the researchers found that there could be as many business models as there are projects and companies. This project focused on the business drivers and attributes behind BIM and established parallels with the well-established business model ValIT approach (ITGI 2006).

#### **4. CONCLUSION: DOES IT MAKE BUSINESS SENSE TO ADOPT BIM?**

Because of the widely varying array of alternatives regarding company size, industry sector (architectural, engineering and construction firms); experience with BIM, CAD and Information Technology in general; the differing sets of skills within the companies; the size, nature and strength of their relationships with other consultant firms; and whether the various stakeholders are private or public sector or a mixture, we have not attempted to come up with a generic business model to adopt BIM. Following, we outline the approach and hopefully provide a sufficient framework for individual companies to apply the Business Case process to their own (much more specific) situation.

In order for a business case to be reliable it must be developed to achieve specific objectives or outcomes taking into consideration the particular needs and characteristics of the company. The clearer the objectives are defined and the specific circumstances of the company analysed, the better the business case will be. Therefore, it is not possible to define a typical business case to adopt BIM. Furthermore, a single company could develop more than just one business case based on different scenarios. For instance, a scenario might assume that there will be no model sharing with third parties (Architects office only) whereas another might define a variation where collaboration between consultants is considered.

The following Business Case Framework aims to help companies that are interested in adopting BIM to gather the required information to undertake a business case.

Outcomes are the clear and measurable results sought. The outcomes are divided into: operational, technical and business capabilities. There can be more than one outcome on each of these capabilities.

Following are examples of outcomes expected when adopting BIM. These expected outcomes are based on results from the case studies.

##### **4.1 TECHNICAL CAPABILITY**

- o **Technical Outcome 1:** Ability to produce the necessary drawings and documentation from the BIM model.
- o **Technical Outcome 2:** Ability to exchange BIM models with consultants (structural, building services, and quantity surveyor).

##### **4.2 OPERATIONAL CAPABILITY**

- o **Operational Outcome 1:** Ability to design in a 3D environment throughout the entire design process.
- o **Operational Outcome 2:** Ability to use BIM to support design collaboration / information exchange with consultants.
- o **Operational Outcome 3:** Ability to reduce error in documentation through better coordination between consultants.

#### 4.3 BUSINESS CAPABILITY

- o **Business Outcome 1:** Ability to complete larger design projects with greater efficiency than present – this is particularly important for the smaller practice.
- o **Business Outcome 2:** Improved design outcomes through better understanding of design alternatives by clients and designers. Measured by client satisfaction levels and designers qualitative opinions of design outcomes.
- o **Business Outcome 3:** Reduced risks associated with information-related errors. Associated with information consistency in drawings, errors introduced during information exchanges, etc.

Fully implementing the above capabilities will certainly have an initial high cost but it is expected that organisations will recover rapidly and their performance will drastically improve. On a more individual level, the architects will now regain the ability to focus again on design and design opportunities as they should be spending less resources on design development – schedules and the massive amount of interior elevations. On the other hand BIM demands better coordination and knowledge of construction and construction processes.

It was identified that even if there are a number of small changes and steps BIM offers the client and design consultants the ability to accurately identify outcomes such as costs dynamically, thus making informed decisions on an array of information including figures, tables, drawings and renderings associated with the time dimension. Real time information is recorded without delay allowing more predictability for the design team and the owner.

Managing the change for architectural and engineering practices can be a challenge and furthering the technology is a full-time agenda that cannot be left only to chance. Practitioners should look for professionals to assist them in the *transformation* process, and governments should look for ways to assist the industry as we have seen in Singapore, Scandinavia and more recently in the US.

This is to set new documentation standards and protocols in industry, improve collaboration and move to better design technology - all with the aim of streamlining processes and improving efficiencies. This is not an option but basically reflects the current demands on an industry that has not shown clear improvement despite the demands of their clients and contractors. The benefits at operational, technical and business levels are too enormous to ignore or leave to chance. Practices are called on to take a proactive approach on the uptake of BIM technologies; in some cases even undertaking leadership and coaching roles. This is especially important for the Australian context as government intervention into industry's process and technical affairs is usually minimal – a bottom-up approach, and a very different scenario to that of Singapore, Scandinavia or the US. The authors of this paper are addressing ways to align parties in making a process transformation through industry seminars and publications.

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## **TOWARDS METHODOLOGY FOR HARMONIZATION OF SEMANTICALLY DIFFERENT BIM's**

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### **ABSTRACT**

Research focus of the paper are heterogeneous information systems. Heterogeneity within a set of software applications can be attributed to the fact that their collaboration is hindered due to the conflicts in software architecture, communication protocols and/or data representation. General interconnectivity and emerging interoperability have caused the fall of mainframe-based systems, which in turn led to variety of information systems with local data representations, communication protocols and software architectures. Today these information systems need to collaborate in different engineering projects. Existing approaches, such as common framework, integration with standard scheme and data mediation, try to diminish the undesired effects within heterogeneous systems. The approaches are indeed successful because they eliminate all conflicts at design time. This way collaborating applications have to abandon their local data views. In this paper heterogeneity is regarded as a property of an information system while disharmony of an information system is defined as a state of the system. Further, structural, semantical and functional disharmony is defined as part of overall information systems's disharmony. As a consequence a new methodology called DRAGON (Disharmony Resolving with Agents and Ontology) is proposed. The methodology aims to dynamically resolve structural and semantical disharmony by preserving applications' local data views. Another novelty is the definition of conceptualization for structural and semantical disharmony (Disharmony ontology) and the use of software agents. Disharmony ontology is specified in OWL. The agents use the ontology for resolving of structural and semantical conflicts between applications at runtime. Agents communicate via shared communication space based on Java technology. The mediation is incremental, which means that agents are able to build their local ontologies. The ontologies are used as persistent meta-data repositories of concepts (structure and semantics) that are captured from applications during runtime.

Extensive applicability of the DRAGON methodology is expected in information system clusters with rich and complex data content, namely management of construction projects.

### **KEYWORDS**

Interoperability, building information model, quality of semantic and structure, semantic and structural difference, mediation, ontology

### **1. COMPLEXITY OF BUILDING INFORMATION MODELS**

Today's best information modelling practices in engineering show a tendency to build a unique allinclusive product information model for a specific engineering field (like shipbuilding, car industry, building industry, road building, etc.). However, none of these attempts has been generally accepted in the civil engineering practice. Rather than that, the past development of building information models (building product model) led to a question, whether a definition and use of a standard product model has sense at all. To overcome the need to have a single product model some authors have proposed inter-model linking schemes (like in [1], and [2]), in this way, however, the complexity of the whole system hasn't decreased, even worse, it has grown.

Another problem arises from the necessity for standard building elements. The history of mankind shows that in communication the only "standard" is the diversity of standards. In other words, it seems most unlikely that the whole of mankind would use a single standard language. Even if such a language would exist, it is very likely that soon many dialects would appear, since every individual or group is seeing the same thing in its own perspective.

This problem is also present in civil engineering and construction, where many different views have to be considered through a building life cycle. Different views are leading to more or less different descriptions (data structures) representing the same entity. Notable progress has been made by the International Alliance for Interoperability [3] with the development of the common specification for information model (IAI IFC 2x3) rooted in the Industrial Foundation Classes (IFC), which can be seen as applicable building blocks tailored to cover the software interoperability within the AEC industry. IAI has made it to become an ISO "Publicly Available Specification". [4]

STEP technology ([5]) has succeeded as an ISO 10303 standard. It was supposed to be much broader in scope than IFC and with the ambition to seamlessly integrate processes in manufacturing engineering. The ISO 10303 standard bundle contains over 100 published technical specifications. But will they prevail over IFC or vice versa?

A conflict between the concept of a single project integrated model and the need for individuality also showed up. Companies (and individuals) have a strong inclination to fully control their own data, which also form the company's "memory", a vital part of every company.

The main deficiencies of product information models could be summed up into the following essential points [6]:

- Product models are based on clearly defined semantics and demand unique standard basic elements, however, such elements don't exist,
- Computers are not (yet) capable to fill up semantic inconsistencies and gaps, which show up in the integration of computer programs - a human is adapting daily to communication patterns with other humans with different mental models, and is capable to reconceptualize parts of information, which don't fit into the whole,
- Product models are subjective interpretations, not objective representations of the real, therefore an effective uniform product definition is not possible,
- Product models only include parts from the building process and disregard some important views (social, environmental, etc.), which form the process in reality,
- Models are restricting creativity due to their complexity and rigidity,
- When implementing prototype models into the real environment they fail due to the inability to capture the rich knowledge and experience of the people,
- Although product models are basically open, they get stiff and hardly upgradeable in reality,
- In an integrated database each client's control over his own data is limited.

Years ago construction IT scientists ([7] and [8]) already proposed some solutions to the problems they described:

- Product models should be rather small and limited to specific areas; coexistence of more models in the same field is not necessarily bad,
- Implementation of middleware tools between applications and models, which will help humans to navigate between the islands of automation,
- Gradual implementation of small models into industry,
- Development of a richer set of language constructs for model description,
- Product and process models should be linked more closely,
- new integration concepts should be developed, which would not reside on integrated semantics,
- It is necessary to allow coexistence of structured information and unstructured data and leave their interpretation to the human,
- Pure information exchange should be upgraded with communication software for collaboration support.

Furthermore, authors [9] conclude that in the last 20 years computer integrated construction research produced software solutions focused on data and application integration that in consequence lead to tightly coupled information systems and complex building information models. The latter, complexity of handling a shared building information model, is also confirmed through research case studies [10].

We can conclude that the applicability of “giant” information models is limited because of their complexity and lack of adaptability. As such they require too many agreements and change from diverse users. In the future we won't see any prevailing international standard for product modelling but number of best-practice examples commonly used at different levels (company-wide, country-wide, maybe even continent-wide) that will require collaboration with each other.

In such a world only those information model concepts that feature some degree of self-initiative and adaptability will be widely accepted. Any other concept risks the high migration cost to be paid by its users.

## 2. FORMALIZATION OF DISHARMONY IN PROPRIETARY BIMS

Our research tries to diminish disharmony effects within heterogeneous federated software systems (HFSS) where set of functionally complementary applications that contribute to a global goal wouldn't need to abandon their local data views. A natural assumption is that applications are autonomous in modelling and managing of structure and semantics of their data.

We define heterogeneity as an intrinsic property of an information system. Disharmony of an information system is defined as a state of the system that changes over time and we are interested in conflicts that arise from that. Further, structural, semantical and functional disharmony is defined as part of overall information system's disharmony.

Two different disharmonies can be defined:

*Static disharmony is a conflict state within a set of collaborative software systems “before its first run”; at least two applications within HFSS cause heterogeneity*

*Dynamic disharmony is a conflict state within a set of collaborative software systems “during the run”; a new application that cause heterogeneity is added to an existing HFSS*

A good example of disharmony problem demonstrates a HFSS with discipline-specific applications that are used to design, construct, and operate buildings by capturing information about all aspects of a building throughout its lifecycle. To facilitate full interoperability between the applications state-of-the-art scenario would be to use standard schema (i.e. IFC) with import/export mechanism between the internal data models of specific building modelling applications, such as ArchiCAD and Autodesk Revit for example, and server based building information model. Therefore the standard schema must define building entities that represent union of all the entities (i.e. window, wall, column, etc.) found in internal data models. Such a schema doesn't exist. Therefore disharmony problems can not be avoided in real construction projects.

### 2.1 STRUCTURAL DISHARMONY

Structural disharmony occurs when one application requests data from another application.

*Structural disharmony is a conflict state between two applications in a HFSS because of differences in data format structure and data names*

Structural disharmony can have different forms:

- Different structure for the same concept
- Equal structure for the same concept but with different names
- Equal name for different concepts

## 2.2 SEMANTICAL DISHARMONY

Semantical disharmony (example: Picture 1) occurs when one application receives data from another application, but interprets its meaning wrong or fails to interpret it at all.

Examples for semantical disharmony are:

*Semantical disharmony is a conflict state between two applications in a HFSS because of differences in meaning of data (semantics) with equal or related structure that represent the same concept*

- Semantically equivalent data with different precision
- Semantically equivalent data represented with different units

Resolving disharmony problems between building information models means resolving structural and semantical disharmony.

Structure and semantics can be further defined as *implicit* or *explicit*.

*Structure or schema for data is implicit if its description is not separated from data.*

*Structure or schema for data is explicit if its description is separated from data.*

BIMs with implicit structure are exclusively managed by a software program released by a given organization. With the proprietary approach, the security is higher and reverse-engineering a proprietary algorithm is difficult, but this is compromising software collaboration within construction project. Explicit structure or schema (data in a file follows a hierarchy, grouping, example is XML with XSD) approach is well suited for machine interpretation.

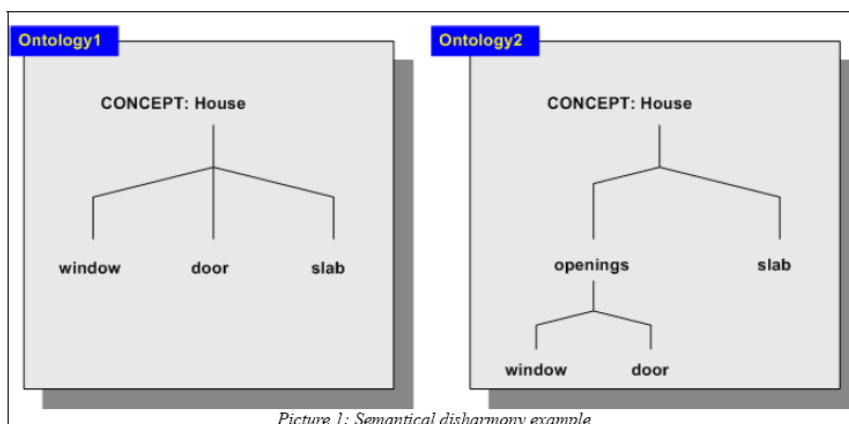
Equivalently we can define *implicit* or *explicit semantic*.

*Meaning or semantics of data is implicit if its description is not separated from data.*

*Meaning or semantics of data is explicit if its description is separated from data.*

Existence of explicit structure and semantics for a BIM enables the BIM to be readable and understandable by software applications. However this is yet unreachable goal for HFSS in construction practice.

A methodology that we propose for resolving structural and semantical disharmony in HFSS applies only to BIMs with explicit structure and semantics respectively.





## 2.3 CLASSIFICATION OF DATA MODELS IN RELATION TO STRUCTURE AND SEMANTIC

To formalize the notion of structural and semantical disharmony we need to identify a quality of description of structure and semantic for a given building information model. For the purpose we introduce a metrics that denotes the quality of structure and semantics, *QSS* (*Quality of Structure and Semantics*), for a given building information model.

$$QSS = (Str_{[i,e]}, Sem_{[i,e]})$$

$Str_i$  = implicit structure

$Str_e$  = explicit structure

$Sem_i$  = implicit semantics

$Sem_e$  = explicit semantics

The value of QSS semantics as four discrete (Table 1. QSS values).

describes a HFSS's structure and states; binary pairs

Table 1. QSS values

|                  |       |                                          |
|------------------|-------|------------------------------------------|
| $(Str_i, Sem_i)$ | (0,0) | (implicit structure, implicit semantics) |
| $(Str_e, Sem_i)$ | (1,0) | (explicit structure, implicit semantics) |
| $(Str_i, Sem_e)$ | (0,1) | (implicit structure, explicit semantics) |
| $(Str_e, Sem_e)$ | (1,1) | (explicit structure, explicit semantics) |

The QSS has a real value if it can be determined for every building information model. How can we possibly explain that a picture has  $QSS = (0,0)$ ? If not, than there should be an explicit schema that describes the order of pixels that compose the image, and explicit semantics description could be used by a pattern recognition algorithm that would realize, for example, that a construction site activities are behind the project schedule.

Another example is a VRML geometry model. A VRML model contains 3D geometry model together with animation path. 3D geometry is described with VRML entities like points, shapes, materials, interpolators, appearances, animation sensors, etc. The VRML model can be visualized with viewers, like CORTONA VRML client, that use proprietary (hard wired) algorithms for processing (implicit) structure and semantic. The VRML model has  $QSS = (0,0)$ .

The QSS value will be used as a trigger that determines how to approach disharmony resolving.

## 3. DRAGON – A METHODOLOGY FOR RESOLVING DISHARMONY BETWEEN PRODUCT MODELS

Based on the above formalization of disharmony in HFSS we propose a new methodology that dynamically resolves structural and semantical disharmony by preserving applications' local data model management. This is possible by understanding conceptualization (ontology) for structural and semantical disharmony. As a consequence a new methodology called DRAGON (*Disharmony Resolving with Agents and Ontology*) uses conceptualization for structural and semantical disharmony, a disharmony ontology, and software agents technology. Disharmony ontology can be specified as an OWL ontology. Software agents can use the ontology to resolve structural and semantical conflicts between applications at runtime.

Software agents communicate via shared communication space, a middleware that enables mediation of semantically different BIMs. The mediation incrementally builds local ontologies. The ontologies are used as persistent repositories of concepts (structure and semantics) that are captured from applications during run-time.

Extensive applicability of the DRAGON methodology is expected in construction industry with rich, complex and dispersed data content. The general goal of DRAGON is to help in discovery decrease semantic and structural difference between product models. The importance of ontological harmonization of enterprise product models is also well described in [12].

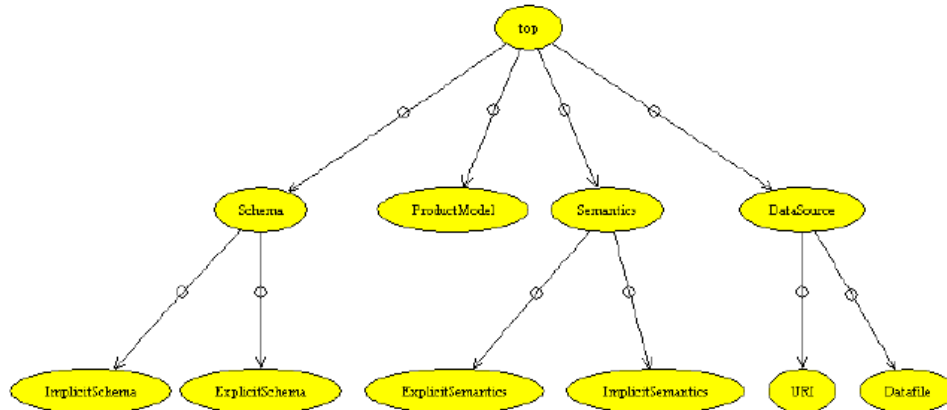
### 3.1 DISHARMONY ONTOLOGY

We can now formally define a conceptualization for structural and semantical disharmony of data in HFSS. We will call it *disharmony ontology*. An ontology is specification of conceptualization. An ontology is a document that describes vocabulary for communication between (humans and) software agents.

Identification of concepts for the ontology is based on the knowledge (facts and rules) about data specification languages, like XML, ISO/STEP, IAI IFC and UML. Top level hierarchy concepts are: **concept Schema** (a meta description of a data structure), **concept Explicit Schema**, **concept Implicit schema**, **concept Schema about schema** (reference to schema components from a schema document, trend is towards using combinations of schemas rather than just one; XML technology enables use of multiple inheritance with schemas), **concept Schema language** (standard STEP uses EXPRESS schema language, while XML representation of schemas is XML in IFC ), **concept Semantics**, **concept implicit semantics**, **concept Explicit semantics**, **concept Product Model**, **concept Building Information Model**, **concept Product model language** (language for product model description and schema language description can be the same), **concept Software tool for schema validation** (schema validators check syntax and structure conformance of schema with schema language rules), **concept Reference to schema** (product model can have an explicit reference to a schema which can be used for product model validation or product model can be validated against a software encoded schema), **concept Tools for product model manipulation** (a complete product model can be beneficial for different business cases that go beyond usual geometry exchange and visualization and involves also non-geometry applications like structural analysis, acoustic design, facility management, CNC machines; there are known cases of robotised laying of new asphalt layer), **concept Pool of supporting tools** (there are number of tools for conversion between different schemas, example is conversion of IFC SPF to IFC XML and vice versa), **concept Egocentric technology** (a product modelling technology apparatus has a rather high gravity force for number of domains), **concept Technology implementation complexity** (a domain specific product modeling application authors are aware of the steep learning curve towards standard product modelling technology).

The conceptualization (hierarchy of concepts) is an input for definition of **disharmony ontology** in DAML-OIL, an ontology specification language. DAML-OIL is oriented towards web and is an upgrade to RDF and RDFS. RDF semantically upgrades XML. RDF/RDFS typically uses triples property, resource and value.

Part of the hierarchy of disharmony ontology is shown on Picture 2. A complete disharmony ontology written in DAML-OIL is located at <http://www.tibaut.net/ontology/dragon.daml>.



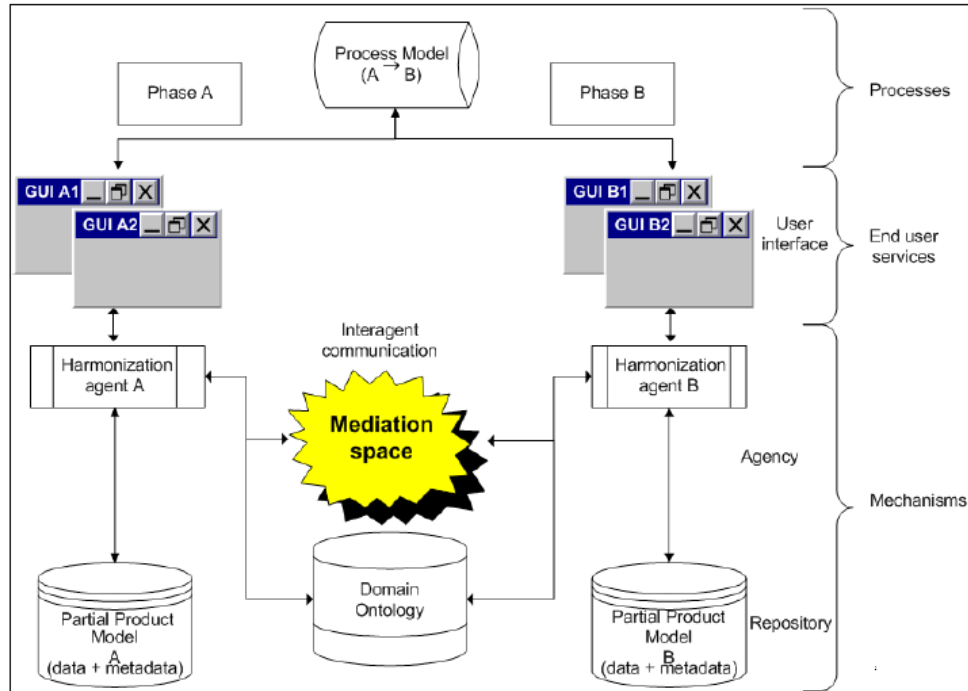
Picture 2: Disharmony ontology (partly): Hierarchy of concepts

### 3.2 DRAGON ARCHITECTURE

In contrast to the traditional schema integration approach, more recent thinking is to “mediate” dissimilar data representations instead of “integrating” them. This mediation approach is typically done by using some mediation rules or specifications, which are used to resolve various kinds of conflicts among component systems at runtime. A mediated information system allows the users to see data in their own views. They can issue queries based on their own views and receive data in representations that are familiar to them. Furthermore, the mediation approach provides better support for system extensibility and scalability because, unlike schema integration approach, adding new component systems to the heterogeneous system can be done by changing or adding mediation rules or specifications instead of redesigning or modifying the integrated schema.

The virtual product model approach can be explained as a decomposed product model, consisting of the three main levels (Picture 3):

- Mechanisms including repository with data structures used by applications and multiagent system which is responsible for structural and semantical harmonization of data in repository,
- End user services that include graphical user interfaces, and
- A process model, which determines the collaboration flow for applications (the “higher sense” of applications).



Picture 3: DRAGON: supporting software architecture

Our integration model can also be viewed as a multilevel integration model where the mechanisms implement the end user services that support the process. The process model encodes the set of goals and constraints of the context in which the end user services will be used to meet some objective of an organization.

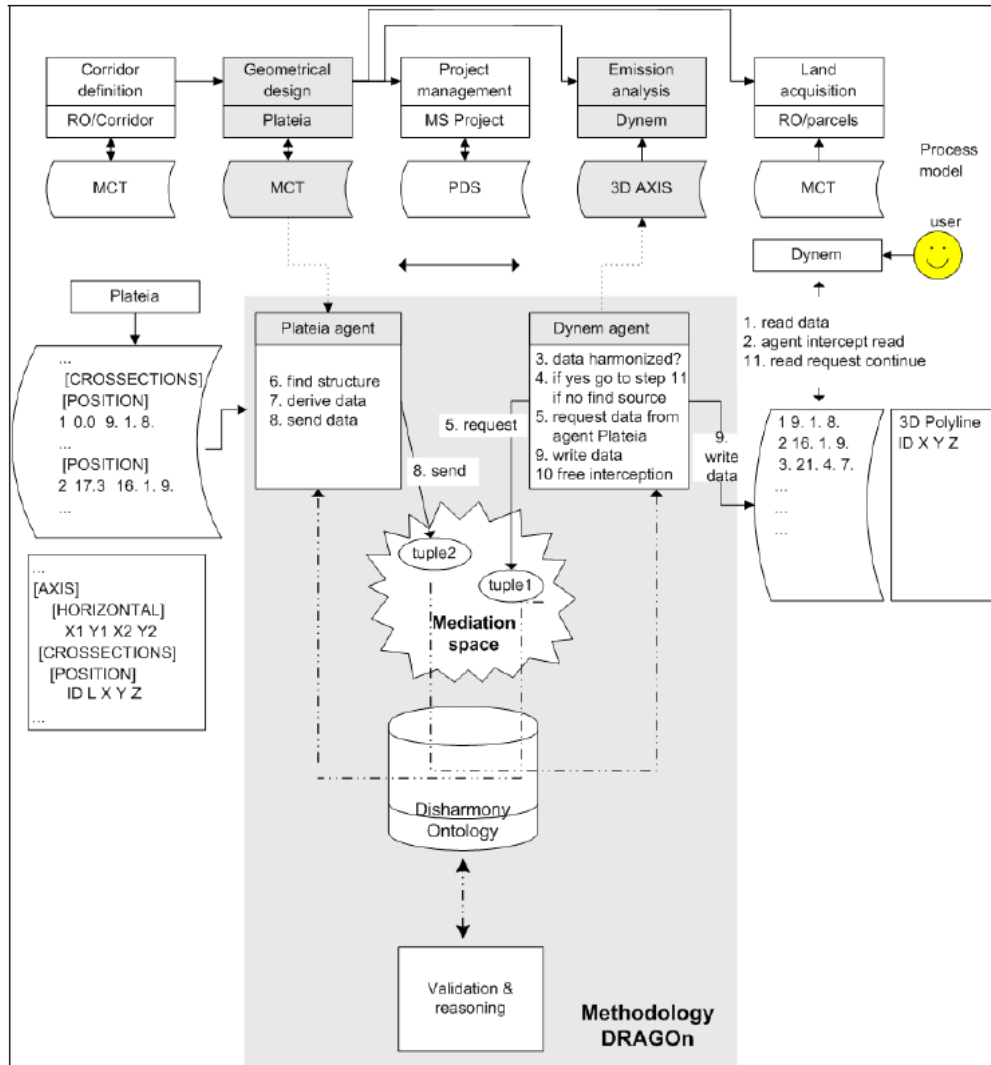
It is believed that such federation of heterogeneous and decomposed data sources (product models A and B in Picture 3) will decrease complexity of the product model to a manageable level and increase its flexibility through the autonomy of partial product models - components.

Some of the important features of our concept, motivated by the shortcomings of existing technology, include:

- The ability to share data across multiple heterogeneous data sources,
- The ability to manipulate the meta-data (schema) component of a data source in the same manner as data can be manipulated,
- Increased adaptability towards foreign product models.

#### 4. EXAMPLE

Picture 3 shows use of the DRAGON methodology in the road lifecycle (the road has been in the focus of our research group for over a decade now [11]). A simplified schema of the process model shows a chain of tasks, with the information about the program(s) and the external data representation used in a specific task. The process model is built, or adopted, for each specific project, because every project can include slightly different tasks, carried out by different programs.



Picture 4: DRAGON applied in a road design process

The scenario starts with the activation of the task “Emission analysis”, which is supported by the program named Dynem. When the user specifies the project name he wants to work on, Dynem tries to read relevant data. The read request is intercepted in an asynchronous way by the Dynem’s harmonization agent through the mediation space that’s created for the environment. The agent checks the status of the data in the project process model (implemented as a project database). If the requested data is harmonized with the predecessor components, the agent stores read request as a new tuple (tuple1, a set of objects) in the mediation space. Location of the data source is not determined in the process model since it only access (reads, writes) the mediation space. The Plateia-agent, which is responsible for the geometrical design, detects the read request (tuple1) in the mediation space. When Plateia-agent gets the description of the requested data structure through the knowledge representation repository, it tries to find it in its partial product model and returns the data as a new tuple (tuple2) in the tuple space. Now the Dynem-agent detects the content he is looking for, reads the tuple (tuple2) and updates data in its partial product model. The user can then continue to work with harmonized data.

From this example it can be seen that data in the process is not harmonized all the time, but only on demand. This mechanism simplifies the harmonization of the model as a whole, but still assures correct data when it is needed.

It is believed that the DRAGOn methodology will be especially effective in civil engineering, where processes and partners, as well as applications used, are changing from project to project. However, same applications are used more often, which makes it possible for their agents to improve knowledge repositories.

## 5. CONCLUSIONS

In a real scenario domain specific BIM often uses different syntax and semantics than other partners' BIMs or "central" BIM. This leads to interpretation conflicts. For practical reasons (security, IPR) construction project partners want to retain their own project data view (as opposed to project data lock-in) using existing software architecture. Industry domain BIM standards, for example IAI IFC, are rapidly extending pool of supportive applications becoming. Still data loss can happen both in importing from and exporting to the standard BIM. For the standard BIM to facilitate full interoperability between applications, it would have to be a superset of all their data models, which would be hardly realistic. Our methodology DRAGOn introduces approach that tries to understand disharmony problems in HFSS and decreases the semantical and structural differences in a construction project. Disharmony ontology helps to identify disharmony conflicts in data representations and software agents could help to resolve them. Such approach enables loosely coupled project software architecture as opposed to rigorous project discipline (to split a model to building levels). As a consequence this can support interoperability across the individual, discipline-specific applications that are used to design, construct, and operate buildings. Our near future work includes proof and analysis of our methodology based on a prototype implementation within the european InPro project. (<http://www.inpro-project.eu/>).

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## **A PROCESS MODEL FOR CONSTRUCTION SYNCHRONISATION USING TIME-SPACE PLANNING METHODS AND FIELD FORCE AUTOMATION**

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### **ABSTRACT**

This paper explores a proposed process model for construction synchronisation. The aim of the paper is to show the potential of working according to the Last Planner System of production and control by combining time-space planning methods and Field Force Automation. In addition, the paper aims to show the benefits of working with real time support regarding taking control actions in the schedule and to collect data for follow-up analysis. The paper first provides a background of the research and a description of the various methods and tools used in the process model. A process model is proposed based on the last planner and control system for the implementation of a new ICT tool with the purpose to enhance, planning and control in order to enhance construction synchronisation. It is concluded that site managers needs tools to change their view of planning from static view of the schedule which can be revised once or twice per project to the view that the schedule is a total dynamic instrument to be used to develop prognosis and measure for avoiding waste and delays in the realisation phase of the construction project. The paper is concluded with suggestions for how the method can be further developed and improved.

### **KEYWORDS**

Construction synchronisation, Last Planner, 4D modelling, location based scheduling, field force automation

### **1. INTRODUCTION**

During latest time the construction industry, in comparison with other industries, has been fighting with profitability problems. This has resulted in higher demands on lower production costs, shorter production-times, faultless buildings and longer guarantee periods. To meet these requirements the demand for just-in-time deliveries, supplier output and precision of deliveries has been higher, both concerning materials, equipment and subcontractors. Several studies indicate that both the level of material waste and thieving at construction sites are high. The materials are damaged or the quality is reduced because of bad handling. This has lead to poor quality of the finished building. Studies also indicate low productivity. A Swedish study of non-value adding work at the construction site indicated that the low productivity follows as a consequence that only 15-20% of a construction worker's time is spent on direct work. Approximately 45% is spent on indirect work (preparations, instructions, getting material, etc.). The remaining 35% is spent on redoing errors, waiting, disruptions, etc., i.e. room for improvements, (Josephson & Saukkoriipi 2005).

In the light of these facts, the interest of industrialized construction has been grown during the last years. Industrialized construction can be interpreted differently depending on who is talking about it. Some refer to the car industry and mean that houses should be built like cars, i.e. make use of the effect of repetitiveness and a high degree of prefabrication, supported by an advanced ICT-system. Others interpret industrial construction as an efficient and well planned traditional construction process but with less trades and decisions on site, (Apleberger et al 2007). From studies regarding production philosophies and concepts, like the Toyota Production System (TPS), Supply Chain Management (SCM), Just-In- Time (JIT), following subjects are taken to as aspects of industrial construction (Lessing 2006):

1. Planning and control of the processes
2. Developed technical systems
3. Off-site manufacture of building parts



4. Long-term relations between participants
5. Logistics integrated in the construction process
6. Customer focus
7. Use of information and communication technologies
8. Systematic performance measurement and re-use of experience

Using today's advanced information technology it would be possible to create an ICT-tool system to manage the most of the subjects mentioned above. Further, these tools must be arranged in a process model to suit the end user. This research is made to evaluate if improvements can be made in planning and management of construction projects using such a system, i.e. if production managers are able to plan and manage their construction project with better results and less time spent. In long term this will lead to less waste on site, which results in lower production costs, which in turn will lead to lower house prices.

## **2. OBJECTIVES**

The objectives of the paper is to find a suitable process to support and synchronize the flow of information, materials, labours and needed resources on the construction site. It is also assumed that needed information from the design can be extracted from a building information model

## **3. THEORY**

According to Koskela (1999) the preconditions to complete a construction task is dependent on seven resource flows, construction design, components and materials, workers, equipment, space, connecting work and external conditions, each of these has to be planned and controlled.

According to Bazjanac (2004), the construction industry has been using specific CAD software for more than 20 years. Today, the industry is in the process of utilising CAD information in downstream applications to model the performance relevant to the building's life cycle. The problem is that unless the applications belong to an integrated suite of software tools, these applications are often not able to exchange or share data. This results in duplication of data causing information errors in downstream activities, (Jongeling 2006). Vendors have developed their own propriety data models but these are just designed to support the work of data exchange within a particular vendor's suit of tools.

Creating 4D models is to link 3D CAD objects with scheduling activities regarding procurement and construction. The result allows project stakeholders to view the planned construction over time on a screen and to review the planned or actual status of a project. In construction projects, site managers run mental 4D models in their heads to think about the best construction sequence of the project. General contractors can use 4D models to coordinate the workflow of their subcontractors and site logistics over time. There are also examples of using 4D models communicate the scope and schedule of the project to subcontractors to solicit their input in a timely manner. It has been shown that 4D models can reduce the time for communicating the schedule to subcontractors while increasing the amount of subcontractor feedback. 4D models can be used live during subcontractor coordination meetings to review the sequence of work and related logistics and thereby prevent time-space conflicts between general contractors and subcontractors, (Fischer and Kunz 2004).

One of the most effective ways to increase productivity in construction is to plan more efficiently, improving production by reducing delays, getting the work done in the best constructability sequence, matching manpower to available work and coordinating multiple interdependent activities, (Ballard 1994). Ballard (1994) also states a number of obstacles that must be overcome to improve planning: 1) Management focus is on control. 2) Planning is understood in terms of the skills and talent of planners instead of seeing it as a system. 3) Planning is only understood as scheduling, not a crew level planning. 4) The planning performance is not measured. 5) Deviations from planning are not followed up to identify causes.

Most construction projects create a master schedule at the beginning of the construction phase, extending from beginning to end of the project. Such schedules cannot be detailed too far into the future because of lack of information about actual durations and deliveries. Most construction projects use some form of short term

schedules to coordinate and direct the various trades and crews working on the job, lookahead schedules. Usually the lookahead schedule is simply a drop out from the master schedule with a greater level of detail, but no screening of schedules soundness or other criteria. (Ballard 1997)

The Last Planner System of production and control consist of three components: 1) lookahead planning, 2) commitment planning (often in form of weekly work plans) and 3) learning. Activities are dropped from the project master schedule into the lookahead window, typically 6 weeks ahead the planned start of the construction activity. During this period the activities are constantly screened for constraints. The constraints that prevent activities from being a sound assignment are identified and actions are taken to remove those constraints. This is done by adding 'make ready' tasks to the activities in the lookahead window. No activity is allowed to retain its scheduled start time unless the planner is confident that all constraints will be removed in time. This assures that problems will be surfaced in an early stage. The primary categories of constraints are directives, prerequisite work and resources. Directives mean guidance about which work should be done. Prerequisite work is work that has to be prepared or done before the assignment can start. Examples include access to material, information and shop drawings. Resources are labour, tools equipment and space. (Ballard & Howell 2003)

Commitment planning is a commitment to what WILL be done, after evaluating SHOULD against CAN based on actual receipt of resources and completion of prerequisites. This strategy imitates one of the rules in the Toyota Production System (TPS). The rule is to stop production rather than send bad quality products down the line. The construction analogue to stopping production is assuring that only quality assignments will be released for production. Commitments to specific activities and tasks are often made weekly. The requirements for a quality assignment are definition, soundness, sequence, size and learning. Definitions means that assignments are specific enough that the right type and amount of materials can be collected, work can be coordinated with other trades, and it is possible to tell at the end of the week if the assignment was completed. An assignment is sound if the answer to questions like: Are materials on hand? Is design complete? Is prerequisite work complete? is yes. The intent is to do whatever can be done to get the work ready before the week in which it is to be done. The sequencing is about selecting assignments in right order according constructability etc. and to identify workable backlogs in case assignments fail. Assignments should be sized to the productive capability of each crew. The assignment should produce work for the next production unit in the size and format required. (Ballard & Howell 1998).

Each week, last week's weekly work plan is reviewed to determine what commitments were completed. If a commitment has not been kept, the reason is provided. The reasons are analyzed to root causes and actions are taken to prevent repetition, (Ballard & Howell 2003). The quality of the weekly work plan is measured by taking the number of committed assignments completed divided by the total number of committed assignments expressed as percentage. This is called Percent Plan Complete (PPC), (Ballard 1994).

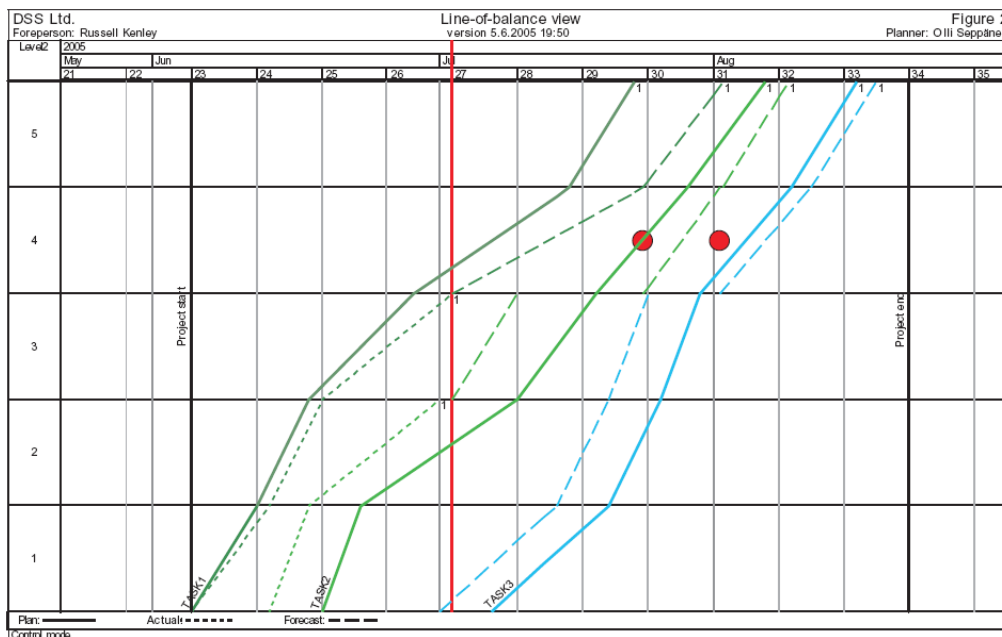
Location based scheduling is a method to provide information about the location of work and work crews. The ability to manage work tasks through locations of a project increase, thereby it is possible to ensure work flow, work reliability, avoidance of interference, improved quality and reduce work. Scheduling the precise location of multiple work crews makes the site management easier. The chart indicates where crews should be on a given moment and if crews are in wrong place it can rapidly be corrected. For site operatives, it is extremely powerful to know the precise location of a work crew. Consider the situation where there is a 50 level building with ten apartments per level. That is 500 locations where you might find a work crew. It certainly provides a lot of opportunities to hide or work out of sequence. With location based scheduling there can be no dispute about where work crews should be physically located, and especially where they should NOT be. This is very useful when managing subcontractors because with location based scheduling this is clearly documented and sequenced. (Kenley 2004)

Seppänen and Kenley (2005) states that location based scheduling are convenient to measure actual productivity versus planned productivity. This is done by recording the start date and finish date, actual quantities and average resources used in each location with the planned values. The location based data gives the ability to measure within tasks unlike PPC that only reveals completion of the different stages. Furthermore, the knowledge of planned, and actual, quantity data, production rates and resources, provides more information than is available with PPC. According to Seppänen and Kenley (2005) experiences on real case studies, the monitoring should be done at least weekly to get accurate enough results. Daily follow-up would give more accurate results but is very difficult to implement using manual systems. The follow-up of

location based schedules makes it possible to forecast activities in the future. The forecasts are based on the assumption that the production continues with the same productivity as before. Figure 1 is showing three tasks in five locations where the continuous lines are the planned tasks, the dotted lines are the actual work and the dashed lines are the forecasts. The red vertical line shows the actual date.

Figure 1: Location based schedule displaying planned, actual and forecasted work. (Seppänen & Kenley 2005)

Task one has started when scheduled but has been slower than planned. Using the current productivity the task will have a total delay of approximately one and half week. Task two started almost one week before schedule and has been working a bit faster than planned. If task two continues with same pace it will soon be in conflict with task one and have to wait for task one to be finished before it can continue. Task three has also started about one week before scheduled but have worked with same pace as planned. Because of the



delay of task two it will be a delay of at least one week between level three and four. (Seppänen & Kenley 2005) A combination of location based scheduling using model based quantity take-off per location can be used to enhance workflow and the production of 4D models, (Jongeling & Olofsson 2007).

Field Force Automation (FFA) is a generic term for mobile field services applications used for real time support of orders, scheduling, supervising and reporting in the field. A FFA system consists of a number of components to give real time support of dynamic fieldwork operations like scheduling, allocation, dispatch, reports and follow-ups. The generic access is independent of hardware platform and network, i.e. it is possible to connect from mobile phones and hand terminals etc. to the Internet connected terminals. The applications in the system give a lot of opportunities e.g.:

- work orders can be distributed by the planner or received on request from field workers
- field workers can announce accepted, rejected, started, interrupted and finished tasks
- work orders can be reported to the office for inspection, attest and invoice handling
- GPS tracking of the geographic position of workers and work locations
- Statistics for analysis of lead times and utilization of resources

The integration with IT environment of the company results in an efficient workflow. For example, master schedules activities can be decomposed for operation and follow-up in the FFA system on a daily basis. (Olofsson and Emborg 2004)

From the literature survey it can be conclude that there exist a number of model-based tools and methods that can be used to enhance the coordination on the construction site. However, these tools are today not integrated in an overall process that supports the pre-condition for a productive work.

#### 4. PROCESS MODEL

The presented process model, which is based on interviews with project managers, is a proposal of how different systems and software applications can be integrated to manage and control the dynamic of the construction process according to the last planner system of construction and control. Experts in each system and software application have been involved during the creation of the process. The model includes *Building Information Models (BIM)*, *Location Based Scheduling*, *4D modelling* and *Field Force Automation (FFA)*. The FFA is divided into several phases which will be described below. The process of the proposed system is described in a flow chart in Figure 2.

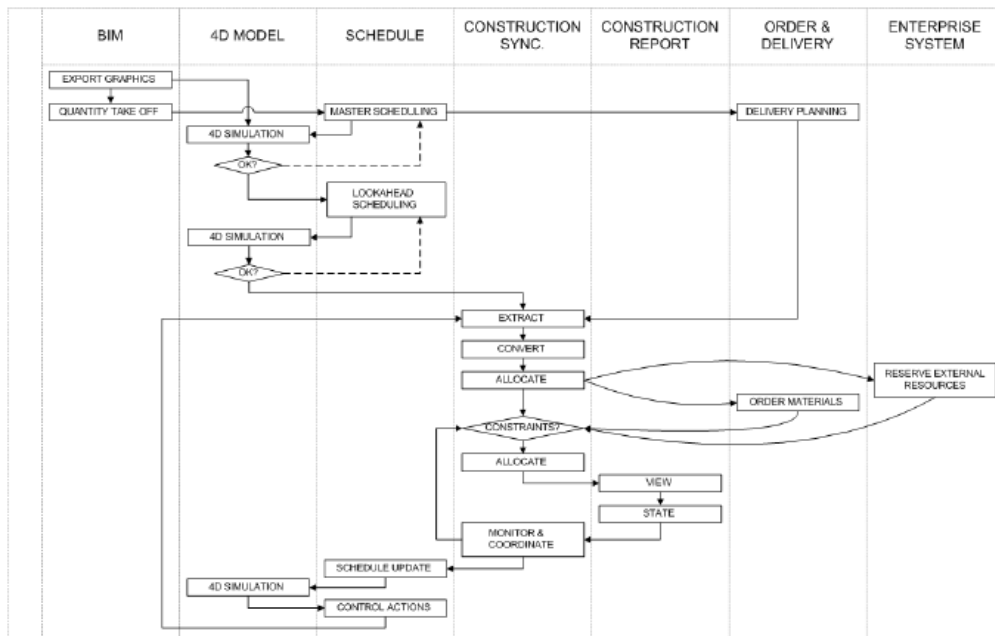


Figure 2: A flow chart for integrating software application in the managing and control of the construction process.

The system need to have access to the order and delivery system and to the enterprise system of the construction company responsible for the project. A model server is used for data storage and exchange with software applications and is accessible via web services. The architecture of the system is based on the theory of the Last Planner System of production and control.

##### 4.1 BUILDING INFORMATION MODELLING

The scope of BIM in this system is to serve the 4D model with graphics and the scheduling with a location based Bill of Quantities (BOQ). The quantity take off can be made directly from the BIM with the help of a plug-in application which has access to company specific database including recipes, see Figure 3.

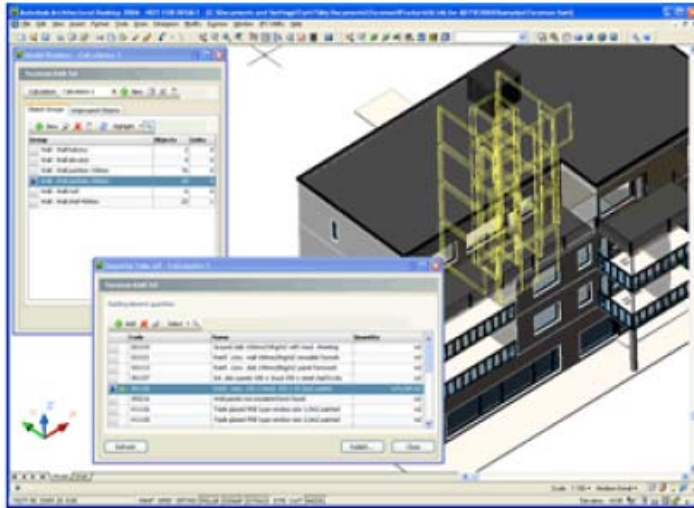


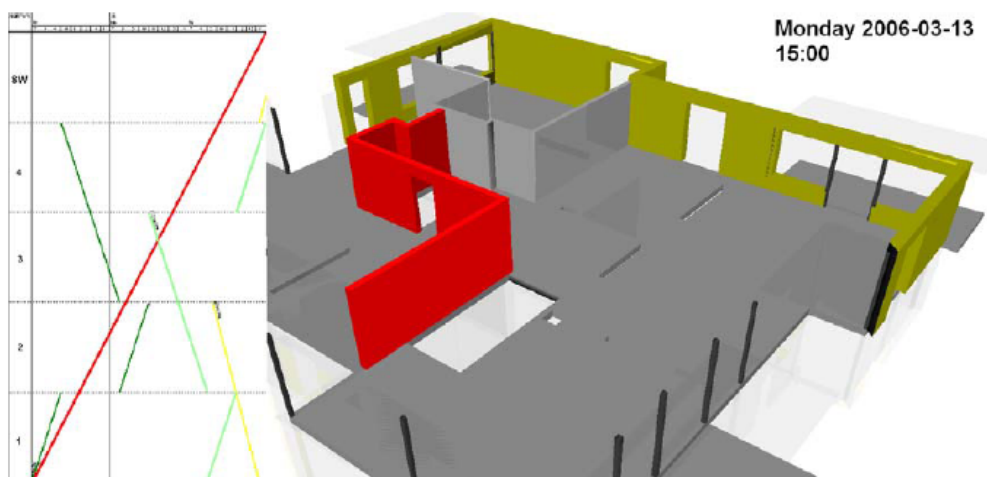
Figure 3: Model based quantity take off. ([www.tocoman.se](http://www.tocoman.se))

The BOQ and recipes are then extracted to the scheduling software. When the BOQ is created the work with purchasing materials can start.

#### 4.2 SCHEDULING AND 4D MODELLING

The scheduling can be made in a traditional activity based scheduling applications, i.e. using the Critical Path Method (CPM) method shown with a Gantt chart. However, we recommend using location based scheduling software to support workflow, but also to link material supply to specific work locations on site. The master schedule, according to LPS, should only consist of main activities. The master schedule can be simulated in a 4D environment to communicate with involved stakeholders in the project which also provides a quality check of the master schedule. Figure 4 is showing a location based schedule simulated in a 4D environment.

Figure 4: A 4D simulation of a location based schedule. (Norberg et al 2006)



Tasks are dropped from the master schedule into the more detailed lookahead schedule, typically 6 weeks ahead the planned start. Actually, the span of the lookahead window decides when a task is detailed in the lookahead schedule. The span of the window is decided by the longest lead times, i.e. procurement, delivery of shop drawings etc., for each task in the master schedule. This schedule can in turn be simulated once again using 4D on a more detailed level.

#### 4.3 FIELD FORCE AUTOMATION

As described in chapter 3 the FFA consists of a number of components. The main components, shown in Figure 5, in the proposed system are *Construction Synchronisation* and *Construction Report* where the *Synchronisation* tool is mainly used by the on-site manager and the *Reporting* tool is used by the construction crews on site.

##### 4.3.1 CONSTRUCTION SYNCHRONISATION

The *Synchronisation* tool consists of several functions, *Extract*, *Convert*, *Allocate*, *Status*, *View*, *Monitor & Coordinate* and *Statistics*.

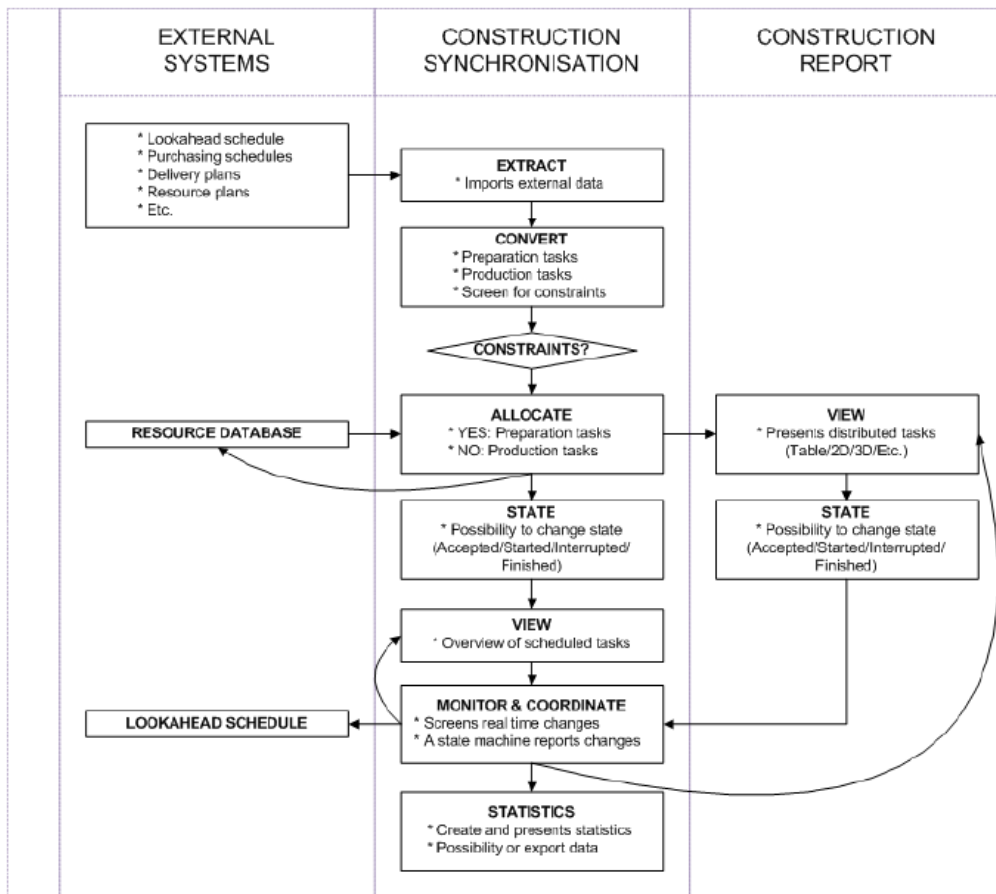


Figure 5: The FFA architecture.

The *Extract* function imports all the data needed to the system, where the most important input comes from the lookahead schedule complemented with data from purchasing schedules, delivery plans and resource

plans etc., necessary to manage and control deliveries of resources and material to the site. The more information that are put into the system the less information the site manager have to keep in mind. When all data are extracted into the system each task has information about, scheduled start, earliest start, latest start, duration, demand for competence, prerequisite work and resources, duration for preparation and deadlines for when different specific task must be started and finished.

In the *Convert* phase it is possible to create *Preparation* tasks and *Production* tasks. *Preparation* tasks are tasks which have to be done to make ready a production task. *Production* task are part of a main activity from the lookahead schedule, i.e. a main activity usually consist of several production tasks.

The preparation and productions tasks mentioned are distributed to team or individuals. This is done with the *Allocate* function.

A task has different kind of a state, i.e. allocated, accepted, started, interrupted and finished. These are changed in the *state* function.

The *view* function gives the site manager an overview of the scheduled tasks. This can be presented in different ways depending of how the site manager wants to present the tasks. Figure 6 shows an example of how the interface of view function can look like. Alarms with different kinds of severity are also possible to define to indicate or prevent delays.

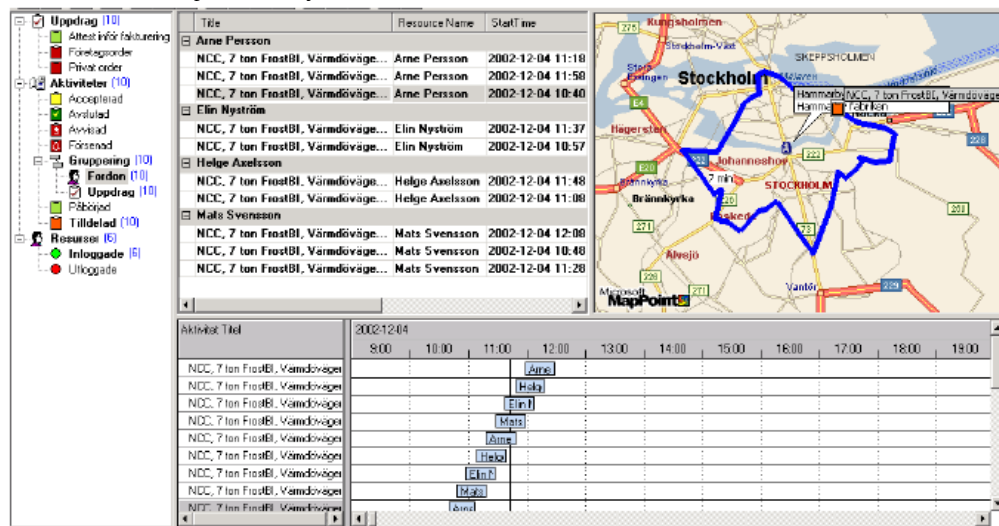


Figure 6: An example of the view function. (Olofsson & Emborg, 2004)

The *Monitor & Coordinate* function is one of the most important functions of the system. This function continuously screens the process for changes and calculates risks caused by delays. Alarms can be defined in different stages, e.g. risk for delay, delayed and critical delay. Coordination between different tasks can also be defined using a state machine defining the relations between different tasks. Signalling between tasks can be setup to be done automatically. For example, if one task is active several resources are blocked to other tasks. When the active task is reported finished, the resources will be available for other tasks and the following task can be notified of the possibility to start a new production task on a specific location, pulling the next team to start a new production task. This function also reports actual state of a production task back to the lookahead and master schedules.

Monitoring the process enables finished work to be analyzed. This is done in the *statistical* function. This data can be further exported to applications designed for statistical research.

#### 4.3.2 CONSTRUCTION REPORTING

The *Reporting* tool consists of the functions *View* and *Status*. This tool is used on site by the workers on site with use of Smart phones or Pocket PCs.

When tasks are distributed from the site manager to teams or individuals they are shown in the *View* function. In this function it is possible choose how the tasks will be presented, e.g. a table with listed tasks, a 2D view with colour coded tasks, a 3D view with highlighted objects, see Figure 7.

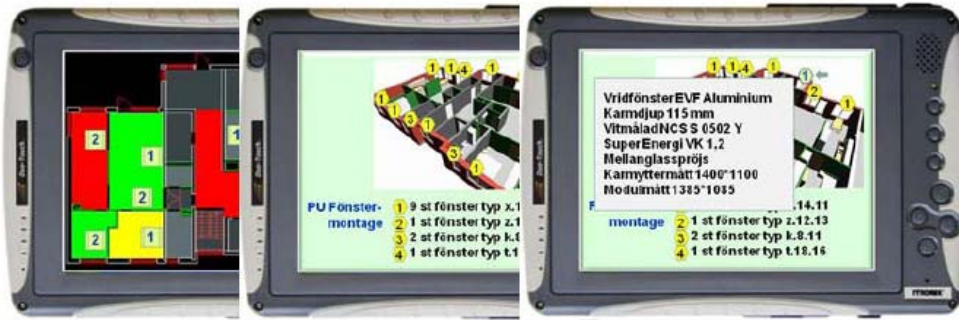


Figure 7: Examples of the interface of the View function.

When selecting a task it is possible to get all information needed to execute that particular task. It is also possible to see where and when other tasks are being performed at the building site.

As in the *Synchronisation* tool the state of each task can be changed between accepted, started, interrupted and finished. This is done in the *State* function, see Figure 8.



Figure 8: Examples of the interface of the State function.

The different states are automatically registered in the *Monitor and Coordinate* function in the *Synchronisation* tool. In case when a task is interrupted the reason can be reported back to the site manager.

#### 4.4 CONNECTION TO OTHER SYSTEMS

The data reported should also be able to be imported by other systems, e.g. to the order and delivery system and the enterprise system for resource and material purchasing normally used at the head office.

#### 5. DISCUSSION AND CONCLUSIONS

The proposed system is defined to support the theory of the Last Planner System of production and control. The connection between the monitor & control function in the construction synchronisation tool and the location based schedule result in a continuously updated schedule that can be communicated in real time. The 4D model complements the planning when communicating the schedule with subcontractors and suppliers. Today, most 4D models visualize the workflow but collected information makes it possible to visualize flow of material within and to the site.



The construction synchronisation tool supports the lookahead planning in the LPS. It is in this phase where sound assignments are created and made ready for execution. The construction reporting tool corresponds to the commitment planning in the LPS. Commitments are made by accepting (WILL in LPS) distributed tasks. The learning phase in LPS corresponds to the monitor & coordination function in combination with the statistical function in the construction synchronisation tool. These functions can be setup to automatically measure PPC, production rates etc. Follow-up on construction tasks can be made automatically from reports produced by the FFA system. Otherwise, reporting that requires extra efforts by the construction crews tends not to be performed.

The process model needs further developments and the most important is to get a case study to evaluate the model. It is also important to focus on an open environment so it is possible to choose whatever software you want. Site managers need tools to change their view of planning from static view of the schedule which can be revised once or twice per project to the view that the schedule is a total dynamic instrument to be used to develop prognosis and measure for avoiding waste and delays in the realisation phase of the construction project. This system enables managing the dynamics on a construction site. Connecting the proposed system to the order and delivery system of the company, enables a better communication between suppliers and the building site which in turn will most probably generate better precision of deliveries. However, the supply chain needs to be able to quickly respond to changes in delivery times to the site.

This type of system also promotes the delegation and distribution of responsibility for the work to the work crews on the site. With a better and more feasible work flow on site the variability and the stress will be reduced leading to better quality and productivity as a result. The follow-up on reasons for failure will also make it possible to benchmark and learn from project to project. It also gives more opportunities for the construction company to coordinate use of crews and procurement of material for many more than one projects running at the same time.

We believe that better linking of the supply chain to the work on-site is a corner stone in transforming the traditional craftsman construction way of working to a more industrialized construction process.

We are currently interviewing site managers to ensure the possibility of implementing the system and change the traditional way of working on the construction site. The next step in this research is to evaluate the model in a real case study.

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## DEVELOPMENT OF 5D-CAD BASED WORK PROCESS MODEL FOR AGED-HOUSING REVAMP PROJECTS

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### ABSTRACT

A growing number of aged-housing building projects have become a great concern in Korean building industry nowadays. Until 2010, over 20 year-old housing units are reported to exceed more than one million. The aged-housing units are required to upgrade the performance on both structural and service issues. Compared to new building projects, revamp projects are relatively under developed in terms of construction management. For example, there is few guidance or detailed procedure which addresses the management practice in dealing with revamp projects. Therefore, new technologies are reluctantly implemented in the revamp projects without in-depth analysis on constructability and/or economic efficiency. The objective of this study is to provide a new approach in dealing with aged-housing revamp projects. By developing 5D-CAD based work process model, project managers are effectively informed of various data, i.e., building elements, network scheduling, and cost items. The 5D-CAD based decision making can also enhance the accuracy and promptness during project execution. The authors developed a standardized work process model in dealing with 5D-CAD modeling via Virtual Construction<sup>TM</sup> software. In addition, the model has been implemented to pilot aged-housing project for the purpose of validating the feasibility and applicability in real future projects. The proposed WBS(Work Breakdown Structure) and CBS(Cost Breakdown Structure) have been proved as useful tools for contractors who deal with aged-housing revamp projects under circumstances that there is few historical projects and few experienced personnel. Also, the study identified potential benefits and limitations of the 5D-CAD based construction process for revamp projects. Key findings from this study are as follows.

- 5D-CAD modeling is no more optional strategy in maximizing the project value.
- The error-free construction planning is much more essential in revamp projects.
- Sharing the real-time project information can overcome communication barriers.
- Collaborative works are definitely can benefit from 5D-CAD modeling
- Full scale usage of 5D-CAD modeling can be achieved by partnering contract

### KEYWORDS

Aged-Housing, CBS(Cost Breakdown Structure), 5D-CAD, WBS(Work Breakdown Structure), Revamp Project.

### 1. INTRODUCTION

The total monetary value of the Korean construction industry is approximately 140 billion dollars in 2007. Among the total amount, more than 60% comes from the multiple or high-rise residential projects. The residential building sector is the dominant area in the Korean construction industry. At present, a growing number of projects in this sector are related with revamping or upgrading works. For example, many of the aged-housing complex projects have been so deteriorated that the structural performance level has become lower than the average and the M/E/P facilities has become old-fashioned and even needed to be replaced. On the contrary, many project practitioners have paid little attention to the renovation or revamp projects compared to new construction projects. There are three main reasons in this reluctance. First of all, the revamp project is less profitable. Compared to the new projects, the contract amount of the revamp projects is small and the working condition is less favorable. Second, the work process for the revamp projects is ill-defined so many project practitioners are reluctant to participate in the risky projects. Thirdly, the existing building condition is hard to recognize in the renovation project so the traditional estimation approach is improper in forecasting the revamp project cost.

However, the growing number of revamp projects is continuously seeking the better-fit contractors. In these circumstances, the better approach in dealing with revamp projects is to maximize the usage of the computer integration system, i.e., 5D-CAD system, in earlier stage of the project delivery. The 5D-CAD is emerging

technology and has proven its effectiveness in the field of project management (Chen et al. 2004, Walley and Tharbet 2002). The computer-based 5D CAD system is still in the beginning stage and there is much room to be developed. Considering this, the revamp project can get much benefited by this new technology in the following areas as many researchers has already indentified.

- Effective communication among project participants
- Optimizing time-cost tradeoff in the planning stage
- Achieving the higher value for money by constructability review
- Coordinating the design and construction works by real-time updating process

In this study, the 5D CAD based design has been conducted during the development of the project planning phase for optimization in cost and schedule issues for high-rise residential revamp project. By doing this, this study provides project practitioners with a guidance in developing 5D-CAD based work process and proves the effectiveness of the computer based planning and design in comparison with the conventional approach.

This paper consists of seven sections. Following this introduction, the background of this research is briefly described. In this section, the history of Korean building industry, the Center for Aged-Housing Remodeling Technology (CART), and the methodology of the research are elaborated. Next, the current status of the housing revamp projects is analyzed by studying both domestic and international case projects. In the following section, the merits and demerits in application of the 5D CAD system are discussed. To effectively use the 5D-CAD system in the revamp projects, a work-process model has been developed and the details of the model have been described in the subsequent section. The findings and path forward issues regarding the new process are discussed and finalized in the discussion and conclusion sections.

## 2. RESEARCH BACKGROUND AND METHODOLOGY

The dominant residential building type in Korea is a high-rise apartment or flat. More than half of the Koreans dwell in the apartment complex. In a very short period (less than two decades), most of the Korean residential buildings were constructed and their blocks, buildings, and the units of the facilities have been deteriorated and needed upgrading nowadays.

Table 1. Korean Aged-housing building stock statistics

| ID               | Years after its completion |           |            |            |             |
|------------------|----------------------------|-----------|------------|------------|-------------|
|                  | 0- 5 yrs                   | 6- 10 yrs | 11- 15 yrs | 16- 20 yrs | Over 20 yrs |
| No. of Blocks    | 3,702                      | 4,525     | 4,035      | 2,285      | 1,376       |
| No. of Buildings | 19,067                     | 21,169    | 14,906     | 10,668     | 7,377       |
| No. of units     | 1,525,152                  | 1,748,173 | 1,093,182  | 534,917    | 360,861     |

As seen in table 1, there are numerous old building blocks that are more than 20 years old. Also, the number of old buildings is growing as time goes on. Recognizing this upgrading issue, the Korean government launched a 5-year, 10 million dollar, mega-research project that aims to develop efficient and effective technologies in renovating or revamping the old-aged apartment complex blocks. Four research organizations were involved in this research and the Center for Aged-Housing Remodeling Technology (CART) was established in 2005. As shown in Figure 1, there are three main objectives that CART is obliged to deliver, including standard revamp construction model, regulatory issues regarding revamp projects, and revamp technology development.



Figure 1. CART Research Roadmap

Standardizing the aged-housing apartment revamp projects is non-trivial because there are a variety of different types of the buildings and the residents' needs and requirements for upgraded facilities are difficult to identify and fit into the certain stereotype. Considering these constraints, the scope of this research is limited to a demonstration project and the final goal is to prove a "possibility" by developing a standardization model for the project. In detail, the study methodology is presented in figure 2.

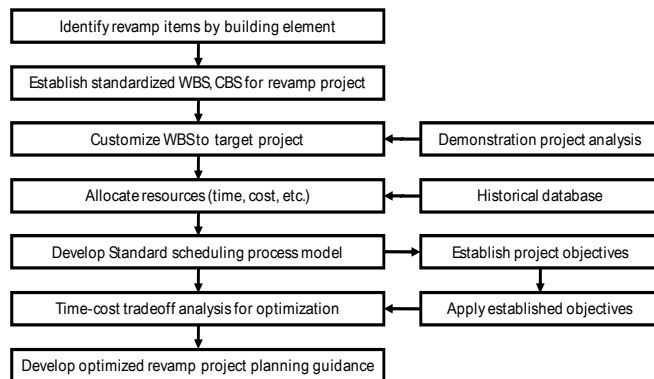


Figure 2. Research methodology

### 3. CURRENT STATUS ON AGED-HOUSING REVAMP PROJECTS

In Korea, the types of revamp projects are classified into three classes, i.e., extension, alteration, and renovation. In this study, extension and renovation are main targets. In figure 3, a brief summary of previous revamp projects completed in Korea are listed. These case projects were analyzed in detail through face-to-face interviews with project engineers and field construction managers.

This analysis showed that it took in average 24 months to complete the construction. It is also characterized that the entire building elements, i.e., finish materials, electrical/mechanical equipments, and supplies, are completely replaced while structural elements remains. The expansion of the existing plan and parking space is mandatory. A typical revamp construction process is summarized as follows.

- The horizontal plan expansion in building unit is important
- Total removal of non-structural elements is dominant
- More than expected structural reinforcement is inevitable
- In-the-wet construction method(i.e., concrete pouring) is commonly used

One of the meaningful findings from the case studies is that this type of revamp project is just on the beginning stage so that all of them are unprofitable resulting in a large amount of cost overrun.

| Project Summary                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>Completion Year: 1971</li> <li>Basement 1, 5story</li> <li>Balcony Extension &amp; Layout Alteration</li> <li>Structural Reinforcement</li> <li>Utilities Upgrading</li> </ul>                                                     |                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Completion Year: 1983</li> <li>Basement 1, 14story</li> <li>Re-sale Type Remodeling</li> <li>Balcony Extension &amp; Unit Unification</li> <li>Structural Reinforcement &amp; Seismic Wall</li> <li>Utilities Upgrading</li> </ul> |                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Completion Year: 1971</li> <li>Basement 2, 12story</li> <li>Balcony Extension &amp; U.G. Car Park</li> <li>Structural Reinforce &amp; Seismic Wall</li> <li>Utilities Upgrading</li> </ul>                                         |     |
| <ul style="list-style-type: none"> <li>Completion Year: 1977</li> <li>Basement 1, 12story</li> <li>Balcony Extension &amp; U.G. Car Park</li> <li>Structural Reinforce &amp; Seismic Wall</li> <li>Utilities Upgrading</li> </ul>                                         |                                                                                                                                                                                                                                                              |

Figure 3. Selected aged-housing revamp projects in Korea

In other Asian countries including Singapore and Japan, the commonly used construction technology is prefabrication or offsite delivery system. In Singapore, as seen in figure 4, the staircases or space added items are produced in the offsite and then delivered to the site and assembled in a speedy way. In Japan as well, the revamping projects are designed and constructed based on Pre-cast Concrete (PC) method (see figure 5).

Compared to Korean cases, those examples are more productive in terms of both schedule and cost efficiency. However, there are some limitations in adopting the prefabrication system for Korean cases. The major issue on this comes from the availability and quality problems in concrete prefabrication market. Even if the revamp projects are planned based on the prefabrication system, the market cannot be sustainable without a steady amount of demand on PC products. Also, the dimensions of the aged-housing buildings are not quite in accord with “at that time” drawings and even the drawings are not appropriately maintained.

In summary, the aged-housing revamp projects should be planned in consideration of both design and construction issues well ahead of construction process.

| Item                   | Contents                                                                                                                                                                                                                                                   | Pictures |
|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| Project Overview       | <ul style="list-style-type: none"> <li>Project : Holland Oasis</li> <li>Contract Period : 2004. 06. 25 ~ 2006. 11. 24</li> <li>Contract Sum : US \$ 17.778 millions</li> <li>No. of Units : 1113 units</li> <li>Contractor : Top Global Limited</li> </ul> |          |
| Method of Construction | <ul style="list-style-type: none"> <li>Program : MUP</li> <li>PC(Precast Construction)</li> <li>Unit Item : Utility room, Balcony Extension, Bedroom Extension, cum Toilet, Staircase Extension, Lift Shaft</li> </ul>                                     |          |

Figure 4. Aged-housing revamp case project in Singapore (source: Singapore Housing Development Board (HDB))

| Item                   | Contents                                                                                                                                                                                                                          | Picture |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
| Project Overview       | <ul style="list-style-type: none"> <li>Name : Murayasi APT Remodeling Project</li> <li>Size : 5 story, 97 buildings, 1940 units</li> <li>Completion Year : 1979</li> <li>Remodeling Period : 2001~2008</li> </ul>                 |         |
| Method of Construction | <ul style="list-style-type: none"> <li>Attaching 26m2 PC unit</li> <li>PC(Precast Construction)</li> <li>Without residents' evacuation</li> <li>New Pc Unit Item : Utility room, Laundry room, Bedroom, Emergency Exit</li> </ul> |         |

Figure 5. Aged-housing revamp case project in Japan

#### 4. 5D CAD MODELING ISSUES

A few decades ago, the Computer Aided Drawing (CAD) was initially introduced in the construction industry for the purpose of facilitating the drawing work for designers and/or engineers (Sun and Howard 2004). Nowadays, the CAD system has been so developed that it has become an essential tool for not only designers but also construction practitioners who need a detail-level of information regarding construction execution, for example, an activity-level schedule and cost estimate (Pro IT News 2003). A more highly-developed computer software technology enables a 5D CAD modeling, which means an integration of 3D modeling with schedule data (4D) and resource data (5D) of a construction project. The 5D CAD modeling is also referred to as Building Information Modeling (BIM). In this modeling field, a *standardization* issue is the key element because the computerized CAD modeling can be a waste of time when every single data has to be generated in a project-by-project basis. To facilitate the international BIM system standardization, International Alliance for Interoperability (IAI) has been recently organized and they are developing Industry Foundation Classes (IFCs), which are a set of building product model or objects. When using the 5D CAD modeling, the main benefits are summarized as the followings (Gallelo 2005).

- Design and estimation are integrated.

- Cost calculations are automatically created.
- Schedule is automatically created and optimized.
- Constructability analysis is facilitated.
- Design to build/build to design processes are enabled.
- Project risks can be identified and mitigated
- Subcontractor costs are reduced
- Contractual issues and claims are effectively managed.

Recently, Vico Software Inc. developed the 5D CAD software package titled as Virtual Construction™. In this package, there are six software programs, including Constructor™, Estimator™, Control™, 5D Presenter™, Cost Manger™, and Change Manager™. Each program is useful tool in representing the 5D-CAD modeling for a construction project. Although the system is relatively new, many projects have already proved the potential benefits described earlier. The project participants can effectively deliver 5D CAD modeling using this system. In revamp projects, the software is also helpful in developing detail-level Construction Execution Plan (PEP) in association with various project objectives, i.e., time, cost, safety, and quality issues.

However, despite the global efforts on computer integration in the construction industry, the 5D CAD modeling has many disadvantages compared to the conventional approach as follows.

- The CAD software programs are incompatible with each other.
- Too much skill is needed to take a full advantage of the CAD system.
- The different levels of detail are not acceptable in the system.
- Too much unnecessary input data needed to operate the system.
- All of the user groups should be well aware of the full context of the system.
- Only a few CAD system operators/users are available in the industry.

Furthermore, in revamping projects, there is no guidance in dealing with the 5D CAD modeling. Compared with the green-field residential projects, the revamp projects are difficult to manage due to the residing home owners and the deficient space for construction. The purpose of this study is to develop a work process model for 5D CAD modeling in executing revamp projects for high-rise residential buildings.

## 5. DEVELOPMENT OF 5D CAD-BASED WORK PROCESS MODEL

Recognizing the merits and demerits of the 5D-CAD system, we developed a 5D-CAD work process model as depicted in figure 6.

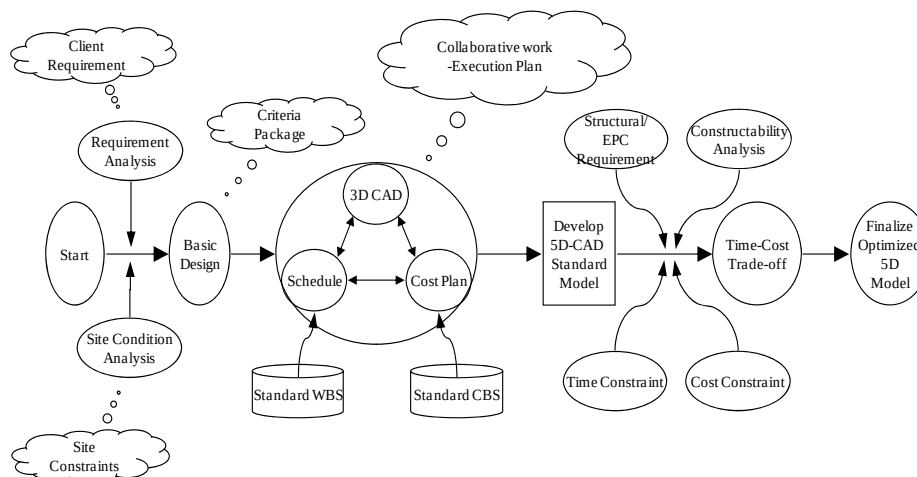




Figure 6. 5D-CAD work process model for aged-housing revamp project

In the first step, analyzing both residents' requirements and site conditions, the basic design is completed. In this stage, no collaborative work is required. The chief architect or designer can only be involved in this preliminary design phase. After this, 5D-CAD modeling is conducted using standard Work Breakdown Structure (WBS) and Cost Breakdown Structure (CBS) databases. In this stage, the standard WBS and CBS are the key elements. Also, this modeling work is conducted in collaboration with all project participants, including designers, estimators, schedulers, and construction managers. After developing the standard 5D-CAD model, the structural and Mechanical/Electrical/Piping works are analyzed and incorporated in the system. In this stage, detail-level constructability items can also be effectively identified and reflected to the model. By designating the target project cost and schedule, the time-cost tradeoff analysis is conducted in this stage. Once the optimization of the time and cost is completed, the final version of the 5D CAD model is produced.

This work process model has been developed to effectively apply to the pilot project in aged-housing revamp project. Since the final goal of our research center (CART) has not been achieved, this work process model is still in progress at the time of this writing. The following section provides the case project the work process model has been applied during the development of the 5D CAD model.

## 6. CASE STUDY

The pilot test project is located in the southernmost part of Korea, Jeju-island. In figure 7, both the existing and revamp plans of the cast project are depicted. This small aged-housing building has five stories and eight units per story. The area of each unit is only 350 square feet. There are two staircases with no elevator shaft. In the revamp planning, two elevators have been added and barrier-free access ramp between the ground level and the first floor has been installed. All of the units have been expanded to the maximum allowance (30% of the gross area). As seen in figure 7(b), the units are expanded to either northern or southern direction.

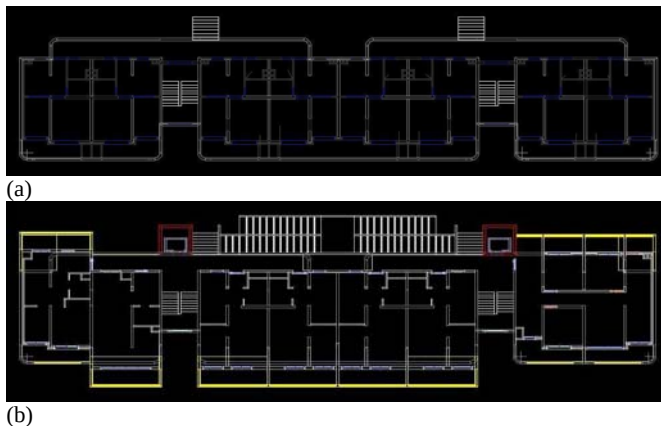


Figure 7. Aged-housing revamp project for pilot study (a. before revamping, b. after revamping)

Once completing the basic drawings, the 5D CAD modeling work can be accomplished. First of all, the standard WBS and CBS have been developed as shown in figure 8. The breakdown system has been established in cooperation with the experienced revamp construction experts. The characteristics for revamp project should be included in the WBS and CBS. For example, the activities regarding dismantling and reinforcing the structural elements play important roles in revamp projects. In addition, the recycling construction debris and wastes should be considered prior to the construction execution phase.

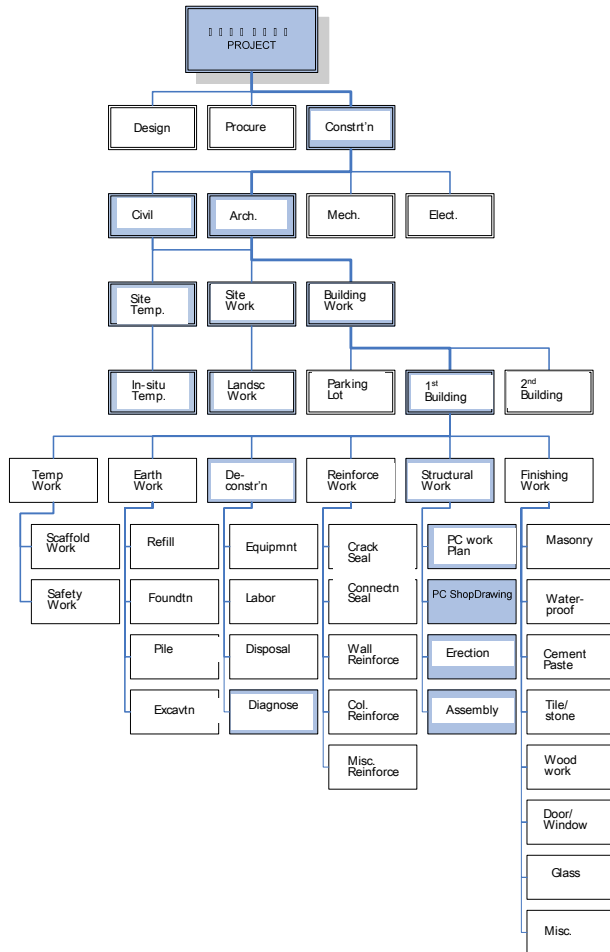


Figure 8. Work Breakdown Structure (WBS) for Aged-housing revamp projects

Using the standard WBS, each building element could be coded based on the databases which the Virtual Construction™ provides. The program has a unique methodology where the cost and schedule data can be effectively incorporated into the 3D model. First, each building object in the CAD model is connected to data element, called *Recipe*. The Recipe lists the activities and ingredients needed to construct the building object. Therefore, different columns can have different recipes. For example, some column can have a Recipe of in-situ concrete pouring with re-bar inside of wood form while others can have a Recipe of Precast Concrete fabricated in offsite. In more detail, the recipe is broken down into a set of *Methods*. The list of activities required to complete the building object is referred to as Method. The cost items such as material, labor, equipment, etc. are then linked to the Method to further identify the specific resources. In developing project schedule, the Methods are categorized into a task and the complete duration of the project can be obtained using the scheduling application program. Figure 9 shows the in-progress 5D CAD modeling screen shot via Virtual Construction™ Software.

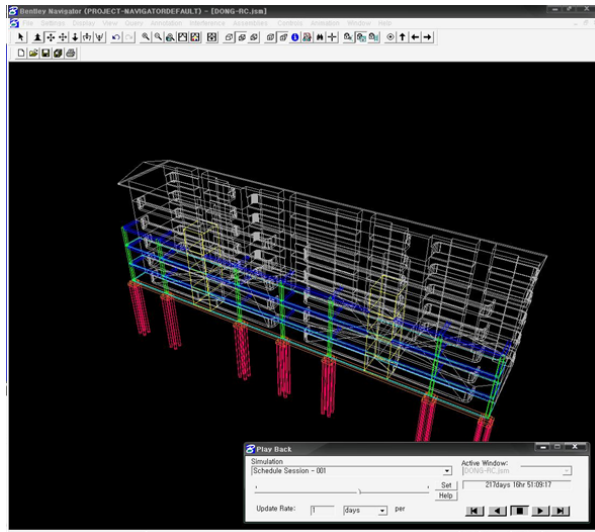


Figure 9. 5D-CAD Modeling (in progress)

## 7. DISCUSSIONS

Although the 5D CAD modeling has many benefits in project planning and construction, there are still many areas for further development. By introducing the 5D CAD modeling to the aged-housing revamp project, the following shortcomings have been identified.

- The software may be unnecessary during basic design development. So, the different versions of the software program may be helpful when developed in consideration of the level of detail on the information.
- The 5D CAD modeling work is time-consuming that the standardized databases or models are required to be pre-developed and embedded in the system.
- A number of project stakeholders and participants are involved during the modeling phase. It may be useful to enable the users to track record of the decision-making history linked to significant building objects.
- Not all the electronic files are exchangeable to the CAD system. The interoperability issue still required to be overcome.

## 8. CONCLUSIONS

The revamp project for aged-housing residential buildings has been a growing market in the Korean building industry. The industry-proven 5D CAD modeling has got benefited in many ways from the project management's perspective. Since there is no standardized 5D CAD modeling work process, this study, although it is premature, provided a step-by-step approach in application of the system. The findings from this study are summarized as follows.

- 5D-CAD modeling is no more optional strategy in maximizing the project value.
- The error-free construction planning is much more essential in revamp projects.
- Sharing the real-time project information can overcome communication barriers.
- Collaborative works are definitely can benefit from 5D-CAD modeling
- Full scale usage of 5D-CAD modeling can be achieved by partnering contract
- Information-driven construction projects should get much benefited from 5D-CAD.
- The project type, including revamp projects, has to be considered in developing the diverse versions of the 5D CAD system.

- Developing 5D-CAD software companies should take the “maintenance and revamp issues” into consideration. If so, the software can be much powerful.

#### ACKNOWLEDGEMENT

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## **MODELLING MULTI-CRITERIA DECISION ANALYSIS FOR BENCHMARKING MANAGEMENT PRACTICES IN PROJECT MANAGEMENT**

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### **ABSTRACT**

The link between management practices and worker's motivations impacting construction productivity is being considered as significant among the research community. This research aimed to identify and analyse the underlying attributes impacting construction productivity from the site management perspective. This research presents a framework designed to analyse and quantify the relative relevance of different drivers in the determination of productivity levels and the degree of effectiveness of potential opportunities for improving performance of overall projects. Owing to the complexity of construction projects and underlying conflicting drivers influencing higher worker's productivity, the Analytical Hierarchy Process (AHP) is employed to deal with interdependent relationships within a multi-criteria decision-making model. In the analytical approach, the large unstructured decision parameters are identified first and then are broken down into the manageable and measurable components using a top down hierarchical structure. This paper demonstrates an example to illustrate how to empirically analyse and prioritise a set of influencing parameters as selection criteria in devising appropriate management practices to ensure higher productivity vis-à-vis optimum performance of projects.

### **KEYWORDS**

Management practices, workers productivity, AHP, construction

### **1. INTRODUCTION**

Measuring the performance in any construction projects in terms of worker's productivity is a very complex process. Modern construction projects even moderate in size are generally multidisciplinary in nature and they involve various contractors and subcontractors range from routine to very specialized jobs. With increasing size and sophistications in construction projects, it is really difficult to motivate the employees to utilize for optimal outputs. Research reveals that the motivation level of employees has a direct influence on their individual output, and furthermore on the level of output of a team of employees. There are many factors that influence the level of motivation of employees. Throughout history employers have sought to find the most successful ways of motivating employees. Historically motivation was thought to be achieved by having punishments associated with non-performance, whereas today's thinking is more along the lines of rewarding success (Adrian, 2001; Bullinger and Menrad, 2002). Incidentally, past researchers have employed various criteria such as bonus and penalty schemes, overtime payments, paid leave, work study techniques etc. to motivate employees and monitor performances in construction industries. However, this paper focuses on the factors associated with the incentive programs (normally coordinated programs) through which employees are rewarded for optimal productivity in the work place. Appropriate incentive programs can be developed incorporating various socio-cultural motivational factors in competitive business success.

Researchers in the past have identified various causes or reasons (known as attributes in this paper) for measuring worker's productivity (Cox et al., 2003). Most of the works are either area-specific or project-specific and are mostly for the management and business objectives. However, focus of this research has been on the benchmarking of critical factors influencing satisfaction and motivation of employees in Australian context. There are certainly many critical factors such as financial, non-financial, tangibles and intangibles that influence the employees work environment in any given project (Jin et al., 2006). These attributes, if not understood and handled properly, may be detrimental for the success of future projects (Casteneda et al., 2005; Chan and Kumaraswamy, 1997). This study tries to identify all such positive and negative attributes for

construction projects in a developed country like Australia.

## 2. RESEARCH OBJECTIVES

Two major challenges have been identified in this research. Firstly, understanding and benchmarking the factors associated with the workers productivity impacting project performance and secondly, multi criteria decision analysis in devising appropriate management decisions for optimum project performance.

The overall objectives of this study are as follows:

- To identify the relative importance of positive and negative attributes influencing the productivity in construction projects as perceived by the construction professionals;
- To benchmark a framework incorporating the critical attributes in devising appropriate incentive and motivational schemes in achieving higher productivity in construction industry;
- To examine and devise the optimal solution facilitating appropriate management decisions.

The study focuses mainly on the construction stage of projects and it required a huge amount of documented data on completed projects. Due to non-availability of documented data on locally completed projects for this study, a questionnaire survey approach is considered to establish the impact of various attributes on productivity of projects. This research includes the survey of over 100 individual employees within various construction industries with regards to their attitude towards the implementation of incentive programs. Results indicated that 78% believed that the prospect of rewards would positively their work productivity. The research found a strong synergy between factors affecting worker's output and coordinated incentive programs which could have a significant impact on overall business outcomes. In the first part of the research, the results were analysed using a statistical factor analysis. The process identified the most influencing factors associated with worker productivity and determined the relative importance and impacts of the same on increased worker's output within the construction industry. In the second part of the research, theoretical work has been done to extend Analytical Hierarchy Process (AHP) for decision makers expressing approximate preferences based on relative importance of two factors at a time. The ultimate aim of this research to develop an automated decision support system (DSS) forecasting the best possible configuration of remuneration schemes incorporating project specific variables. The output of this research will significantly influence the management approached in senior management levels that contributes in project success (Doloi et al., 2004; Hanna et al., 2005).

## 3. FRAMEWORK AND METHODOLOGY

Figure 1 shows 7 wide spectrums of motivational drivers influencing project's success. These broad drivers have been identified based on the review of the current best practices as well as the ongoing industry practices (Harada, 2004). In order to derive the project's performance outputs, motivational drivers must be understood in terms of their underlying dependencies and integrate them accordingly for holistic decision making process.

Selecting the most appropriate alternative from a set of alternatives and eliciting the consistent subjective judgment from the decision makers in the selection process require a holistic analysis (Hargreaves, 1994). In general, this selection process is more effectively performed with the aid of computerized decision support systems. Some of the past researchers have adopted questionnaire survey approach for data collection in measuring project success and failure attributes and employed mathematical tools such as Analytical Hierarchy Process (AHP) (Saaty, 1980), Artificial Neural Networks (ANN) (Doloi et al., 2004; Lootsma and Schuijt, 1997) and statistical techniques such as factor analysis and multivariate regression etc. (Iyre and Jha, 2005) for analysis and drawing conclusions.

Leading from the existing knowledge in data collection and analysis methodologies in the field, this study focuses on the current practices and experiences through the personal interviews with construction professionals in Australia. Total of 25 project attributes were identified in relation to workers status and working environments. Though the list of this 25 attributes may not be called exhaustive due to the vast magnitude and fragmented nature of construction industry and construction environments, the list covered attributes pertaining to a large variety of construction projects. In order to understand the impact and

contributions of these attributes in project productivity, two different methods have been employed, multi-criteria decision making approach based in Analytical Hierarchy Process (AHP) (Saaty, 1980) and the statistical approach based on multivariate regression and factor analysis using Statistical Package for Social Sciences (SPSS) software package. For the sake of brevity, this paper discusses only the AHP approach and focus of the remainder of the paper will be on the analysis of data and the overall findings.

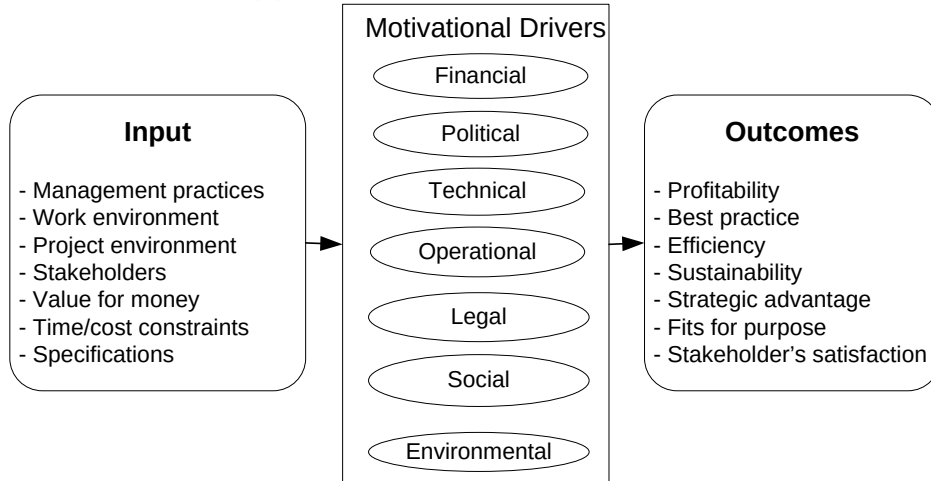


Figure 1: Motivational Drivers and their impacts

#### 4. APPROACH ADOPTED

In order to benchmark the impacts of influencing parameters for decision analysis, an extensive fieldwork were undertaken as part of a two honour theses under the authors' supervision (Johnson and Sims, 2004). There were three staged approaches for the analysis of the raw data collected in the field. The first is the descriptive approach with direct interpretation of the survey results, the second is the factor analysis and the third is multi-criteria analysis as mentioned above. For the sake of brevity, this paper discusses only the multi-criteria analysis in following sections.

#### 5. MULTI-CRITERIA ANALYSIS

As mentioned earlier, the Analytical Hierarchy Process (AHP) has been utilized for multi criteria analysis. The AHP is a powerful technique to deal with complex decisions where interdependence exists in a decision model (Cheng and Li, 2005). The AHP incorporates both quantitative and qualitative criteria influencing decisions in a hierarchical approach. This involves breaking the decision problem down into a hierarchy of interrelated decision elements (Figure 2). At the top of the tree is a statement of the most general objective of the decision problem, e.g. find the optimal solution. Then the criteria of the decision are set out below the structure. At the next level in the tree these criteria can be broken down into more detail, and so on. Simply the AHP structures a decision into a hierarchy of factors and determines the relative importance of criteria and sub-criteria against feasible technical solutions in pair-wise comparison. In essence, the hierarchical levels comprehend the objective of the decision, the criteria and the alternatives. Detail of the AHP application has been discussed in following section.

#### 6. MCDM ANALYSIS

The first step in the AHP analysis was the creation criteria and sub-criterion that influence decisions on a number of technical solutions. In this research, a two layered hierarchy was formulated comprising criteria at the top level and sub-criteria at the lower level as shown in Figure 2. Total of three criteria, *Commitment*,

*Motivation* and *Skill*, have been identified at the top level hierarchy in AHP calculation. These criteria were decided upon in reference to the optimum solution and in conjunction with interviews conducted with senior management personnel within the construction industry. A questionnaire was developed and 30 senior management personnel from eight big organisations in Australia were interviewed and quizzed on the optimum solution, “to increase the output and work productivity of employees in the construction industry”. The interview was aimed at establishing key employee traits that contribute heavily to the optimum solution. Three traits were consistently iterated from the interviews, Commitment, Motivation and Skill. Secondly, the senior management was required to compare these three traits against one another in reference to the optimum solution. Example of the calculation of priority matrices for criteria against a single technical solution is shown in Figure 3. The rest of the calculations and results have not been shown for brevity. The results were then transformed into a three criteria matrix in order to establish a priority matrix using AHP calculations (Saaty, 1980).

## 7. AHP DECISION HIERARCHY

Figure 2 represents the hierarchical links between alternatives and criteria used in AHP to find the optimum solution. The optimum solution is at the top of the decision tree followed by a series of criteria that affect the outcome of the solution, through the use of technical solutions. The various solutions and their relationship between criteria is the process by which the AHP matrices are determined, and the technical solution, which fits the optimum solution, is chosen (Saaty, 1980).

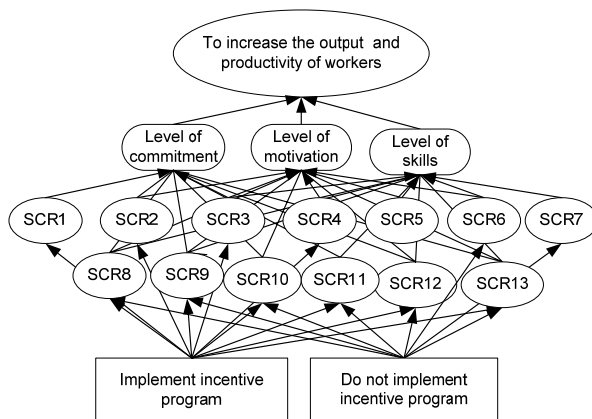


Figure 2: Hierarchical links between alternatives and criteria

The AHP tree diagram for this particular study also includes sub criteria. These sub criteria formed the basis for the questions that formed the aforementioned survey. It is interesting to note that there is not always a relationship between the sub criteria, criteria and the technical solution, in this case the sub criteria are said to be independent of a particular criterion (Harada, 2004). Total of 13 sub-criteria out of 25 project attributes have been identified to use in the AHP analysis. These sub criteria form the second level of decision hierarchy are abbreviated as shown in Figure 3. Details of these sub criteria are discussed below.

- *SC 1: Training:* The level of training directly influences the level of output of an individual and it is therefore a relevant sub criteria. Training influences the level of skill that the employee possesses, however it can also be perceived as negative due to the fact that corporations that are known as “trainers” are often used for this purpose and then employees often move on to new firms.
- *SC 2: Number of Labour Hours:* The number of hours that an employee works may or may not increase their level of output. Combined with other sub criteria such as improved work environments however the number of labour hours worked will increase output.



- *SC 3: Level of Experience:* Level of experience is fairly self explanatory as to why and how it affects the level of output of an individual.
- *SC 4: Work Environment:* Of those participants that responded to survey number 1, the greatest percentage of respondents reported that work place environment was the number 1 factor that influenced their motivation at work, and therefore it must be included as a factor effecting level of output.
- *SC 5: Rewards:* Rewards here refers to the giving by the employer of an object or cash to an individual employee in thanks for work completed. It is important that this factor be included as it relates directly to the idea of incentive programs. Rewards are the most basic form of incentive programs.
- *SC 6: Superannuation:* An individual level of commitment to an organisation can be affected by their level and payment of superannuation. Superannuation in its basic form is not a key factor influencing the level of output due to the fact that the majority of employees in Australia take it for granted, however bonus superannuation payments do often for part of incentive programs and therefore it has been included within the analysis.
- *SC 7: Level of Salary:* The salary level of an individual, or rather the change in salary through successive pay reviews is an influence on the level of a worker output, even if literature suggests that it is of diminishing importance as a motivation tool.
- *SC 8: Challenging nature of Occupation:* There has been much research that suggests that the challenging nature of an employee's job is a large factor in their motivation. It doesn't relate to incentive programs however it is important in this study to not bias the questions towards ones that only relate to the implementation of incentive programs.
- *SC 9: Employee Innovation:* The innovative nature of employees is the greatest resource that an employer can tap. Incentive programs that encourage innovation can be very helpful in this regard.
- *SC 10: Employee Efficiency:* Efficiency by its definition means to increase the level of output with a fixed amount of resources. It stands to reason therefore that it is important for employees to be efficient in order to increase output.
- *SC 11: Prospect of Promotion:* The prospect of being promoted, is a large motivator for many employees, however it can't be guaranteed to motivate all employees, due to the fact that many employees do not aim to "climb the corporate ladder" the purpose for its inclusion is to ensure once again that the survey is not biased toward the implementation of incentive programs.
- *SC 12: General Manner:* This question was posed within the survey due to the effect that an individuals personality has on their output, it is generally recognised that people with a good attitude perform better in the workplace.
- *SC 13: Communication Skills:* Communication skills are perhaps the most important skill that an employee can possess. Incentive programs have no bearing on this however it is included due to the fact that a good communicator often can allow for the efficient functioning of a workplace.

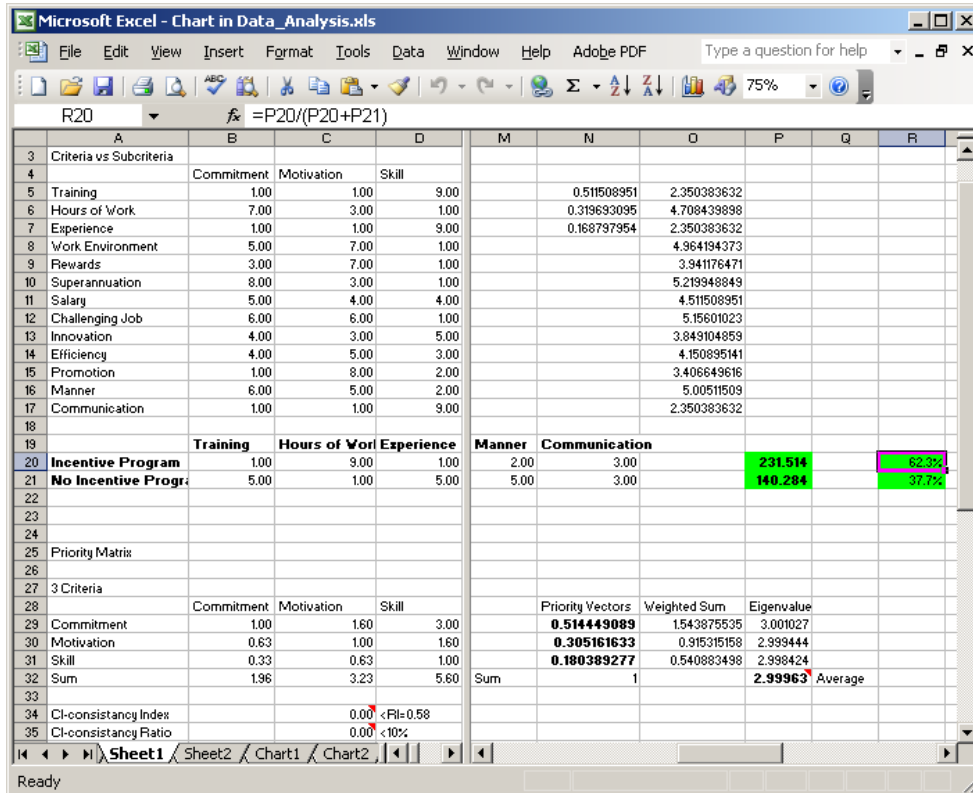


Figure 3: Priority matrices using AHP calculations

## 8. TECHNICAL SOLUTIONS AND THE OPTIMUM SOLUTION

AHP calculations were computed using the survey responses on relative importance of project attributes and performed using Microsoft Excel as a dry run in developing the overall framework (Figure 3). The sequence of calculations involves the analysis of the three criteria, followed by the analysis of the sub-criteria, which leads to ascertaining the appropriateness of the technical solutions in reference to the optimum solution.

Technical solutions, as contained within AHP analysis, are in place as a means of determining the most preferable method of achieving the optimum solution. The technical solutions are indirectly related to the sub criteria to which it is tested. In this study the author seeks to prove whether or not incentive programs increased worker output as against not implementing such a system. Therefore the two technical solutions tested were: "to implement an incentive program", or "not too" as shown in Figure 2. This study proposes that the use of incentive programs helps achieving the optimum solution by "increasing the output and work productivity of employees in the construction industry".

## 9. ANALYSIS AND RESULTS

The literature review undertaken in this study revealed the fact that incentive programs have achieved significant improvements in employee productivity. It was indicated however that incentive programs were not widespread within the construction industry. This research aimed at determining whether or not the implementation of incentive programs within the construction industry would be a wise decision for management.

It is a general perception of the public that flashy names or badges do not affect construction workers. However close to half of the recipients noted that it was important for their employer to have a high profile. This result may have been slightly biased due to the fact that the majority of the construction workers surveyed worked for large companies. The question begs 'what does such a response have to do with incentive programs?' The answer is that feelings associated with pride are one of the key factors in employee motivation, if an employee feels that his/her work may affect their employer in a major way then studies have found that their work will be of a higher standard.

Other interesting results included the fact that many construction workers responded that they were demotivated when they worked under the influence of management pressure, suggesting that common industry practices of 'stand over' tactics should not only cease due to legal reasons, but also because it was in the best interests of the employer that such practices ceased. Only eight percent of respondents were against workplace recognition. In an industry dominated by males, and a very 'macho' workplace, it is unexpected that almost all respondents wanted to be recognised and thanked for their contribution. This result is very interesting due to the fact that it opens the door for all kinds of recognition based incentive programs.

The most significant results came from this research are the influence of incentive programs on workers motivation. Over eighty percent of respondents said that being part of an incentive program was important to them, and that if subject to incentive payments over ninety percent of respondents said that their work productivity would increase. Two of the most expected responses came however in regards to respondents feeling about their current contract and what type of incentive reward they would be most happy with. The majority of respondents said they were unhappy with their current contract and that they would most prefer cash as the form of incentive bonus. These findings were also validated from the factor analysis.

In order to understand the significance of the results derived from the AHP analysis, one must understand the criteria on which the analysis was based. The literature revealed that the level of output of an employee was directly related to three board criteria being an employee's level of *Skill*, *Motivation* and *Commitment*. With these factors in mind the author sorts the opinion of employers as to how to rank these criteria. The consensus of employers was that the three criteria were of differing levels of importance, from the most important to least important; *Commitment*, *Motivation* and then *Skill*. This fact is very important in the analysis of this study as incentive programs are much more likely to affect an employee's level of commitment and motivation then their level of skill.

The result of the AHP analysis was very conclusive as to whether or not incentive programs would increase the level of output of workers. Technical solution number 1 - *Implement incentive programs* came out at a weight vector of **0.62** versus technical solution number 2 - *do not implement an incentive program* with a weight vector of **0.38**. It is worthwhile to mention that in the AHP calculation, all the judgment matrices were iterated to their consistency ratio was less than 10%. The consistency ratio based on the maximum eigenvalue was calculated using following formula

$$CI = \frac{(\alpha - n)}{(n - 1)},$$

where, ' $\alpha$ ' is the maximum eigenvalue and ' $n$ ' is the size of judgment matrix.

$$CR = CI / RI \quad (\text{less than } 0.1 \text{ for consistent matrix})$$

where, RI = Random index is based on the mean CI value of random matrices

## 10. CONCLUSION

Employee output is the single greatest driver behind business success. The labour intense nature of the construction industry most certainly then relies very heavily on its workforce to remain competitive and profitable. This study has proven that it is possible for employers to determine what factors will influence employee motivation and thus increase employee output contributing to overall project success. The questionnaire survey on an extensive project attributes influencing workers performance in project has revealed the important success and failure attributes. The preliminary study has concluded that the conductive

work environment and incentivised employment contracts in the construction industry will increase the output of industry employees. This study has opened the door for further studies to be conducted to investigate appropriate the incentive programs that will best suit the construction industry. The hypotheses and the preliminary results presented in this paper are based on a joint industry study in Australia. Factor analysis of responses on the project attributes has extracted four major factors. Stepwise regression analysis technique was further performed on the factors to investigate the impacts of each factor and determine the most critical one. It was found that the work environment and employment contract are the critical drivers influencing positive construction in workers productivity in Australian construction industry. It has been realised that the identification of the critical factors resulted from this research may still be inadequate in terms of benchmarking the conducive work environment due to limited case studies. The results from AHP analysis conclusively highlighted the importance of incentive programs in achieving strategic business intents.

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## **GPOP: REPRESENTATION OF SUSTAINABILITY CONSIDERATIONS ON BUILDING PROJECTS**

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### **ABSTRACT**

Sustainable development has attracted much attention in recent years and has created an increasing awareness of environmental issues affecting construction projects. Stakeholders of sustainable building projects seek inspiration and benchmarks on existing sustainable buildings. However, the documentation of the sustainability considerations (SC) on building projects is inconsistent and usually focused on the design solution with little or no attention to the project requirements or process and organizational aspects of the design. The comparison of sustainable projects is therefore difficult due to the varied nature and extent of the documented sustainability considerations. We propose a systematic representation of the SC, which we call gPOP model, that facilitates the comparison of sustainable projects. We created gPOP models of twelve recognized green buildings which led to a list of the 36 most common sustainability considerations (MCSC). We show that our representation of the SC allows the comparison of sustainable projects and helps uncover insights that otherwise remained hidden in the free-form text-based narratives used for documenting the SC.

### **KEYWORDS**

*Sustainability, product model, process model, green building.*

### **1. INTRODUCTION**

Sustainable development has attracted much attention in recent years. Consequently, owners, designers and public officials facing the challenges of delivering sustainable facilities have sought inspirational examples of sustainability practices and performance benchmarks on already built green or high performance buildings. However, in most cases the documentation of sustainability considerations have focused on descriptions of technologies incorporated in a particular design, and little attention has been put on elaborating the process followed or the organizational considerations that made that project happen. Therefore, without this context, practitioners are left with the description of the design solution (the facility itself), but without an understanding of the problem that this design addresses (requirements), the process followed to achieve it, nor the stakeholders' characteristics and dynamics, which might be critical for the project outcome (defining success or failure).

Private and public sectors acknowledge the growing "green" or "sustainable" trend among homebuilders and commercial buildings within the U.S. (Plunkett, 2004; USGBC, 2003). The National Association of Home Builders (NAHB) estimates that between 5% and 10% of new homes in the U.S. will be eco-friendly by 2010, up from 2% in 2005 (Plunkett, 2007). NAHB's eco-friendly specifications require resource-efficient design, construction and operation, focusing on environmentally friendly materials. Furthermore, state regulations and local building codes in many cities are requiring that greater energy efficiency be incorporated in plans before a building permit can be issued (Schwarzenegger, 2004). In more general terms, sustainable

consideration (SC) such as energy consumption, water consumption, indoor air quality, site selection and material use are commonplace in the sustainability literature (Pearce and Vanegas, 2002) and in the influential sustainability guidelines (e.g., Minnesota Sustainable Building Guidelines or MSBG); sustainability assessment methods, such as the Leadership in Energy and Environmental Design (LEED™ by the US Green Building Council); or the Sustainable Project Appraisal Routine (SPeAR™ by Arup) developed to assist practitioners in designing and constructing sustainable buildings (USGBC, 2005; McGregor and Roberts, 2006).

Stakeholders of sustainable building projects –the design team in particular– look for comparable facilities for benchmarking purposes and as a source of inspiration for design ideas. The pragmatic approach of guidelines and assessment methods, such as MSBG, LEED™ or SPeAR™, has helped design teams to implement sustainability in the built environment. However, inconsistent documentation and explanation of SC and the process used to include them in the design has resulted in descriptions of a project's SC that are usually a mix of qualitative and quantitative statements without a particular order. Comparison of sustainable projects is therefore difficult due to the varied nature (e.g., water, energy, air quality, materials, etc.) and extent (e.g., reduction, elimination, minimization, etc.) of the SC. Often the description of such SC focus on listing what kind of technologies have been integrated into the design, while the rationale (or lack of it) that justify their inclusion in the design as well as other key factors for success or failure of the project remain hidden. When asked, stakeholders of green building projects have identified process elements and individual stakeholders' role and dynamics as key success factors for the sustainable outcome of the projects they were involved in<sup>1</sup>. García et al (2003) refer to such aspects as the product (building), organization and process (POP) aspects of the project. They argue that, throughout the project design, designers have to understand the distinctive and interrelated requirements that the project is trying to satisfy (functions), the chosen design solution (forms), and how well the requirements are met (behaviors). They propose a 3x3 matrix called the POP model to describe the functions, forms and behaviors (FFB) of a project's product, organization and process (Figure 1a shows a POP model with the product-organization-process columns and the function-form-behavior rows).

We propose a systematic and descriptive representation of the SC for projects that we call a gPOP model (green or sustainability-loaded POP model). gPOP models describe SC for the product, organization and process in terms of their functions, forms and behaviors. Our representation of the SC makes the comparison of sustainable projects easier using simple diagrams and metrics. In addition, we developed a list of key SC –including success/failure factors of the building projects– that provide the basis for standardizing the gPOP models.

Following, we discuss the points of departure for this work, including guidelines and assessment methods followed by practitioners faced with the task of delivering sustainable building projects. We explain our methodology and we describe how to create gPOP models. We show how they can be used to compare sustainable projects. Finally, we discuss future applications and research opportunities for the gPOP models.

## 2. POINTS OF DEPARTURE AND METHODOLOGY

The literature on built environment sustainability has grown dramatically in the last decade as a consequence of the increasing interest in sustainable development (Pearce and Vanegas, 2002). Practitioners have relied on sustainability guidelines and assessment tools –the most pragmatic types of sustainability literature– to address the challenges of designing and building sustainable facilities. The State of Minnesota Sustainable

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<sup>1</sup> We interviewed Dr. Philippe Cohen, the Administrative Director of the Jasper Ridge Biological Preserve and Brad Jacobson, a Project Architect from EHDD who worked on the award-winning Global Ecology project from conception to the end of construction. Dr. Cohen gave credit to the Stanford Project Managers for the role they played in achieving a sustainable facility. He also acknowledged that a well defined building program was decisive for the positive project outcome. Mr. Jacobson attributes the successful outcome of the project in part to a clear set of goals from the beginning of the project and the positive attitude of the General Contractor toward sustainability learning and exploration of innovative alternatives. In both cases, we observe that organizational aspects (roles and characteristics of the organizational actors) and process aspects (well defined set of goals and building program) are considered essential to achieve project success, although these aspects are rarely reported as SC.

Building Guidelines (MSBG) is an example of this type of resource that helps a design team to define the functional requirements for a project and suggest sustainability strategies (aligned with the local needs) and performance goals in categories such as: site and water; energy and atmosphere; indoor environmental quality; and material and waste. These categories are representative of the most common considerations, though the extent to which they should be pursued varies for different guidelines and the organization/entity that originated them. Another common type of guideline comes from assessment tools such as LEED<sup>TM</sup> or SPeAR<sup>TM</sup>. In nature, these assessment methods are prescriptive and they suggest strategies to comply with predefined “credits” that represent the interpretation of sustainability of a large and experienced consulting firm like Arup in the case of SPeAR<sup>TM</sup> or the sustainability view of the US Green Building Council in the case of LEED<sup>TM</sup>. McGregor and Roberts (2006) point out that SPeAR<sup>TM</sup> provides flexibility to customize the four main categories of assessment: environment, social, natural resources and economic, according to the stakeholders’ needs. The LEED<sup>TM</sup> rating system is more rigid and focuses mostly on the product (building) and distinguishes five categories for the credits: sustainable sites; water efficiency; energy and atmosphere; material and resources; and indoor environmental quality. There is an additional category for innovation and design process that provides some flexibility in the recognition of sustainability considerations (up to 4 credits for innovation out of a possible total of 69 credits). A project can achieve certification (26-32 points), or three levels of accomplishment: Silver (33-38 points), Gold (39-51 points) or Platinum (52-69). LEED<sup>TM</sup> has become a synonym of sustainability for many project stakeholders and a certain level of accomplishment (e.g., LEED<sup>TM</sup> Silver) is frequently considered a functional requirement for a facility (Schwarzenegger, 2004).

Practitioners have traditionally used all sorts of models to address their discipline-specific design needs (e.g., architects create scaled physical models of buildings to understand forms, spaces and materials; mechanical engineers create thermal/mathematical models of buildings to understand the energy dynamics associated with buildings, and so on). Designers can now quickly create and modify these models in a computer, therefore, the models become virtual. The Center for Integrated Facility Engineering (CIFE) has coined the term: Virtual Design and Construction (VDC) to refer to the use of multi-disciplinary performance models of design-construction projects. These models include the Product (i.e., building/facilities), Work Processes to deliver those facilities, and the Organization of the design-construction-operation to support the project business objectives. García et al (2003) explain that “the VDC approach defines project models as the composition of related models of Product, Organization and Process (POP)”. Developing and modeling the Product, Organization and Process consistently and concurrently contributes to the success of the project development (García et al, 2003; Levitt and Kunz, 2002). The VDC methodology relies on incremental creation and integration of POP project models at increasing levels of detail: after creating an initial model at a coarse level of detail, designers analyze the model for cost, schedule and functional risks; and then elaborate on selected segments of the model to elucidate and eventually mitigate potential risks to project success (as defined by the project functional requirements). A project owner is concerned about the SC of the product, but obtaining these SC requires management, which means that the appropriate organization and process need to be specified.

A sustainable project involves economic, environmental and social aspects, therefore a holistic approach to address these aspects is needed. POP models offer a balanced way to plan and document SC. We propose to use the POP model methodology to represent the SC of projects according to the most common categories identified by assessment methods and guidelines. We selected twelve recognized “green” buildings from the High Performance Buildings Database (HPBD) maintained by the Department of Energy (DOE) and that have been recognized as AIA/COTE Top Ten Green Projects for 2004 and 2005<sup>2</sup>. We picked six buildings that pursued LEED certification and six that did not. We then built a gPOP model with about 10 elements to represent the product, organization and process for each of the twelve high performance buildings. We compared the twelve gPOP models and documented the insights drawn from these representations of the SC. The following section describes how to create a gPOP model for the sustainable projects and shows how those models can be used by the design team.

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<sup>2</sup> A sustainability case study for each of the chosen buildings can be found at the following URLs:  
<http://www.aiatopten.org/hpb/results.cfm?search=rating&RatingID=60&RatingYear=2004> and  
<http://www.aiatopten.org/hpb/results.cfm?search=rating&RatingID=281&RatingYear=2005>.

### 3. HOW GPOP WORKS

In this section we explain how to build a gPOP model and how to calculate two simple, but useful metrics associated with a gPOP model. We then summarize our analysis and comparison of the SC of the projects using the gPOP models and their metrics. Finally, we explain why we created a gPOP model template that yielded a list of 36 of the most common sustainability considerations, and we discuss how to use this template to compare projects.

We built a gPOP model for each of the twelve green building projects selected from the HPBD to compare SC across projects. We then created a gPOP model template that normalized the varied wording used by design teams to refer to a similar concept, thus facilitating the project understanding for non-technical stakeholders. We analyzed the SC documented for each project, and particularly the SC described in the overview section of the project's case study. More details are usually provided in the remaining sections of the case studies (e.g., energy, materials, indoor environment, etc.). We focused our attention on the documented considerations that distinguish the building as sustainable and we classified such considerations as either: product, organization or process elements of the gPOP matrix. We then further refined the classification of the considerations as either: function (functional requirement), form (design team choice of solution to address the functional requirement needs) or behavior (predicted or observed performance of the product, organization or process). Therefore, a SC (or gPOP element) occupies a single cell of the gPOP matrix.

Since LEED<sup>TM</sup> is an important method to guide and assess SC in the U.S., we applied the gPOP method to the SC in the LEED<sup>TM</sup> rating system. We classified the LEED<sup>TM</sup> pre-requisites and credits into one of the nine POP-FFB categories based on the USGBC declared intent for them (mostly functional requirements in the gPOP context). There are 7 pre-requisites and a maximum of 69 credits, but only 65 credits can be classified into the POP-FFB categories, given that up to 4 credits can be earned for innovative/non-prescribed practices incorporated into the design. We found that 62 out of the 72 SC of the LEED<sup>TM</sup> rating system (65 credits plus 7 pre-requisites) focus on features of the building facility (product). There are 9 SC for the process and 1 for the organization. Therefore we conclude that a particular LEED<sup>TM</sup> achievement requirement is a product-function element in gPOP.

The following list shows examples of SC for each category of the gPOP matrix for the Lake View Terrace Library (LVTL) in Los Angeles, CA (Figure 1a) and explains the classification.

- *Product-Function.* The gPOP matrix shows that the stakeholders designed the LVTL to achieve a LEED<sup>TM</sup> Platinum level. Most of the SC of the LEED<sup>TM</sup> rating system refer to the building facility and its expected performance, this constitutes a functional requirement of the product.
- *Organization-Function.* The "Incorporate public review" SC in the Organization-Function category of the gPOP matrix describes a functional requirement of the organization responsible for delivering the project. This SC refers to the need of engaging the "public" in the sustainability discussion about the building.
- *Process-Function.* The "Minimize soil erosion from construction activities" SC in the Process-Function category of the gPOP matrix refers to the commitment of the design team to conduct the construction process in an environmentally friendly manner. It describes a functional requirement for the construction process.
- *Product-Form.* It constitutes the designers' choice of technology to address the project requirements. A typical example for this category is "Roof mounted PVs". This gPOP element represents the most common way of describing a sustainable facility by enumerating the technologies included in the design.
- *Organization-Form.* The "Third party commissioning agency" SC refers to an organizational actor chosen to participate in the project delivery process.
- *Process-Form.* It is the stakeholders' chosen approach to create a sustainable facility. The "Daily design meetings from the outset of the project" SC points to a work process that took place during the project to make the facility and its delivery process more sustainable.
- *Product-Behavior.* The "25% reduced stormwater runoff" SC refers to the predicted performance improvement of the building compared to a baseline, due to the chosen design alternatives (e.g., bioswales and restoration of soil using native plants in this case).
- *Organization-Behavior.* There is no SC in this category, but predictions or actual observations of organization related performance would populate this cell (e.g., predictions or observations of latency to respond to design inquiries requested by other designers).



- *Process-Behavior.* The “75% construction waste reduction (diverted to local recycling facilities)” SC is an observed behavior of the construction process. It constitutes a performance benchmark for the chosen construction process.

We classified each SC of the 12 projects into one of the gPOP categories to build each project’s gPOP model. We then grouped the twelve projects into two major categories: projects that pursued LEED™ certification and projects that did not, and we explored quantitative and qualitative uses for these gPOP models. The quantitative comparison of the gPOP models points to the number of SC in each POP-FFB category. We could then determine the minimum and maximum number of SC per category. However, we could also calculate the distribution of SC among the POP-FFB categories. We attempted to standardize the SC, so we created a list of the most common sustainability considerations (MCSC). The qualitative comparison is based on this list of the MCSC. We computed the frequency of appearance of the MCSC in the twelve projects and we identified commonalities and differences across the projects. Following we discuss the quantitative and qualitative analysis and comparison of the twelve gPOP models.

On the quantitative side, we counted and recorded the number of SC in each category of the gPOP matrix. We then calculated the total number of these gPOP elements per row and column of the gPOP matrix and finally we computed the total number of SC for the project. We defined a simple metric called the gPOP index as the ratio between the total number of gPOP elements divided by nine. The gPOP index represents the average number of SC per gPOP category. We realize that a single average number can not fully represent the complexity of the SC and that knowing where in the gPOP matrix the SC are contributes to the understanding of the sustainable nature of the project. We created a simple graphic that depicts the number of occurrences of SC for each cell of the gPOP matrix which we call the gPOP profile. This gPOP profile is a three-dimensional representation of the information contained in the gPOP matrix. Figures 1b and 1c show the gPOP index and the gPOP profile for the LVTL.

|          | PRODUCT                                                                                                    | ORGANIZATION                                                   | PROCESS                                                                                          |
|----------|------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| FUNCTION | 1 Located within walking distance of public transportation                                                 | 1 Incorporate public review                                    | 1 Integrated design process guided by energy modeling and frequent public review                 |
|          | 2 Designed to achieve LEED Platinum                                                                        | 2 Public and Staff: early included stakeholders                | 2 Workshop for public and staff to educate and collect information and ideas                     |
|          | 3 Demonstration project for future library projects in LA (expected higher unit cost)                      | 3                                                              | 3 During predesign and design high degree of interaction of architects and engineers             |
|          | 4                                                                                                          | 4                                                              | 4 LEED used as framework for sustainability achievement                                          |
|          | 5                                                                                                          | 5                                                              | 5 Community funds and third parties mandated to promote environmental stewardship                |
|          | 6                                                                                                          | 6                                                              | 6 Minimized soil erosion from construction activities.                                           |
|          | 7                                                                                                          | 7                                                              | 7 Look for synergies between environmental and client goals.                                     |
| FORM     | 1 Daylight dimming and occupancy sensors                                                                   | 1 Design team leader was a LEED AP                             | 1 Daily design meeting from outset of project                                                    |
|          | 2 Use of bioswales to control water runoff. Native plants restore habitat for wildlife (drought tolerant). | 2 Separate LEED AP for managing info about environmental goals | 2 Solar2 and Solar5 used for schematic energy models.                                            |
|          | 3 Local breezes are harvested by a passive cooling tower that conditions portions of the building.         | 3 Many consultants assisted design                             | 3 Commissioning extended to occupancy phase                                                      |
|          | 4 Water management system for optimization of irrigation system.                                           | 4 Third party commissioning agency                             | 4 LCQA used for ROI of several energy-efficiency measures                                        |
|          | 5 Skylights and photocells for daylight control.                                                           | 5                                                              | 5 2-weeks building flushout (for VOC)                                                            |
|          | 6 Roof mounted PVs                                                                                         | 6                                                              | 6 Early commitment to energy-simulation models (incremental refinement).                         |
|          | 7 Night flush for cooling                                                                                  | 7                                                              | 7 Commissioning started "before construction" to understand goals and expected deliverables.     |
|          | 8 Materials: Glu-laminated beams are FSC certified; concrete masonry (less finishes);                      | 8                                                              | 8                                                                                                |
|          | 9 Emphasis in local resources: 60% within 500 mi, 30% within 100 mi                                        | 9                                                              | 9                                                                                                |
| BEHAVIOR | 1 25% Reduced stormwater runoff                                                                            | 1                                                              | 1 75% construction waste reduction (diverted to local recycling facilities)                      |
|          | 2 34% less water than EPA 1992                                                                             | 2                                                              | 2 650k out of 4400k (15%) of funds brought to project from environmental interests (stewardship) |
|          | 3 40% more energy efficient than CA standards and 50% compared to ASHRAE 1989                              | 3                                                              | 3                                                                                                |
|          | 4 80% of building is naturally ventilated                                                                  | 4                                                              | 4                                                                                                |
|          | 5 PV's will provide 15% of electricity                                                                     | 5                                                              | 5                                                                                                |
|          | 6 93% of public areas in typical day are daylighted                                                        | 6                                                              | 6                                                                                                |
|          | 7 Achieved LEED Platinum (52/69) - SS11/14 - WE3/5 - EA15/17 - MR6/13 - IEQ12/15 - IDP5/5                  | 7                                                              | 7 (a)                                                                                            |
|          | 8 Fly ash replace 20% cement content.                                                                      | 8                                                              | 8                                                                                                |

Instances of gPOP components  
(default=10 elements)

| (b)      | Product | Organization | Process |    |            |
|----------|---------|--------------|---------|----|------------|
| Function | 3       | 2            | 7       | 12 |            |
| Form     | 9       | 4            | 7       | 20 |            |
| Behavior | 8       | 0            | 2       | 10 | gPOP index |
|          | 20      | 6            | 16      | 42 | 4.7        |

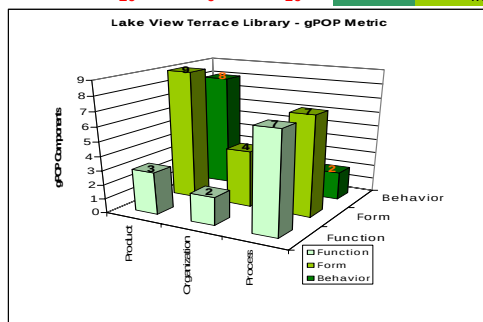


Figure 1. gPOP Model (a – top), gPOP index (b – bottom left) and gPOP profile (c – bottom right) for the Lake View Terrace Library project.

We compared the projects using the gPOP model, the gPOP index and the gPOP profile (see Table 1 and Figures 2a and 2b) and following we present the insights from this comparison:

1. From Table 1 we observe that the projects have the highest number of SC in the product-form category (average of 9), which corresponds mostly to a description of the sustainable technologies used to achieve

the buildings' high performance in areas such as energy, water conservation, harvesting of solar power, etc.

- The buildings we modeled do not have many organization-behavior SC (an average of fewer than 1). Almost none of the documented case studies record predicted or observed behaviors of the organizations that carried out the design and construction of the buildings.
- 64% of all the SC from our sample are related to the product (Table 1).
- 53% of the SC from our sample describe the form of either the Product, Organization or Process (e.g., technologies and building component used [product-form]; participants of the team [organization-form], tasks that made the project happen [process-form]).
- The organization SC were the least frequent (average of three instances) followed by the SC describing predicted or observed behaviors (average of six instances).
- The SC distribution among the POP categories was independent of the value of the gPOP index (see percentages columns in Table 1 and Figure 2b). The decreasing curves in Figure 2a –associated with the descending gPOP index value from left to right– became flatter in Figure 2b.

Table 1. Number of occurrences of SC per gPOP category and summary grouped per POP and FFB. The projects were arranged in descending order according to their gPOP index. The gPOP index column is calculated as the sum of the Product, Organization and Process columns divided by 9. Green shaded projects represent LEED™ projects.

| #                 | Project                                                                                  | LEED | Pr-Fn | Or-Fn | Ps-Fn | Pr-Fm | Or-Fm | Ps-Fm | Pr-Bh | Or-Bh | Ps-Bh | Product | %   | Org | %   | Process | %   | Function | %   | Form | %   | Behavior | %   | gPOP Index |
|-------------------|------------------------------------------------------------------------------------------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---------|-----|-----|-----|---------|-----|----------|-----|------|-----|----------|-----|------------|
| 1                 | Lake View Terrace Library (City of Los Angeles)                                          | y    | 3     | 2     | 7     | 9     | 4     | 7     | 8     | -     | 2     | 20      | 48% | 6   | 14% | 16      | 38% | 12       | 29% | 20   | 48% | 10       | 24% | 4.67       |
| 2                 | 20 River Terrace                                                                         | y    | 6     | 1     | 3     | 10    | 4     | 8     | 5     | -     | 2     | 21      | 54% | 5   | 13% | 13      | 33% | 10       | 26% | 22   | 56% | 7        | 18% | 4.33       |
| 3                 | The Plaza at PPL Center (Liberty Property Trust)                                         | y    | 4     | 1     | 2     | 10    | 3     | 5     | 10    | -     | -     | 24      | 69% | 4   | 11% | 7       | 20% | 7        | 20% | 18   | 51% | 10       | 29% | 3.89       |
| 4                 | Pittsburgh Glass Center - AIA 2005                                                       |      | 1     | 1     | 2     | 10    | 2     | 10    | 5     | 2     | 2     | 16      | 46% | 5   | 14% | 14      | 40% | 4        | 11% | 22   | 63% | 9        | 26% | 3.89       |
|                   | Woods Hole Research Center (Woods Hole Research Center)                                  |      | 7     | -     | 4     | 10    | 2     | 1     | 4     | -     | 1     | 21      | 72% | 2   | 7%  | 6       | 21% | 11       | 38% | 13   | 45% | 5        | 17% | 3.22       |
| 6                 | City of White Rock Operations Building                                                   | y    | 4     | -     | 2     | 10    | 2     | 4     | 4     | -     | 2     | 18      | 64% | 2   | 7%  | 8       | 29% | 6        | 21% | 16   | 57% | 6        | 21% | 3.11       |
| 7                 | Genzyme Center                                                                           | y    | 5     | 2     | 2     | 10    | 1     | 2     | 5     | -     | -     | 20      | 74% | 3   | 11% | 4       | 15% | 9        | 33% | 13   | 48% | 5        | 19% | 3.00       |
| 8                 | Eastern Sierra House - AIA 2005                                                          |      | 7     | -     | 2     | 10    | 1     | 4     | 2     | 1     | -     | 19      | 70% | 2   | 7%  | 6       | 22% | 9        | 33% | 15   | 56% | 3        | 11% | 3.00       |
| 9                 | Herman Miller MarketPlace (The Granger Group)                                            | y    | 5     | 1     | 5     | 6     | 1     | 2     | 3     | -     | -     | 14      | 61% | 2   | 9%  | 7       | 30% | 11       | 48% | 9    | 39% | 3        | 13% | 2.56       |
| 10                | Factor 10 House (F10)                                                                    |      | 4     | 1     | 1     | 10    | -     | 2     | 2     | -     | -     | 16      | 80% | 1   | 5%  | 3       | 15% | 6        | 30% | 12   | 60% | 2        | 10% | 2.22       |
| 11                | Greyston Bakery (Greyston Foundation)                                                    |      | 6     | 1     | 2     | 8     | -     | -     | 2     | -     | 1     | 16      | 80% | 1   | 5%  | 3       | 15% | 9        | 45% | 8    | 40% | 3        | 15% | 2.22       |
|                   | Pierce County Environmental Services Building (Pierce County Public Works and Utilities) |      | -     | 1     | 2     | 9     | 1     | 4     | 2     | -     | 1     | 11      | 55% | 2   | 10% | 7       | 35% | 3        | 15% | 14   | 70% | 3        | 15% | 2.22       |
| AVERAGE           |                                                                                          |      | 4     | 1     | 3     | 9     | 2     | 4     | 4     | 0     | 1     | 18      | 64% | 3   | 10% | 8       | 26% | 8        | 29% | 15   | 53% | 6        | 18% | 3.19       |
| LEED Projects     |                                                                                          |      | 5     | 1     | 4     | 9     | 3     | 5     | 6     | -     | 1     | 20      | 62% | 4   | 11% | 9       | 28% | 9        | 29% | 16   | 50% | 7        | 21% | 3.59       |
| NON-LEED Projects |                                                                                          |      | 4     | 1     | 2     | 10    | 1     | 4     | 3     | 1     | 1     | 17      | 67% | 2   | 8%  | 7       | 25% | 7        | 29% | 14   | 56% | 4        | 16% | 2.94       |

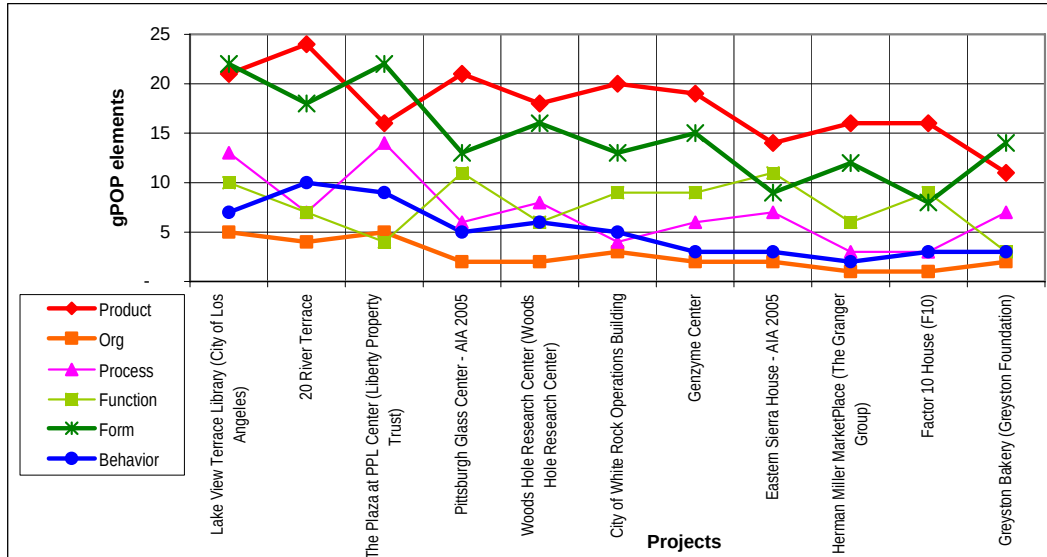


Figure 2a. SC per category for each project. The figure shows a set of decreasing curves, given that the projects were ordered by decreasing gPOP index, which is a proxy for the number of SC in the project.

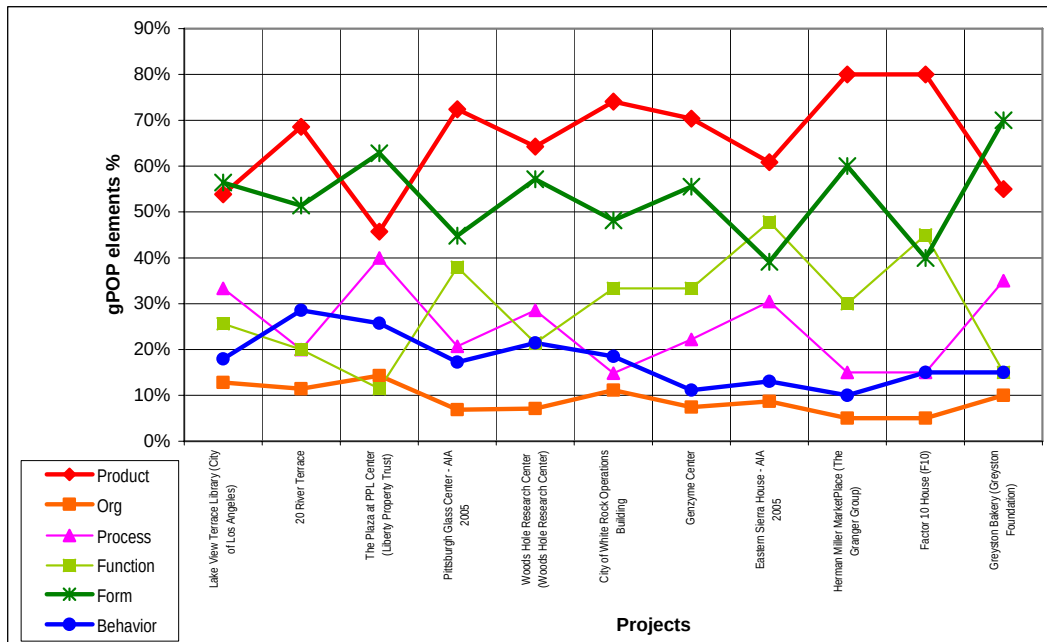


Figure 2b. Sustainability considerations per category for each project - Percentages. Each column shows the percentage of gPOP elements or SC for each POP-FFB category compared with the total number gPOP elements. The figure in this case shows that the curves are flat when we consider percentages, indicating that regardless of the value of the gPOP index, the distribution of SC among the POP-FFB categories remains constant (relatively flat curves) for the twelve projects studied.

Observations three to five are also evident when studying Figures 2a and 2b, where the thicker top lines (product and form) and thicker bottom lines (organization and behavior) depict the number of instances of gPOP elements for each of the twelve projects of our study.

On the qualitative side, we identified the SC that appear most frequently for each category of the gPOP matrix. We tried to describe each of the most common sustainability considerations (MCSC) as broadly as possible to avoid characterizations applicable only to a particular project. For example, in Figure 3, the first SC from the product-function category (“Achieve a given (or max/min) environmental performance target”) can include goal setting for either energy consumption, water consumption or both. If both of these performance targets are mentioned in the documented case study for a particular project, they both will appear in the respective gPOP model, but they are counted just once. The shades of purple in Figure 3 correspond to product SC (function, form and behavior in descending order); the shades of red correspond to organization SC (note that we did not find explicit mention of organization behaviors as pointed out earlier); and the shades of blue correspond to process SC.

It is interesting to note that despite the disparity in terms of frequency for product, organization and process SC, there is one SC for each form category among the considerations with the highest frequency of appearance:

- *Product-Form (10 instances)* – In general, most of the documented cases address the topic of construction materials as an important element to achieve a sustainable building (10 out of 12), by either incorporating high recycled content materials, reusing materials (e.g., lumber, wood siding, etc.) or using innovative sustainable materials (e.g., sustainable harvested lumber materials, low VOC emitting interior finishes, etc.).
- *Organization-Form and Process-Form (9 instances each)* – There is a recognition of the importance of commissioning [process-form] to ensure that the building will perform as designed and that the organization best suited to perform this job is an independent commissioning entity [organization-form] hired directly by the owner. We should point out that a significant percentage of our sample (6 projects or 50%) pursued LEED™ certification and several others used the LEED™ system as a guideline for sustainable design, which could explain the high frequency of commissioning (both organization and process form) as it constitutes a prerequisite for LEED™ certification (i.e., it is an unavoidable requirement for buildings pursuing certification).

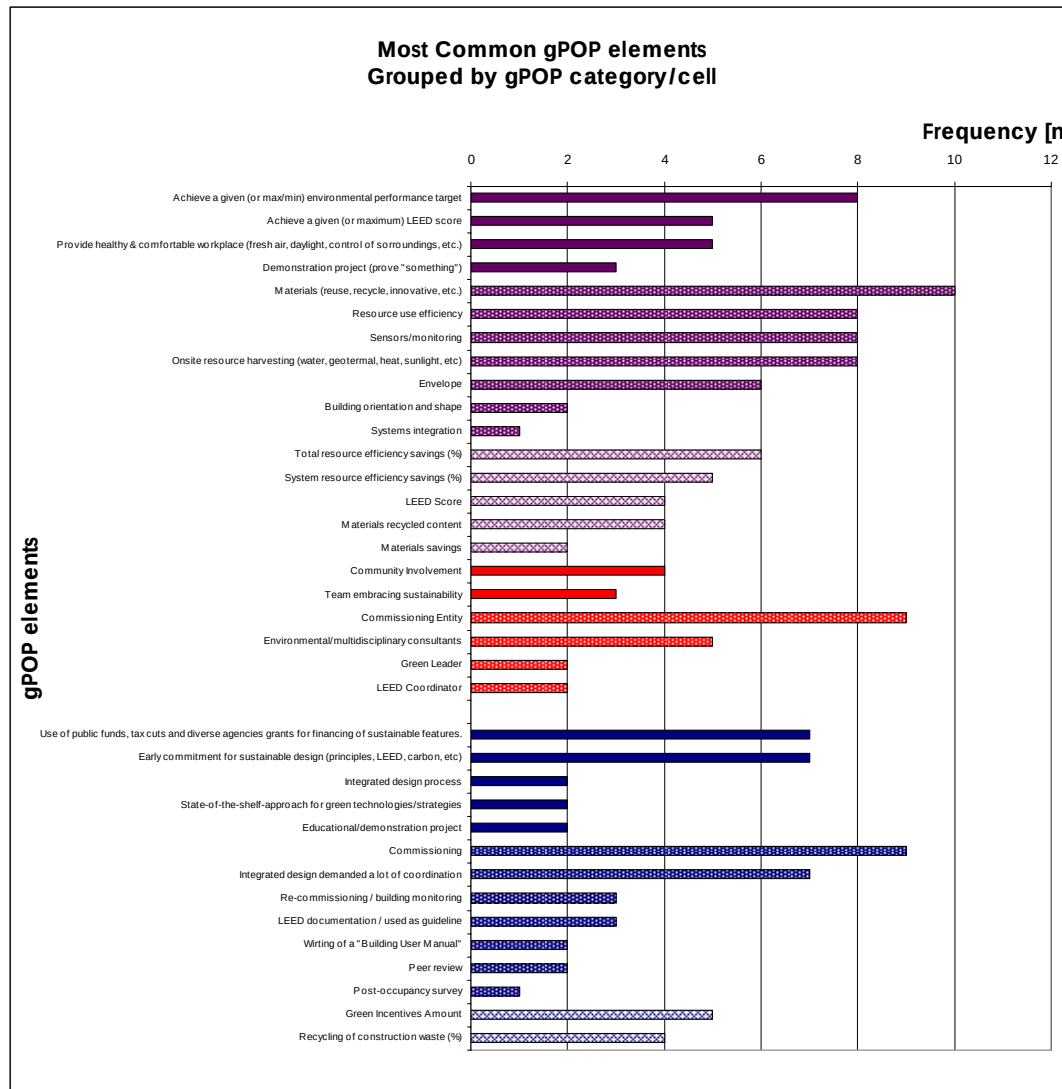


Figure 3. MCSC grouped by gPOP category. Shades of purple distinguish the product considerations, while shades of red indicate organizational considerations, and shades of blue indicate process considerations of the gPOP model. Within each set of shades of a color (purple, red, or blue) the function, form and behavior elements are arranged from top to bottom (solid, dotted and hatched, respectively). The gap after the red shades indicates that there are no organization-behavior elements.

Another observation from Figure 3 is that 8 out of the 12 building projects (67%) documented a functional requirement that explicitly requests pursuing a performance based sustainable design [product-function], i.e., they either sought a maximization of resource savings, a minimization of consumption of resources or they set a given target goal (e.g., reduce energy consumption by 50% compared to ASHRAE standards). It is interesting to note that there is consistency between the product-function just mentioned and the fact that 8 out of the 12 buildings documented resource use efficiency measures or strategies [product-form] to address the performance requirements just mentioned. The resource use balance includes both the demand and supply of resources. Many of the strategies (forms) have focused on lowering the demand side of the equation by using

more efficient systems and/or equipment, but there is also a significant number of buildings (8 out of the 12) that explore the supply side of the resource use balance, with technologies devoted to “onsite harvesting” of resources, such as wind or solar (for electricity production and/or heat); storm water management that can provide water for irrigation and other non-potable uses (e.g., flushing toilets); greywater recovery (for non-potable uses); heat recovery from water, waste or from other processes, etc. In general, efficiency comes first (is the cheapest way to lower net consumption of resources), but the use of financial incentives and special programs has made it economically attractive to explore the onsite harvesting of resources and, for example, photovoltaic arrays have become a common sustainable feature (although the percentage of total electricity supplied by these arrays varies widely from about 5% to 33%).

A final qualitative observation points to the use of public funds, tax cuts, grants from diverse agencies and other programs that stimulate the advancement of high performance buildings for partially funding the first cost premiums usually associated with delivering a sustainable facility. This is a remarkable common SC that sometimes constitutes a significant portion of the cost of the building. It is not uncommon that 10% or more of the total construction cost is covered by these sources of funding (e.g., 75% of construction cost was provided by this type of funds for the City of White Rock Operations Building; the Greyston Bakery was entirely funded by site remediation and passive energy design grants; 15% of the cost of the Lake View Terrace Library was covered by stewardship funds; and 12% of the construction cost for the Woods Hole Research Center came from grants promoting sustainable construction). This kind of funds was also used on other projects (e.g., 20 River Terrace and Genzyme Center), but with a lower relative contribution to the total construction cost.

#### 4. DISCUSSION

The list with the MCSC is an attempt of standardizing the creation of gPOP models that allowed us to compare sustainable projects beyond the enumeration of green features included in the design. The representation of the SC using the gPOP models template helped us to uncover some hidden insights about the sustainability project delivery process that are described next. We conclude this article suggesting future research directions for gPOP models.

gPOP Models Comparison Insights. There are no big differences among the gPOP models of projects pursuing LEED™ certification and the NON-LEED™ projects, with the exception of a larger number of process-function, organization-form and especially product-behavior considerations for projects seeking LEED™ certification (Table 1). Therefore, our sample of buildings shows that following the LEED™ certification process means: better defined process-related functional objectives; more sustainability-related organizational forms; and a larger number of product-related behaviors when compared to projects not pursuing LEED™. The only relevant difference in Table 1 between LEED™ and NON-LEED™ projects is in the last column: the gPOP index. On average, LEED™ projects have a larger number of SC than NON-LEED™ projects (a gPOP index of 3.6 versus 2.9 respectively). We could interpret this gPOP index variance as a sign that the rigor imposed by the compliance with the many LEED™ pre-requisites and credits forced the design team to explicitly address more sustainable considerations.

MCSC insights. From the list shown in Figure 3 we were surprised to discover that there is an explicit acknowledgement (documented on the HPBD) of the use of LEED™ documentation as a guideline to achieve a sustainable outcome for only three instances, although 6 of the 12 projects in our sample pursued LEED™ certification. This could mean that either the design and construction of the facility was guided and organized by self-developed standards or documents other than those provided by the USGBC for certification purposes (which would rule out a “LEED™ point collection” approach to sustainability), or this could also mean that the parties involved did not report explicitly the use of the LEED™ guidelines – a more likely scenario, we think. Likewise, although all the projects in the sample are recognized sustainable buildings, only in three instances is there documented evidence (in the HPBD) that the design/construction team had committed itself to embrace sustainability as a central part of the project delivery process.

At the *function* level, the most common SC we observed are related to the pursuit of environmental performance targets [product-function] and the early commitment to a sustainable design process [process-function]. The use of funds designed to promote sustainable buildings to cover a significant portion of the

construction cost (7 out of the 12 projects) speaks to the importance of such incentives to either cover the additional design expenses associated with the high performance buildings (to cover for instance early engagement of stakeholders or additional consultants, etc.) and/or pay for the first cost premiums of some of the technologies such as control and monitoring systems.

At the *form* level, the most common SC that we observed relate to the sustainable strategies selected to achieve the high performance goals (product) either by addressing resource efficiency (demand) and/or by providing onsite harvesting of resources (supply). The most common organization and process form SC are related with commissioning the building to ensure that it performs as designed (hiring of a commissioning entity and design and implementation of the commissioning tasks). There is also a significant recognition that sustainable design is a very integrated process [process-form] with a resulting highly integrated product-form (i.e., the building itself).

At the *behavior* level, the most common SC that we observed are those that provide a prediction or actual figures for the functional requirements established by the design team. Examples of these behaviors are LEED™ scores or expected energy savings [product-behavior] and percentage of recycled construction waste or amount of funding coming from green incentive programs [process-behavior].

#### Future Steps

A natural extension of our work can include the creation of a comprehensive database of the MCSC. Every additional gPOP model we build can potentially add new SC that are added to the MCSC database. This process should be repeated until saturation is achieved (new projects and their gPOP models do not add new MCSC). A comprehensive database of MCSC might help to standardize and ease the creation of gPOP models and to facilitate cross-project comparisons.

The gPOP profile enabled us to see the “imbalance” of gPOP models in terms of number of SC per gPOP category (POP/FFB). Severe gPOP imbalance might constitute a red flag that jeopardizes the sustainable outcome of a project and deserves the design team’s attention. Therefore, we suggest further exploration of the concept of “(im)balance” in the gPOP models and its impact in the sustainable outcome of a project.

In this research, we used gPOP models to study already built sustainable buildings (retrospective analysis). However, according to Paulson (1976), the earliest the design changes occur during the project lifecycle, the largest the potential for design improvements at a relative low cost. For this reason, we think it is interesting to explore the use of gPOP models to compare different alternatives of SC being studied during the early phases of a project. Additionally, the incorporation of SC from a standardized database of the MCSC; and the analysis of (im)balance in the early-project-phase gPOP models could help designers/builders to improve the design and deliver a better [sustainable] facility. Haymaker et al (2006) and Toledo et al (2006) document an exploratory research that includes the use of POP models prospectively in early phases of design, which is a step in the suggested direction.

#### **5. ACKNOWLEDGEMENTS**

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### **Generic Process Template Description for the Effect of Risks on Project Schedule**

Raimar J.Scherer<sup>3</sup>, Wael Sharmak<sup>4</sup>

#### **ABSTRACT**

Many factors impact construction projects and cause changes in the project management plans. These factors can be considered as risks which are impossible to be identified completely in early project stages. Therefore, risk management in construction requires proactive as well as reactive procedures. Risk treatment, among the other risk management subprocesses, has the concrete change action which may modify one or more of the project management plans. In this paper, process modeling techniques are used to describe risk treatment effect on the structure of the project schedule plan. This structural change description is introduced as formalized configurable treatment templates. According to our findings seven generalized templates are efficient to represent the risk part in project reference models concerning process changes which in turn can be tailored and assembled to form up-to-date schedule plans. This kind of risk representation in reference repository will serve as means of knowledge management by providing all risk-related available information as response to a critical event. The Event-driven process Chains (EPC) will be used to model risk treatment templates using normal and configurable EPC elements.

#### **KEY WORDS**

Process Modeling, Risk Treatment, Configuration, EPC.

#### **1. INTRODUCTION**

In the construction industry no project ever goes totally as planned, because of the effect of some unforeseen risks which are often beyond anyone control. Risks may occur suddenly and consequently will cause problems after a project task execution is started. As a consequence of a risk, changes may occur in the project cost estimate, schedule baseline, or recourse requirements and hence task rework may be needed. This may result in project delay, in critical or near-critical activity-cases, and project cost overrun. Therefore, it is required to readjusting the project management plan (schedule, cost, procurement, resources, risk etc) according to the new situation. The changes in the project plan can be caused by external or internal factors. External factors are such as technological changes, government and policies, or customer's expectations and preferences. Internal factors are like, management policy, or organizational objectives (Sun et al 2006) and (Gehbauer et al 2007). Particularly, construction-driven risks such as soil and ground conditions and possible accidents are difficult to assess. Moreover, maybe also sever design-driven risks such like design changes that result from changes in owner requirement as well as design errors induced by short design times and the uniqueness and complexity of the products. These risks are often recognized at a later stage of the project and often require considerable redesign and rework.

In this paper, only the change effect of these risks on the schedule plan will be discussed using process modeling techniques as risk treatment templates. The focus on risk treatment process and not on the total risk management cycle comes from the fact that concrete change action of the risk management is done only by executing risk treatment plans. Event-driven process Chains (EPC) method will be used to develop risk treatment templates as configurable scenarios, which can be configured to show the most likely, optimistic, or pessimistic cases, and therefore can be utilized in virtual or actual situations. This paper is structured as follows. Firstly, we will start with a general overview about risk management with deeper look at the risk treatment process. Secondly, the principles of the used modeling method "EPC" will be explained in its two parts; the normal and configurable one, and the reason behind choosing this method to model schedule change risks will be presented. Thirdly, the suggested treatment templates will be introduced with brief explanation about the usage of each one of them. Finally, the paper will be concluded and further work steps will be mentioned.

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## 2. RISK TREATMENT IN AEC

According to the established risk management standards (AS/NZS 4360, 1999 - PMBOK Guide, 2004), any risk management typically includes a series of the following tasks: (1) identification, (2) assessment, (3) treatment planning, (4) treatment, (5) monitoring, and (6) documentation.

Risk treatment is assumed in this work to be consisted of two parts; proactive and reactive treatment, figure 1 shows the two cycles of proactive and reactive risk management. Proactive treatment is the traditional known type within risk management in which only anticipated high probability/impact risks, according to the agreed thresholds, are treated by executing the planned treatment strategies. This is typically done before execution starts or at least before the risk evolves to a real problem and affects the targeted activities. However, another type of risk treatment, reactive treatment, obtains increasing attention in construction industry because of the following reasons:

1. It is impossible to identify all potential risks in advance. As it is inevitable that some risks often arise as a result of completely unpredictable events, e.g. human errors, even if all proactive risk identification techniques have been applied.
2. Even if a risk is identified, it can be for some reason underestimated during preliminary assessment, e.g. because of lack of reliable information and therefore was excluded from the proactive risk treatment group.
3. In addition, there is a tendency in the construction industry to leave probable risks and react to them when they have occurred, rather than dealing with them in advance, see (Loosemore et al 2006).

Therefore, there is a need to react effectively and efficiently to these risks using appropriate reactive treatment procedures.

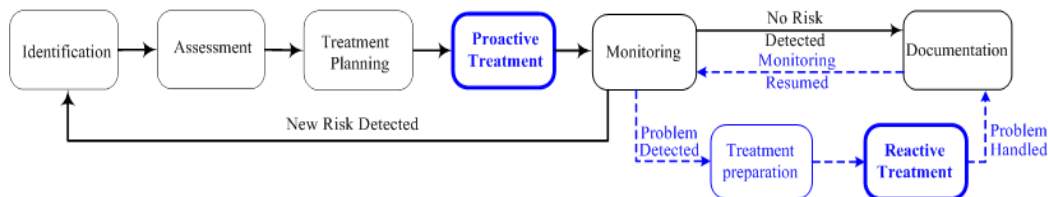


Figure1: Proactive and reactive treatment cycles within RM process.

In accordance with the reactive/proactive treatment types, the following ways of change in the project schedule can be realized:

- 1- The project schedule baseline will not change, but some changes may be needed in the resource plan, or the cost plan, e.g. in the case of cost overruns caused by higher material costs than what was estimated before.
- 2- Changes in the project plan are done as proactive treatment, i.e. before a risk evolves to a real problem. This kind of changes most probably happens in the pre-construction phase and it may be done for example by adopting new construction methods to avoid falling in risks. In the case of proactive treatment planned within the preconstruction phase, counteractions are included as a part of schedule baseline before the construction starts, resources are respectively assigned to execute these measures. Another example of proactive treatment is by incorporating additional time as contingency reserve into the overall project schedule as recognition of schedule risks.
- 3- Changes in the activity-sequence of the schedule plan must be done in a dynamic way to represent the undertaken countermeasures and to detect their effects on planned interrelated activities. More than one planned activity may suffer from different changes as a response to one risk, e.g. canceling, substituting, or even inclusion of an activity may need to be followed by recourses leveling for the successor logically-dependent activities to keep the deadline of the contract.

## 3. EVENT-DRIVEN PROCESS CHAINS (EPC)

EPC is a method developed within the frame of Architecture of Integrated Information Systems (ARIS) (Keller et al. 1991), to model business processes. It is a graphic modeling language and its visual notation

consists mainly of Events, Functions, logical connectors, and control flow. EPC describes business processes by creating a chronological sequence of events, functions and their logical interdependencies using logical connectors.

### 3.1 NORMAL EPC

Functions in EPC represent activities to be executed. Each function can be refined into another EPC and it is called in this case a hierarchical function. A function is represented as a rounded rectangle (see figure 2). While events are the passive elements in EPC, i.e. no decision is made using an event as it describes only the pre-state or the post-state of a function. Events are represented in the EPC process model as a hexagon. A control flow is an arrow connecting events, functions, and connectors with each other creating chronological sequence between them. Connectors in EPC show the logical relationships between the elements (function-event, event-function). A connector may split the control flow to more than one path, or join more than one path in one control flow. These types of connectors are, AND connectors, Inclusive OR connectors, Exclusive OR (XOR) connectors.

There are some roles controls the usage of EPC to represent a process model and guide its design, like:

- 1- Because EPC is an event-driven modeling method, it has no function-function or event-event connections since each function follows a generating event and in the same time it is followed by a generated event.
- 2- Only connectors are allowed to branch, nor events neither functions.
- 3- Split connector of type (Event-to-Function) cannot be of type "XOR" or "OR", because the event is a passive element which means that the event cannot be used to make decisions. It can be used only to trigger parallel activities using AND connector.
- 4- Logical connector should match, which means that an opening XOR serving as a branch should be closed by another XOR connector. The same rule applies to fork/join using AND connector and OR connector.

Event-driven Process Chains method is chosen in this work to model risk treatment effect on the project schedule plan because EPC can support some special features, which are very suited to this issue:

- 1- As its name indicates, it is an event-driven method used to model business processes. This makes it suitable to represent risks as "deviation or problem" events in the process model and to show treatment as a response activity to the risk event. Such kind of representation is not possible in normal project scheduling methods.
- 2- EPC method supports configurable modeling, as it has some specification to represent configurable elements within the developed process model. Configurable modeling can be beneficially applied in risk treatment modeling, because risks are uncertain events which may occur and may not, so it will be wrong and will not reflect the actual reality of a risk and countermeasures to be modeled as normal elements. So the assumed best solution here is to represent risk and treatment measures as configurable part in the model which can be configured as adopted "normal" elements in case of risk occurrence and can be skipped in normal situations.
- 3- EPC was introduced as a modeling concept to represent temporal and logical dependencies in business processes (Keller et al. 1991). Therefore, EPC can be seen as a Precedence Diagram Method (PDM) with some advantages due to suiting IT requirements, databases etc. In addition to it can be extended, i.e. using extended EPC (Scheer 2000), to include resource limitations for each activity.

### 3.2 CONFIGURABLE EVENT-DRIVEN PROCESS CHAINS (C-EPC)

Configurable EPC extends regular EPC to allow for the specification of configuration connectors and configuration functions in process models. In this extension of normal EPC, configuration elements have been identified to highlight distinguishable configuration alternatives. These elements can be classified in the following types:

- 1) Configurable functions: A configurable function may be included (ON), skipped (OFF) or conditionally skipped (OPT). It is represented as grey highlighted rectangle with bold border, see figure 2.
- 2) Configurable connectors: A configurable connector may only be mapped to a connector type that restricts its behavior (Rosemann & van der Aalst 2003). C-OR connector for example can be configured to normal OR, normal XOR, normal AND, or mapped to a single sequence of events and functions (SEQ). All configuration constraints for the configurable connectors are summarized in table (1).

|                  | OR | XOR | AND | SEQ |
|------------------|----|-----|-----|-----|
| OR <sup>C</sup>  | X  | X   | X   | X   |
| XOR <sup>C</sup> |    | X   |     | X   |
| AND <sup>C</sup> |    |     | X   |     |

Table. 1: Constraints for the configuration of connectors (after Mendling et al. 2005)

- 3) Sequence relationships: The sequence relationships connect variation points with either mandatory rules (Configuration requirements) or optional rules (configuration guidelines) to facilitate the configuration of the model. They are defined via logical expressions in the form of if-then statements.

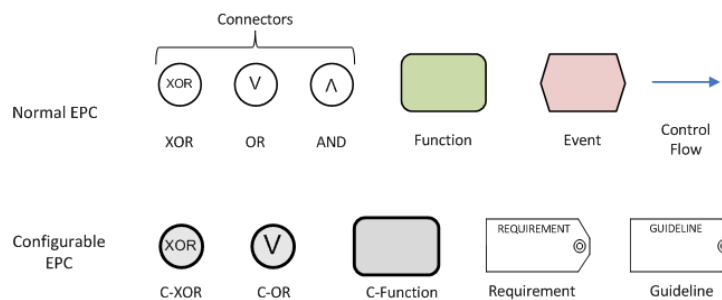


Figure2: Normal and configurable EPC elements

#### 4. CONFIGURABLE RISK TREATMENT TEMPLATES

Our hypothesis is that all possible ways of schedule change as a response to probable/actual risks can be standardized by generalized risk treatment templates. Seven treatment templates are suggested in this work. A template can be identified as a case-oriented configurable process model which describes the possible risk-related scenarios as configured process models. Only one of these scenarios will be used to represent the actual or virtual structural change in the schedule plan caused by a specific risk event. Risk treatment templates are classified in two main groups, proactive and reactive risk treatment templates. If-then statements are used as requirements to control the configuration alternatives. In these statements the used expression RISK=ON means that the specific risk parameters has exceeded the agreed threshold in the proactive treatment cases. In reactive treatment it means that the risk has evolved to a real problem and the required change has been approved. RISK=OFF indicates the opposite. In these templates also treating each risk requires a function named "treatment". This function as hierarchical one can be refined into another EPC, which shows the details of the needed actions to handle the specific risk-task case. Risk treatment can affect, directly or indirectly, multiple logically-related tasks. After the problem in the affected task is treated, other problems may come to surface as indirect effect of the last treatment and in turn needs to be handled, e.g. durations and dates readjusting or resources leveling, this is not considered in our work. Anyhow, the treatment of a task can show which and how the parameters in the dependent tasks will change and according to this individual and sequential treatments may be carried out to keep the project plan within the imposed constraints.

##### 4.1 PROACTIVE RISK TREATMENT TEMPLATES

We have identified four different templates for proactive and three for reactive risk treatment, which are described in the following:

###### 4.1.1 INSERTION CASE

In the insertion template, see figure (3-1), the treatment is done before the risk evolves to a real problem, i.e. at least before the affected function (n) starts. When it is obvious that the risk event has a considerable probability/impact on the targeted activities according to the agreed tolerance thresholds, then the treatment

function will be included in the schedule plan. When the decision will be made to treat the risk event in advance in a proactive way, the needed resources will be assigned to execute the proactive treatment tasks and its needed cost and time will be considered in the general project cost and schedule. Some proactive treatment measures will already be done before the execution will start, i.e. in the planning phase of the project by avoiding or transferring the expected risks and consequently the countermeasures will not appear in the project plan.

#### 4.1.2 SUBSTITUTION CASE

Assume that an identified risk is considered not a threat to the project objectives, because the assessment showed that its probability of occurrence is below the thresholds. After construction started and according to more reliable information, the risk has been found to be more dangerous than it was expected. As a countermeasure to the expected danger, certain activities may need to be substituted with other activities which are more suited to the new situation. Also it can be the case when a new risk not identified before, appears to the surface and according to the study of the characteristics of this risk it was found that the substitution of some present activities with more suitable activities will be the best solution. In this template shown in figure (3-2), function (n) is substituted with function (m) to eliminate/avoid/mitigate the highly expected high risk impact. This alternative function, function (m), was not preferred in normal cases because of, e.g. its higher cost, its longer duration, or may be because it is technically more complicated to be executed.

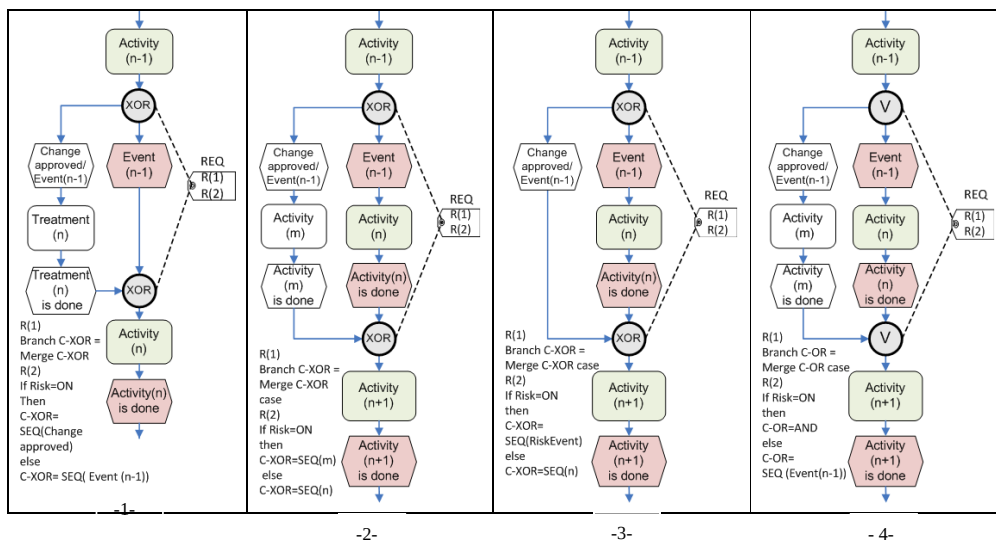


Figure 3: Proactive risk treatment templates

#### 4.1.3 CANCELATION CASE

The cancellation template, figure (3-3) can be used for example (1) in the case when a threat becomes highly expected, and some changes must be done as a proactive response to the coming danger by canceling some planned tasks and adding other new tasks somewhere else in the project plan, so at first the cancellation template will be used and after that the insertion template. Also (2) it can be used in the case when some tasks are planned to handle an expected risk case, and after the execution started more reliable information were obtained indicating that the risk is not anymore to be considered as a threat, and hence these planned tasks can be canceled.

#### 4.1.4 PARALLELISM CASE

In the parallelism template shown in figure 3, the needed activities to treat anticipated risk will be undertaken in parallel with some planned functions, in this case a configurable OR is used and an If-Then requirement

will limit its configured scenarios to two models only: (1) AND in case of parallelism, (2) normal sequence in the normal situation, i.e. when RISK= OFF.

#### 4.2 REACTIVE RISK TREATMENT TEMPLATES

In the three reactive templates, risk event will interrupt and stop “temporarily” the execution of a function. This risk event was (1) not expected and therefore not prepared against before, e.g. very bad weather or supply delay, or (2) it was thought to be within the accepted thresholds but its real effect was much bigger than what was expected, also (3) it happened suddenly hence was not handled in proactive way such as human errors.

In these templates three important elements appear:

1. The risk event: in reactive treatment, risk will appear in the model as interruptive event which will be located between the interrupted function and its finishing indicator event.
2. Treatment preparation function: it is impossible to start the treatment immediately after the risk occurrence, as some intermediate measures may be needed, such as problem analysis, treatment planning and/or decision making. The needed preparation measures may differ from case to case according to different factors, for instance staff experience and risk characteristics.
3. Resuming function: in all reactive templates the function is interrupted, which means that it will be stopped temporarily, this function need to be resumed after the risk is treated. The resumption appears as a function called “Function Resuming” which will be located directly before the function finishing indicator event. The interruption concept adopted in this work is explained in Figure 4. Assume that function B is interrupted; this function can be refined as a hierarchical function to some atomic functions. The interruption may be assumed to occur between two atomic functions and not in any one of them. All the atomic functions before the interruption can be merged in one “pre-risk” function. The functions after the interruption can be merged in a “post-risk” function, which is represented as “Function Resuming”. The risk event and the following treatment action will be located between the pre- and post-risk function parts. In our developed templates the pre-risk function will inherit the name of the interrupted function.

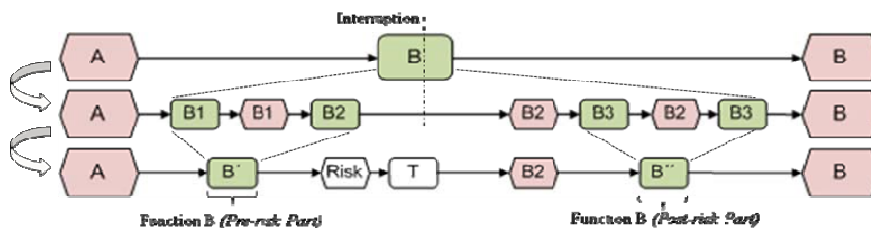


Figure 4: Interpretation of Function interruption in EPC.

##### 4.2.1 TREATMENT TEMPLATE

Risk (1n) in figure (5-1) was not expected before or it was thought that its probability/impact will be within the accepted thresholds. But risk (1n) evolved to a real problem and interrupted Function (n). Therefore Treatment (1n) is needed to handle the risk, after Function (n) can be resumed. As the risk occurred, the configurable XOR connector will be mapped to a sequence of events and functions containing (1) the risk event, (2) treatment preparation function, (3) the treatment function and the (4) Function resuming. Otherwise the configurable connector will be mapped to a sequence from the function to its finishing indicator function without encountering any disturbance.

##### 4.2.2 TREATMENT TEMPLATE

Stop template, shown in figure (5-2), is a special case of the treatment template. It represents the negative reaction to the risk, the risk event will delay the function execution and nothing can be done except waiting until the risk bad effect will be finished, e.g. the case of unexpected very bad weather or natural hazard which will stop the work in the outdoor activities until the conditions become better.

#### 4.2.3 PARALLEL ACTIVITIES CASE

In the case a risk will interrupt some parallel tasks. All affected parallel paths will need to be merged in one path, on which the treatment of this risk will take place. After the treatment is done the risk effect is finished. The path can be splitted again to the same old paths and the interrupted tasks will be resumed and after that the successor planned tasks will be executed in parallel as planned, see figure (5-3).

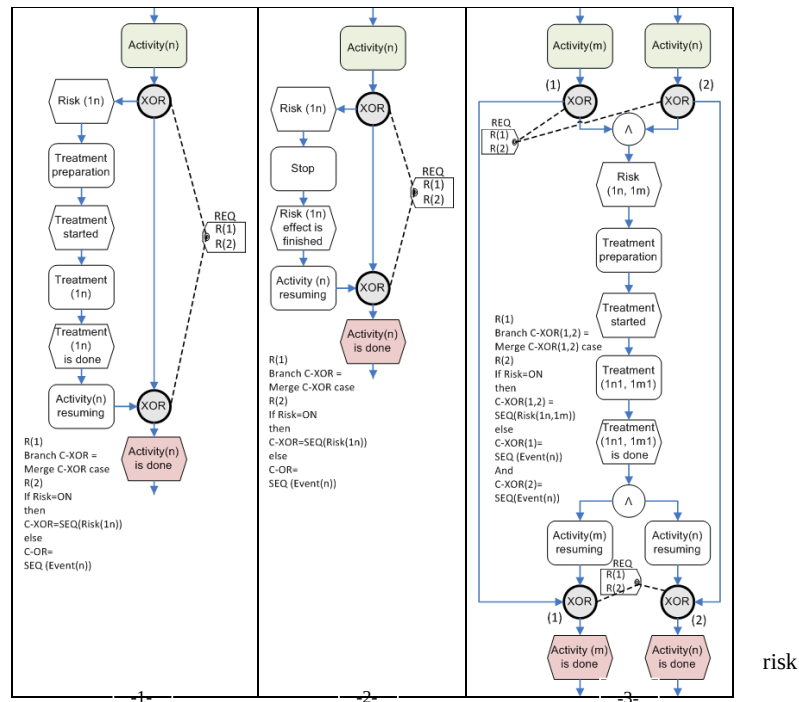


Figure 5: Interruptive treatment template

#### 4.3 CONFIGURATION EXAMPLE

In figure 7, the configurable model shows that the Function (n) may be interrupted by risk (1n) two treatment methods (T, T2) are available to handle this risk. Therefore, decision making is needed to choose the most suitable case for the situation at hand. Configuration alternatives are controlled by logic statements. The first requirement R (1) insures that the merge C-XOR has the same case like the branch C-XOR case. Consequently no deadlock will occur in the process model. R (2) limits the possible configuration alternatives in the C-XOR connector to the only needed cases, here only the sequence cases, and determines which configured state is needed in which condition. The third requirement R (3) represents a second level of configuration, as it will control that only one treatment action from multi-possible methods will be chosen. In the first illustrated configured model risk did not occur, i.e. Risk=ON is false. Therefore the empty sequence path will be chosen as value for the C-XOR, which means that the function will be executed without any disturbance. In the second configured model the first level of configuration is adapted as RISK=ON is true and risk event appears after the function in the model. This means that Risk (1n) sequence path is chosen as a value for the C-XOR connector. In the third configured model the decision was made to approve the method (2) to treat the risk by adopting C-XOR value equal to SEQ (T2) as T2=True.



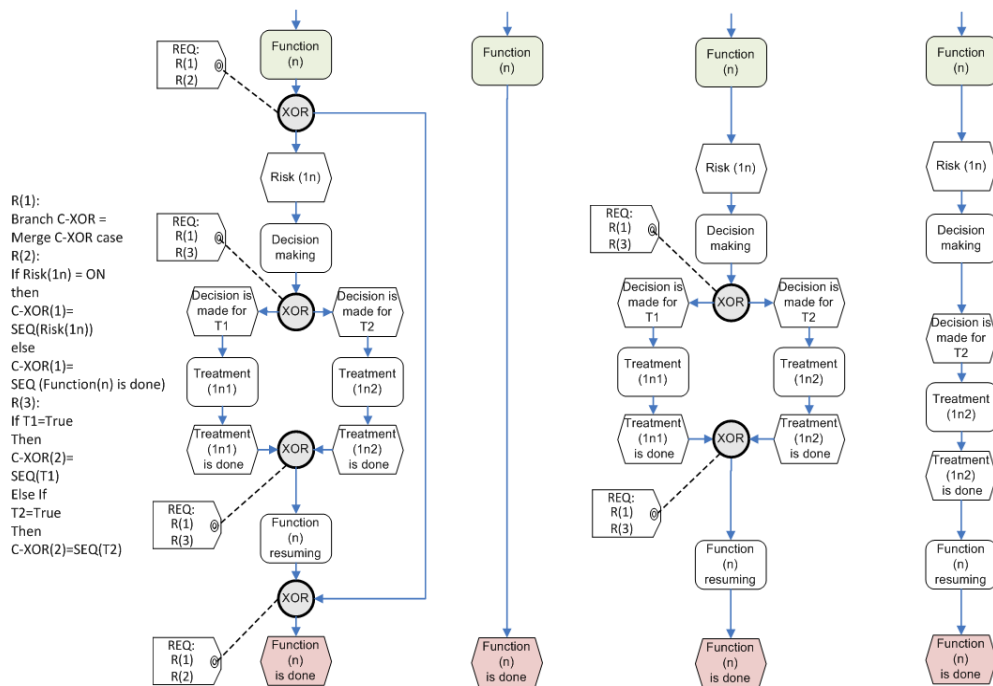


Figure 7: Configuration alternatives of a configurable RRT

## 5. CONCLUSIONS AND FURTHER WORK

EPC was used in this work to represent the possible change in the schedule structure using normal and configurable EPC elements. These changes were ascribed to risks that may affect the project schedule plan. Therefore, the changes occur as response to the anticipated high probability/impact as well as to already occurred risks. Responses to these risks which may change part of the schedule are designed as configurable risk treatment templates since treatment task carries out the planned change in other risk management tasks. The configurable templates can be adapted to the case which suits the actual situation by including the configurable template as a normal part in the process model when “RISK= ON” case is true, or by deleting this path from the process model if “RISK = ON” case is false. Each configurable risk treatment template illustrates one way of risk-caused change in the project plan. However each risk can cause more than one way of change so more than one template may be needed to express the changes caused by one risk. These templates will not show how to treat a risk, since they describe only the changes in schedule structure which can suit many kinds of risks or risky situations. Therefore, a risk-treatment database is needed to describe the known risks and the related alternative treatment methods associated with each construction task/deliverable. This database must be designed and linked to the specific project process model. Such database will give the needed level of detail about the needed treatment. The description of the data model and the structure of this risk-treatment database is one of the next steps of this work.

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## **ALIGNING INTERESTS KEY TO DEVELOPING TRUST IN DEPLOYING COLLABORATIVE TECHNOLOGIES IN CONSTRUCTION**

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### **ABSTRACT**

The importance of trust in construction is well documented especially when the desire is to encourage people to work as a team and to collaborate on construction projects using diverse information technologies. Trust is an integral component of effective teams, successful partnering, and implementing new technology. Building and maintaining trust between contracting parties can lower costs, improve performance and minimize disputes. Construction literature has discussed the types of trust, dimensions of trust and trust building tools. However, a need exists to further explore the importance of aligning the interests of contracting parties. Aligning interests are in addition to the traditional critical success factors for construction projects (profit, cost, schedule, quality). Trust is a state of mind that is strengthened or weakened as each party's hierarchical and subjective interests are supported or challenged. This paper presents an integrated trust model and describes strategies aimed to build and maintain trust in construction when using collaborative technologies. The model further demonstrates that project managers using a specified strategy and system to elicit, monitor and align collaborative interests, in addition to other traditional measures of project success, can improve the likelihood of building and maintaining trust in deploying collaborative technologies in construction.

### **1. INTRODUCTION**

The construction industry is entering a new era where using technologies that improve collaboration on construction projects is becoming common, if not even essential (Nikas et al. 2007). Collaboration is an intended process that creates value beyond communication and is dependent on the trust of the collaborators (Vangen and Huxham 2003). It is driven by a desire to solve problems, create solutions, or discover new methods of completing work (Peters and Manz 2007). Technologies that foster collaboration in the construction industry improve project management, information management, transaction time, transparency of project information, relationships between partners, communication, schedule, costs and profitability (Nikas et al. 2007). Even with these benefits the construction industry is notorious for its slow adoption of collaborative technologies. This is problematic as it holds back industry development in terms of increasing productivity, sustainability and profitability. In 2006, the U.S. Bureau of Labor Statistics reported that the construction industry had the lowest use of computers (28% of employees) and the second lowest use of the Internet (21% of employees) for all private industries (US Department of Labor 2007). A major reason for the low use of collaborative technologies or their perceived ineffectiveness is the lack of trust in the technologies and/or the lack of trust between the collaborators (Brown et al. 2004; Panteli and Duncan 2004; Peters and Manz 2007).

#### **1.1 SUCCESS FACTORS FOR USING TECHNOLOGY IN CONSTRUCTION**

The success of using technology and collaborating virtually in the construction industry depends to a large degree on trust, commitment and information sharing (Uden and Naaranoja 2007; Chiu et al. 2006; and Nuntasunti and Bernold 2006). Table 1 illustrates the results of a review of the literature discussing the success factors for effectively using technology and collaborating virtually in construction. Five main success factors were identified: trust, commitment, shared vision, information sharing and shared culture and language. Trust, commitment and information sharing were the most cited success factors. Without building and maintaining trust, the probability of profiting from the benefits of collaborative technology is less likely (Nuntasunti and Bernold 2006). Trust in the technology and virtual collaborators enable the management of construction projects to advance its goals of improved costs, quality, schedule, profit and safety.

Table 1. Factors of Success for Using Technology and Virtual Collaboration in Construction

| Author                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Trust | Commitment | Shared Culture and Language | Shared Vision | Information Sharing |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|------------|-----------------------------|---------------|---------------------|
| Uden and Naaranoja 2007                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | √     |            |                             |               | √                   |
| Regui 2007                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | √     | √          |                             |               | √                   |
| Chiu et al. 2006                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | √     | √          | √                           | √             | √                   |
| Nuntasunti and Bernold 2006                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | √     |            |                             |               | √                   |
| Chinowsky and Rojas 2003                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | √     | √          | √                           | √             | √                   |
| Davy et al. 2001                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | √     |            |                             |               | √                   |
| Thorpe and Mead 2001                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |       | √          |                             |               | √                   |
| <b>Definitions of Success Factors Technology (0)</b> <ul style="list-style-type: none"> <li>• <i>Trust</i> – the willingness of a party to be vulnerable to the action of another party based on the expectation of a favorable outcome (Uden and Naaranoja 2007)</li> <li>• <i>Collaboration</i> – “synchronous discussion with ability to exchange project information and real-time data manipulation and exchange” (Chinowski and Rojas 2003)</li> <li>• <i>Commitment</i> – participation and follow through of project team (Thorpe and Stephan 2001)</li> <li>• <i>Shared Language</i> – common understanding between team members allowing them to gain access to their information (Chiu et al. 2006)</li> <li>• <i>Shared Vision</i> – a bonding mechanism that helps different team members focus their resources on common goals (Chiu et al. 2006)</li> </ul> |       |            |                             |               |                     |

## 2 COLLABORATIVE TRUST

Collaborative trust is an important component of effectively implementing and using collaborative technologies in construction. In discussing collaborative trust, the term “trustor” is used to signify the individual engaged in the action of trusting and the term “trustee” is used to signify the individual being trusted.

### 2.1 DEFINING TRUST

In approximately 50 years of research, Scholars have failed to agree on an accepted definition of trust. The common elements of these definitions include positive expectations, vulnerability and risk, alignment of interests, contextual influence, a subjective psychological state of mind, and a hierarchy of emotional involvement in the process (Lewicki et al. 2006; Elliot and Yannopoulou 2007). The theory of trust to a large part has been based and still includes the importance of the alignment of interests between contracting parties (Luhmann 1979, Gambetta 1989, Dietz and Hartog 2006).

### 2.2 INTEGRATED MODEL OF COLLABORATIVE TRUST

Collaborative Trust is a multi-faceted process with a number of different components and stages. Much of the trust literature stems from the fields of psychology, management, marketing and sociology. The model presented in Figure 1 is the result of an extensive literature review and is separated into four distinct phases, each building on one another.

#### 2.2.1 ORIENTATION PHASE

The orientation phase assesses the initial risk associated with the trust process.

**Trustor’s Subjective and Hierarchical Perception.** Scholars have found that trust is a subjective process that is different with each individual (Rousseau et al. 1998). Each party enters a trust relationship with different interests, values and needs that have a subjective hierarchy of importance (Elliot and Yannopoulou 2007) that act as a perceptual lens in which each component of the orientation phase is experienced.

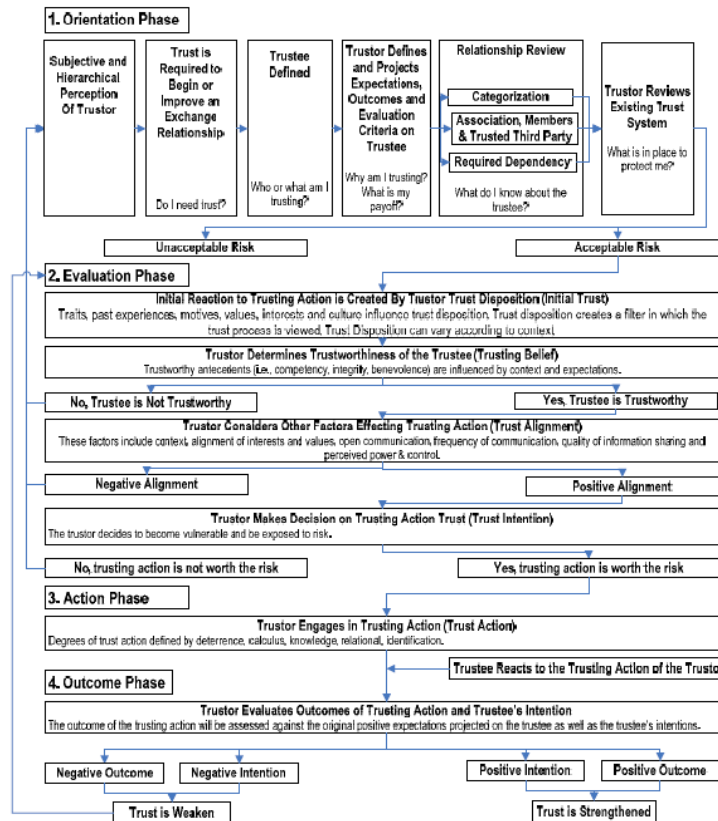


Figure 1 Integrated Model of the Trust Process

**Requirement of Trust.** Before the trust process begins an exchange relationship exists between two or more parties. Even though a number of different factors could influence the perception of risk, exchanges that involve perceived risk require trust (Gambetta 1988).

“Thus trust is not best viewed as a fixed or given commodity that exists within a specific social community or network of relationships, but rather should be understood to be the output of dynamic exchange relationships that are fuelled by individual interests, as well as being the lubricant for the formation of new exchange relationships. Thus, exchange is both embedded in trust, and engenders its formation” (Lane and Backmann 1998, page 140).”

The determination of risk and the need to engage in trusting action is subjective making it a different process for each entity involved in an exchange relationship (Luhmann 1979). Before an entity engages in trusting action a need for trust must be established. This implies that the trustor cannot achieve the desired outcome without the aid of the trustee where the actions of the trustee are uncontrollable. If a need is not established a trustor prefers to avoid trusting action with the objective of protecting against opportunistic behavior (Dietz and Hartog 2006).

**Trustee Defined.** Once the need for trust is established within the exchange relationship, the form of the trustor and the trustee become evident (Figure 2). A trustor, the party that engages in the act of trusting and the trustee, the party that becomes the target of the trust, could have several different forms. A trustor or a trustee or both could take the form of an individual, employee, manager, customer, group, department, organization, etc. These forms of trustors and trustees could be within organizations, teams or groups or

between organizations, teams or groups. Additionally, a party could be both the trustor and the trustee simultaneously depending on the context (Lewicki et al. 2006).

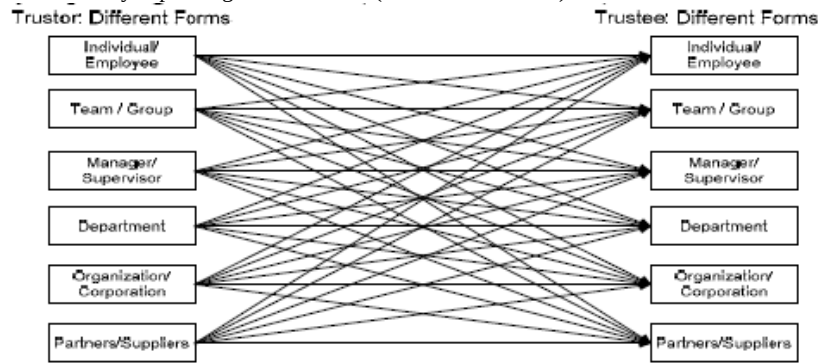


Figure 2  
Different

forms of Trustor and Trustee relationships

**Trustor Collaborative Evaluation Criteria.** As the trustor contemplates engaging in collaborative trusting action, positive expectations and desired outcomes are defined and projected on the Trustee. These positive expectations act as the unofficial terms (from the trustor point of view) between the trustor and trustee and the payoff for the trustor for taking the risk in trusting the trustee. The trustor defines the criteria that the trustee's actions will be evaluated against and to the degree that these expectations are met or not met (from the perspective of the trustor) will determine whether trust strengthens or weakens (Rousseau et al. 1998). An ongoing challenge is that the trustor's evaluation criteria are not always shared with the trustee or could change according to context or phase of the trust process. This is also an essential component for aligning the interests of the contracting parties.

**Relationship Review.** With an understanding of the desired outcomes from the exchange relationship, the trustor reviews the existing relationship with the trustee. This review is made up of three different components. The first component focuses on cognitive and emotional experiences that enables that categorization of the trustee. These experiences include quality of information sharing, witnessed opportunistic behavior and shared interests (McEvily et al. 2003). If the trustor and the trustee have had previous relations, the trustor's experiences (positive or negative) will have more a significant impact on moving the trust process forward (Dietz and Hartog 2006). The second component reviews associations (including memberships and affiliations with trusted third parties) (Kramer 1999). These items are complimentary or disparaging. The significance of associations is decided by the trustor (Coetzee and Eloff 2005) and hold a higher importance in new and virtual relationships by creating the perception of protection against potential opportunistic behavior (McEvily et al. 2003). The last component of the review is the perceived dependency on the trustee. As the perceived dependency on the trustee increases, the degree of trust required increases and the perceived risk increases (Sheppard and Sherman 1998). Again this is amplified in new or virtual relationships.

**Existing Trust Systems.** The next component of the orientation phase in the trust process is assessment of the existing trust systems or mechanisms. Trust systems are aimed at protecting against the costs of misplaced trust and opportunistic behavior of the trustee (Bachmann 2001).

"In every case [trust] rests on the structure of the system which confers trust...the readiness to trust is an important instance of ...the absorption of complexity through structures that can relieve the burden of action." (Luhmann 1979, page 83)

The system of trust could be on a number of different levels including societal, national, institutional, organizational, departmental, group, and individual (Gambetta 1988; Bigley and Pierce 1998); and in a number of different forms, contracts, HR policies, penalties, etc. In some contexts, these systems are termed

“guardians of trust” (Shapiro 1987). The trust systems are viewed reliable if they provide predictability and reliability and protection perceived protection against risk (Grey and Garsten 2001; Gould-Williams 2003).

### 2.2.2 PHASE 2: EVALUATION PHASE

The trust process enters the evaluation phase if the acceptable risk was determined in the orientation phase.

**Disposition Factors (Initial Trust/Collaboration).** A trustor’s trust disposition or propensity to trust refers to the natural openness or comfort a trustor has in trusting others (Cloquitt et al. 2007). The disposition of a trustor can comprise many different facets, including personal traits, past experiences, personal motives, values, interests and culture (Payne and Clark 2003). Mckight et al. (1998) found that trust disposition can be important for initial trust including the initial trust founding new relationships. However, as interaction increases and more information is gained, trust disposition becomes less of a factor in developing trusting relationships.

“As communication grows, individual predispositions loose relevance in favor of organizational context in which trustee and trustor are immersed. Perceived trustworthiness is initially in the eye of the beholder, but as the frequency of communication increases, the specific interests and linkages to the organization of both trustor and trustee become more important. Context is critical to understanding trust” (Becerra and Gupta 2003, page 42)

A trustor’s disposition to trust can be one of the most important factors leading to trusting action in certain environments (Payne and Clark 2003; Kiffin-Petersen and Cordery 2003; Blunsdon and Reed 2003). Depending on the context, the degree of influence of the individual’s trust disposition varies and can not always be assumed transferable from context to context (Kramer 1999).

**Trustworthy Factors (Trust/Collaborative Belief).** Before a trustor engages in trusting action, a determination of the trustworthiness of the trustee is completed. Mayer et al. (1995) conducted an extensive review of trust antecedents and found that benevolence, ability and integrity were cited frequently as antecedents of trustworthiness. Benevolence referred to the degree the trustee is willing support the trustor beyond profit motives. Ability pertains to a specific domain and refers to the skills, competencies and characteristics that enable an individual to excel. Integrity involves the trustor’s perception that the trustee abides by a set of principles that support by the trustor (Mayer et al. 1995). More recent studies have added competency (closely related to ability), credibility, and predictability as other significant antecedents of trustworthiness (Sichtmann 2007; Dietz and Hartog 2006).

**Alignment Factors (Collaborative Trust Alignment).** The alignment of personal interests, values and needs of the parties involved in the trust relationship is at the core the trust building process (Gambetta 1999; Jones and George 1998; Nooteboom and Six 2003; Kiffin- Petersen and Cordery 2003; Carson et al. 2003). Gambetta explained that the problem of trust was essentially one of communication with the goal of aligning interests, values and needs (Gambetta 1988). The ability to communicate effectively by learning and reading each party’s interests and behaviors increases the potential of trusting action. “The concept of trust is taken to signify and present a coordinating mechanism based on shared moral values and norms supporting collective cooperation and collaboration within uncertain environments” (Reed 2001, page 201). However, it is not only the interests, values and needs that need to be aligned, but the most important (hierarchical) interests, needs and values. This is an element that is lost in research. Contextual mechanisms promoting and supporting the learning of interests, values and needs advances the trust building process (Nooteboom and Six 2003). This infers that even if an employee has a high trusting character (disposition), without the alignment of interests, values and needs the probability of trusting action is unlikely (Kiffin- Petersen and Cordery 2003).

**Intention Factors (Trust/Collaborative Intention).** The intention to trust is different from engaging in trusting action. The trustor could have established a firm intention to trust, but still not engage in trusting action (Lewicki et al. 2006). The intention to trust is based on the information gathered to date. If the perceived vulnerabilities and risks are tolerable and the payoffs are worthwhile, the intention to trust or the willingness to take risks manifests (Dietz and Hartog 2006). “First and foremost, trust entails a state of perceived vulnerability or risk that is derived from individual’s uncertainty regarding the motives, intentions, and prospective actions of others on whom they depend” (Kramer 1999, page 571). This perceived

vulnerability and risk exhibits itself in a number of different degrees and levels that are evaluated by the trustor in accordance to his trust disposition and hierarchical interests, values and needs. “Trusting a person means believing that when offered the chance he or she is not likely to behave in a way that is damaging to us” (Gambetta 1988, p. 218).

### 2.2.3 ACTION PHASE

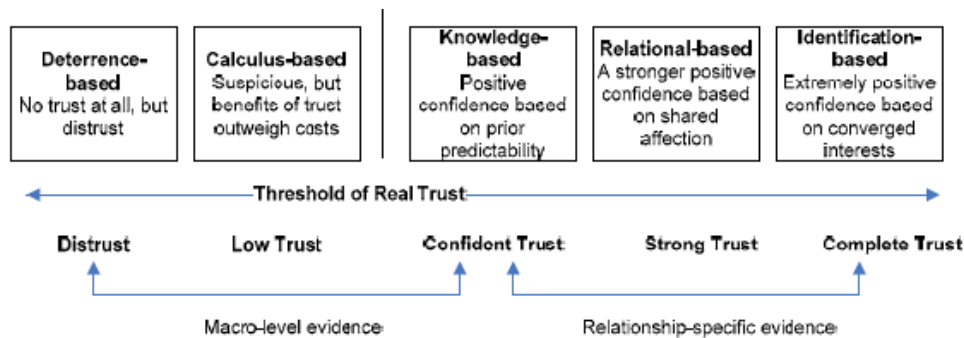
The action phase is focused on risk taking and engaging in trusting action. Schoorman et al. (2007) indicated that there two ways of dealing with risk. One method was by trust and the other was by control systems.

“Trust and controls systems are not mutually exclusive...when the risk in a situation is greater than trust (and the willingness to take risk) a control system can bridge the difference by lowering the perceived risk to a level that can be managed by trust...However, if there is a very strong system of controls in an organization, it will inhibit the development of trust. Not only will there be few situations where there is any remaining perceived risk but trustworthy actions will be attributed to the existence of control system rather than to the trustee. Thus the trustee’s actions that should be interpreted as driven by benevolence or by integrity may be viewed simply as responses to control systems (Schoorman et al. 2007, page 347).

**Trustor Engages in Trust/Collaborative Action and Risk Taking.** Trusting action entails an entire continuum of degrees ranging from blind trust to distrust. The forms of trust change with the interests and risk tolerance of the trustor (Rousseau et al. 1998) while lacking full knowledge regarding the behaviors, motives or future responses of the trustee (Gambetta 1988). Trusting action by its nature is unstable and fragile. Its status can change with every disappointment or satisfaction and as a result the relationship changes accordingly.

“Trust evolves out of past experiences and prior interactions. It also develops in stages of moving from predictability to dependability to trust and eventual and sometimes faith. This represents a hierarchy of emotional involvement which reaches trust when people make an emotional involvement in another person...The move is likely to depend heavily on the accumulation of evidence from a limited and diagnostic set of experiences involving risk and personal vulnerability” (Elliot and Yannopoulou 2007, page 990).

Dietz and Hartog proposed five different degrees of trusting action (Figure 3). These five degrees of trust ranged from distrust (deterrence-based) to complete trust (identification-based). Each degree has a corresponding degree of risk and expectation. For instance in deterrence- based trust there is minimal risk and expectations, while in identification-based trust there is more risk but more expectations (Dietz and Hartog



2006).

Figure 3 The Continuum of Degrees of Trusting Action (Dietz and Hartog 2006, page 563).



## 2.2.4 OUTCOME PHASE

**Trustor Evaluates Outcomes.** Using the expectations and outcomes defined in the orientation phase, the trustor evaluates the outcome of his trusting action. On a high level, if the outcomes match the expectations trust is strengthened and the exchange based on trust will continue. If the opposite occurs trust will erode and the trusting action will refrain (Rousseau et al. 1998). The intention behind the trust violation has a strong impact on whether trust erodes and distrust increases. Trust erodes more when the trustee is perceived as “not willing” rather than “not able” to fulfill the trustor’s expectations (Elangovan et al. 2006).

**Trust Cycle: Strengthened or Weakened.** Vangen and Huxham (2003) discussed the cyclical trust building loop for collaboration. Trust builds on trust in upwardly cycle or spiral while facilitating collaboration and distrust builds on distrust with a downwardly spiral while disempowering collaboration.

## 3. APPLYING THE INTEGRATED COLLABORATIVE TRUST MODEL TO THE CHALLENGE OF ALIGNING THE INTERESTS OF CONTRACTING PARTIES WHILE USING COLLABORATIVE TECHNOLOGIES

Trust between contracting parties strengthens when the interests between contacting parties are aligned. This implies that the interests of each party are perceived to be aimed in a similar direction, can be achieved simultaneously, or are based on similar principles. This is difficult to achieve in any circumstance not to mention when using collaborative technologies. Depending on the size and the complexity of the project the web of different interests could be complicated and unruly. Each party faced with the task of aligning their interests with the interests of other contracting parties. Figure 4 conceptualizes the web and complexity of attempting to align the interests between the more common parties found on construction projects.

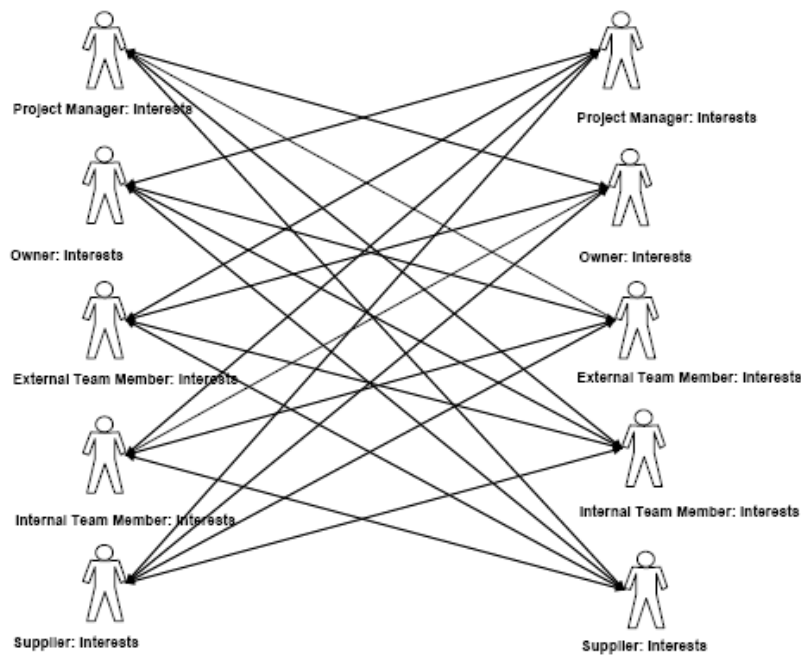


Figure 4 The Complex Web of Collaborative Interests on Construction Projects.

The challenge of aligning the collaborative interest of contracting parties runs throughout the entire trust process. In the orientation phase, collaborative interests are seen through a hierarchical and subjective lens. In the evaluation phase, the trust process does not proceed unless collaborative interests are aligned which in

turn minimizes risk. The outcome phase and its evaluation are determined by whether each party's collaborative interests were met. However, there are potential conflicts in aligning the collaborative interests of contracting parties. Figure 5 illustrates the challenge from the view of a project manager. The project manager has its own hierarchical, subjective interests (project, company, personal) and is tasked to align these interests with the interests of the other parties on the project (owner, suppliers, internal team members and external team members). This dynamic could present a number of potential conflicts that could block the trust building process and collaboration. As Figure 5 depicts, each party on the projects has its own hierarchical, subjective project, company and personal collaborative interests identifying the need to have an individual customized strategy for each party.

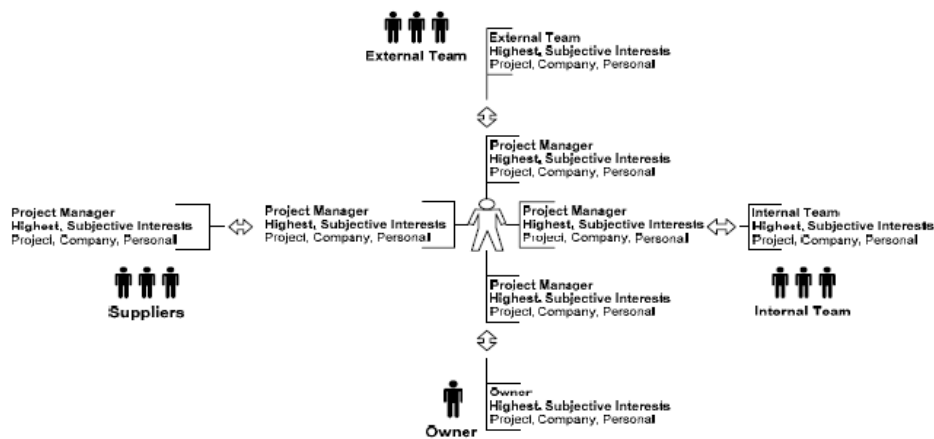


Figure 5 Inherent Challenges in Aligning Collaborative Interests of Contracting Parties.

The question that arises is how a project manager aligns his collaborative interests to the collaborative interests of the different contracting parties involved in the project. A practical method of collaborative aligning interests between parties in exchange relationships is the creation of a taxonomy that documents the prioritized interests through the activity of probing questions. The taxonomy would be similar to a "living" entity as it grows and adapts with the changing needs of the project and varying interests of the parties. The taxonomy would illicit the hierarchical, subjective collaborative interests of each party involved in the project and make this information available to each party. This process would assist in identifying potential conflicts of interests that would block the trust and collaboration process. Figure 6 shows how the taxonomy of interests could be saved in the form of a computerized database that allows the information to be maintained, managed, and accessed efficiently. It is difficult to work through the risks involved in using collaborative technologies if a party does not see how their collaborative interests will be met or aligned with the

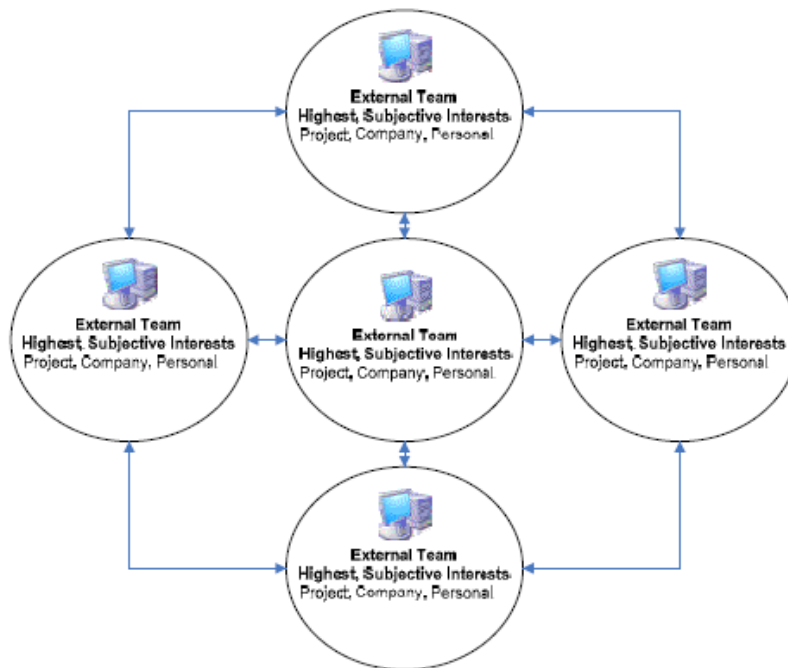


Figure 6  
Computerized  
Mechanism for  
Tracking the

Interests of Contracting Parties.

the collaborative interests of the other parties (Doney et al. 2007, Lewicki et al. 1998). Additionally, having a taxonomy of collaborative interests that can be regularly consulted allows each party to discuss the matters at hand according to the collaborative interests of the other parties which creates a sense of unification. When aligned and working together, these factors can transform conditional trust and collaboration to unconditional trust and collaboration (Jones and George 1998) and the benefits of collaborative technologies in construction have a greater probability of occurring.

#### 4 CONCLUSION

It is clear that there are benefits to using collaborative technologies in the construction industry. However, lack collaborative trust is one factor that prevents collaborative technologies from being used more frequently. Collaborative trust is a complex process that requires the alignment of different and potentially conflicting collaborative interests. Building trust in collaborative technologies requires an action process based on frequent communication and interaction while aiming for small wins and realistic expectations. The strategies used to increase trust with collaborative technologies need to be tested in order to verify that they are useful in the context of construction.

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## INTERACTIVE VISUALISATION AS A POWERFUL DECISION SUPPORT TOOL FOR CONCEPTUAL DESIGN

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### ABSTRACT

Recent advances in evolutionary computation (EC) have made it possible for researchers to develop decision support tools that to some degree assist designers in decision making. Some of the difficulties with the EC are that they generate a population of alternative solutions to choose from and they are generated in a 'black box' mode, where there is little or no user interaction. The research presented in this paper is using an interactive visualisation tool that allows designers to conduct a human-led exploration of the solution space that has been generated by the EC. Multi-disciplinary design team members can interact independently with the system to explore and identify regions of the solution space which best meet their disciplinary objectives. The visualisation tools also allow them to find a common framework for multi-disciplinary design. This research then post-processes the data inside the region of the agreed framework, using a Pareto algorithm, to isolate non-dominated solutions for selection purposes.

### KEYWORDS

Evolutionary computation, Visualisation, Conceptual design, Decision making.

### 1. INTRODUCTION

Successful application of evolutionary computation (EC), particularly genetic algorithms (GAs) to solve multi-dimensional problems has shown to be promising. Applications of EC in building design goes back to the early 90s when Grierson & Pack (1993) attempted simultaneous sizing, topological and geometrical optimisation problems, not possible with conventional mathematical programming techniques. They approached the combined optimisation problem of planar frames, by first taking a simple example and later extending the approach to a more detailed skeletal structure resembling a building in section. They also applied an approximation technique to analyse the frames generated by the GA in order to significantly reduce the computational effort required. Rajan, (1995) conducted a similar investigation using trusses instead of frames. In addition to member size variation, Rajan studied techniques that simulated the removal of non-essential bracing members from a truss. Jenkins, (1994) reported the need to investigate re-analysis techniques to improve the computational efficiency in structural analysis procedures.

Parmee and Bullock, (1993) described how the GA has been successfully applied to the design of a hydropower scheme, which incorporated the optimal geometric design of a concrete arch dam to resist self-weight and hydrostatic forces. In their work, they recognized that radically different geometric forms (i.e. different curvatures) embodied different design concepts that warranted consideration. Subsequently they proposed that an optimisation based on the Structured Genetic Algorithm (SGA), developed by Dasgupta and McGregor, (1991) was appropriate for handling multiple different concepts simultaneously.

From 1997 to the present day, there has been noticeable growth in interest in the application of GAs specifically to conceptual building design. One reason for this is that building design problems are highly multi-dimensional, multi-criteria and multi disciplinary problems with lots of inherently conflicting criteria. Studies by Grierson and his co-researchers in Waterloo, (Grierson and Khajepour, 1999, Grierson and Park, 1997), Rafiq et al. in Plymouth (Mathews et al., 1996, Rafiq and Mathews, 1998, Rafiq et al., 2003) and Miles et al. in Cardiff (Miles et al., 1995, Miles et al., 2001, Sisk et al., 2003) are perhaps the first people who have made particular contribution to this area.

## **2. MAJOR ATTRIBUTES OF AN INTERACTIVE VISUALISATION SYSTEM**

Interactive evolutionary systems can be categorized into two broad groupings: Where the user makes a subjective evaluation at the selection stage, and where the user changes design objective preferences (see also Parmee, 2002, for similar categorisation.)

In terms of visualisation two broad approaches can be identified. Firstly, it is the result of the search process which is presented to the designer, thus in the single objective case the classic approach has been a simple fitness plot and in the multi-objective case, plotting the Pareto front or Pareto surface (the work of Grierson and Khajepour, 2002, puts this technique to good effect). Secondly, in more sophisticated systems the focus has been on the visualisation of the GA search process itself. This may involve tracing the ancestry of the evolving individuals or representing the genetic composition of individuals (see Hart and Ross, 2001, Collins, 2002, and Smith et al., 2002). In all cases visualisation is performed during or after the GA run has terminated and the user is not able to interact with the system either to refine the search or to move the search to a different area of the search space.

A major objective of an interactive visualisation system, presented in this paper, is to assist the designer through a human-led interaction to explore a range of feasible and innovative solutions that best fit the design brief requirements.

The process of exploration of search and solution spaces is more useful at the conceptual stage of the design process where design information is ill defined. The interactive visualisation process is fundamentally different from the traditional search and optimisation as it opens a human window in which the user freely interacts with the system to explore and visualise the search and solution spaces to find regions of more promising solutions that suit the design requirements. It does not solely rely on encoded quantifiable objectives as the search is guided by the human-led interaction and new boundaries, constraints and requirements are dynamically introduced. Many conceptual design considerations that are qualitative parameters can be incorporated through direct human-interaction. It is capable of visualising multi-dimensional problems and presenting information interrelationships between design parameters and/or objectives.

## **3. AN INTERACTIVE VISUALISATION AND CLUSTERING GENETIC ALGORITHM SYSTEM**

The Interactive Visualisation and Clustering Genetic Algorithm System (IVCGA) developed by Packham et al. (Packham, 2003, Packham et al., 2004a, Packham et al., 2004b, Rafiq et al., 2005) is a system that was designed and built to focus on user interaction at the outset and allows the user to freely interact with specific regions of the search space. The work is centred on a user interface that allows the user to 'zoom in' to specific regions of the search and solution space, defined by the user, and create new data using further GA runs.

By including a flexible interactive user interface supported by visualisation tools, the IVCGA allows the designer to conduct a focused and concentrated search inside regions of high performance solutions or to extend the search outside the boundaries of the current search. It is possible to incorporate non-encoded design requirements into the human-driven search and evaluation process.

In the IVCGA, the constraints are removed as much as possible and *all* the data produced by a short number of the GA runs is initially available for visualisation. The user can then choose to keep or filter out information as required interactively. The data is then clustered using a fast, novel technique according to user requirements, based on parameters of objectives spaces. The advantage of this method is that data is generated very quickly and low performing, but potentially interesting solutions are not filtered out from the results by imposing constraints.

The authors believe that by combining flexible user interaction and visualization capabilities with the power of the evolutionary computation in a human-driven interactive system, such a system could deliver invaluable decision support and knowledge discovery, as advocated by Parmee et al. (2000) and Mathews et al. (1995).

The IVCGA was designed to offer the following features:

- The fast generation of diverse data by running a simple GA for a low number of generations to reduce the number of function calls with normal crossover and mutation rates. The diversity of solutions is maintained by applying a high mutation rate when duplicate solutions are identified.
- An easy to use interface that allows direct manipulation of the data and views. Various high dimensional visualization techniques are supplied to enable understanding of the data from different viewpoints and a combination of parameters.
- An automatic clustering procedure is built into the system that identifies clusters relevant to the problem in hand. Colour is used to highlight important clusters, enhancing perceptual understanding of the data.
- Extensive interaction is supported allowing the generation of further data with the GA inside or outside regions identified by the user or clustering algorithm. The definition of clusters can be modified by the user or even created manually, ensuring complete freedom of search and human-led exploration of the search space.

The objective of this study is to post-process a large amount of data within a region of the solution space that has been agreed by the multi-disciplinary design team as the mutually inclusive region, to present a smaller set of non-dominated solutions using Pareto optimal techniques for further consideration by the multi disciplinary team.

#### 4. PROBLEM DEFINITION

In this study three disciplines: the architectural; the structural engineering and the health and ventilation engineering disciplines are included. Two construction materials (steel and concrete) are used in the case studies.

Although solutions generated by the evolutionary computation (EC) use a complex objective fitness evaluation process, considering essential design requirements related to each discipline, mostly the optimum layouts of the buildings are presented as a visual measure of fitness evaluation for presentation purposes. At the end some examples of the interface between the visualization tools and 3D CAD systems are demonstrate, but work in this area is in its infancy.

To simplify the problem, 9 independent parameters (construction material, number of floors, bay size, number of bays in x-direction, cladding type, floor type, window type, window ratio and unit land cost) and 5 dependent design parameters (total area, bay size, number of bays in y-direction, building length and width) are used.

Independent parameters are the GA variables, values of which are assigned through the GA optimization process. Values of the depending parameters are determined from the independent GA variables. Four objectives are defined by the multi-disciplinary team (area loss, energy cost, floor cost and structure cost). These objectives are related to the three disciplines involved in a multi-disciplinary design.

Multidisciplinary issues regarding the design of a commercial building with a total lettable area of 8000 m<sup>2</sup> are investigated. Maximum number of storeys is limited to 8.

There are over 8 million possible solutions using EC. Using the IVCGA the total number of solutions initially generated was 6300 alternative solutions. The mutually inclusive region consisted of 1857 individual solutions. Number of non-dominated solutions isolated by the Pareto technique was 164. Out of which 112



solutions were steel structures and the rest were concrete structures. For details of multi-disciplinary exploration and identifying regions of mutually inclusive designs, refer to (Rafiq et al. 2008a, Rafiq et al. 2008b).

## **5. EXPLORATION OF SOLUTION SPACE USING IVCGA**

An advantage of the IVCGA as a powerful visualization tool is that it allows interactive user interaction to efficiently explore the solution space. IVCGA consists of two main modules: the GA as a powerful search engine and the visualization tools as an aid for interactive exploration.

During the GA search process no constraints are permitted. The GA runs for 21 generations and with a standard population size of 100, produces a possible 2100 alternative solutions. This process is repeated for each objective independently.

The interactive exploration process used in this study is conducted in three levels:

1. Independent exploration of the solution space by individual members of the multi-disciplinary team to explore the solution space in order to locate regions which better satisfy their individual design requirements. In this process designers from each of the disciplines run the GA search tool using their own objectives as a measure of fitness for assessing the suitability of individual solutions.
2. Integrated exploration by all members of the design team collectively to negotiate boundaries of the mutually inclusive region of the solution space that partially satisfy requirements of all parties involved. In this process regions selected during the independent exploration are superimposed to agree on the boundaries of the mutually inclusive region. This mutually inclusive region is considered as an agreed framework for further multi-disciplinary activities.
3. Pareto solutions to narrow down and focus the exploration to about 10% of the non-dominated solutions within the mutually inclusive region.

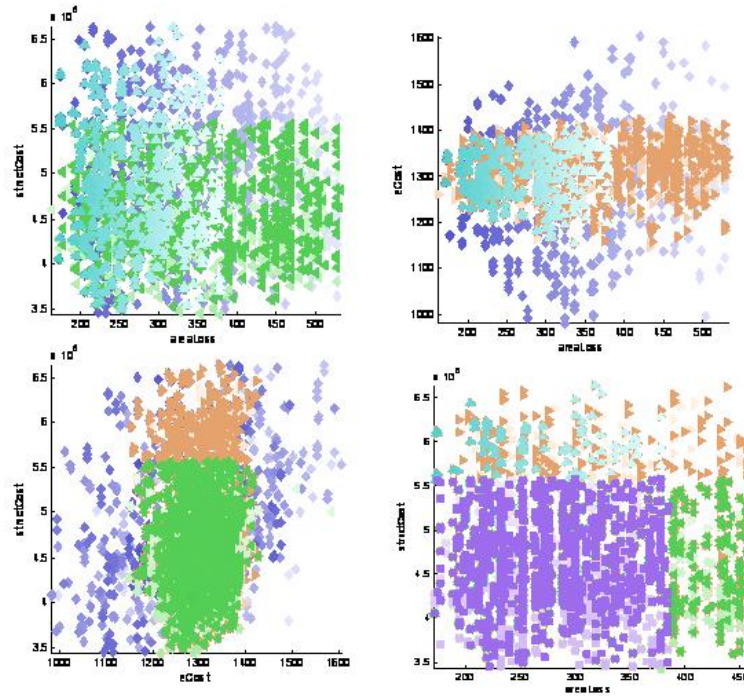
Details of the first two processes can be found in Rafiq and Beck (2008a, 2008b). Here we only focus on the third step which concentrates on pre-processing the data generated by the first two processes to identify a set of non-dominated solutions and explore the suitability of these solutions against the requirements of each the three parties involved in the design.

## **6. POST PROCESSING OF DATA INSIDE MUTUALLY INCLUSIVE REGION USING PARETO RANKING**

### **6.1. MULTI-DISCIPLINARY EXPLORATION**

Figure 1 shows the process of defining the mutually inclusive region of the solution. The top left frame shows superimposing the architectural preferred region of the solutions space, indicated by the cluster of cyan triangles (each triangle represent an individual solution) with the structural engineering region, indicated by the green cluster.

Similarly the top right and bottom left frames respectively represent superimposing process for the architecture and M&E and the M&E and the structural engineering preferred regions. Finally the bottom right frame shows the common area for all three disciplines, the mutually inclusive region of the solution space, signified by the purple cluster.



Cayn = areaLoss, Green = structCost Copper = eCost & Purple mutually inclusive region  
Figure 1. Defining mutually inclusive region

A 3-dimensional view of the mutually inclusive region along with a floor plan and some details of two near optimal solutions are shown in Fig. 2.

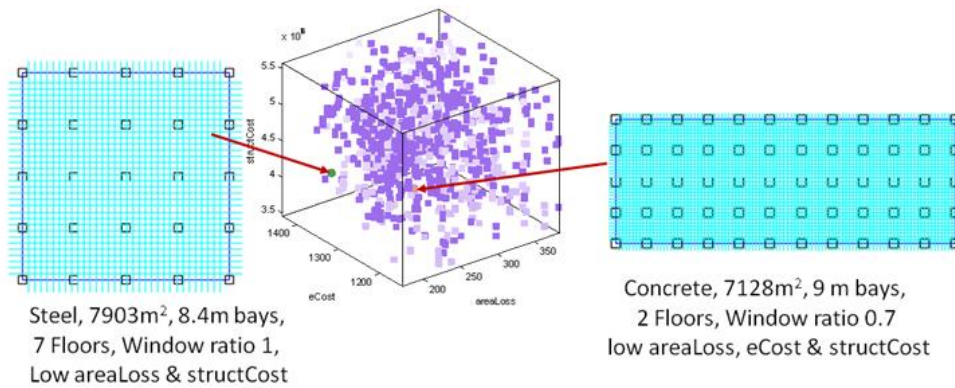


Figure 2 A 3-D representation of the mutually inclusive region along with two candidate designs solutions (one concrete and one steel option)

## 6.2. POST PROCESSING DATA USING PARETO NON-DOMINATED RULES

Once the mutually inclusive region of the solution process has been agreed by the three disciplines and the framework of the future multi-disciplinary activities are agreed, members of the design team can focus only on solutions within the boundaries of this region (the purple cluster in Figs. 1&2).

As mentioned before, 1857 individual solutions are enclosed within the purple cluster, which by itself is a large solution space to deal with.

In order to narrow down the exploration space, a Pareto algorithm was used to rank solutions within the purple cluster into several Pareto sets based on the non-dominated rule defined by Pareto. This non-dominated rule states that *it is not possible to improve any of the criteria without a compromise, which would worsen at least one other criterion*.

Design solutions within the mutually inclusive regions were divided into a number of Pareto sets as follows:

1. The Pareto algorithm was run using all 1857 individual designs within the mutually inclusive region for three objectives (minimizing areaLoss, eCost and structCost). Implementing this process all non-dominated solutions within the mutually inclusive region were ranked to identify the first Pareto set. There were 64 solutions within this region.
2. In the next step all 64 solutions identified as the first Pareto set were removed and the Pareto algorithm was run with the remainder of solutions and the second Pareto set was identified.
3. This process was repeated until all solutions within the mutually inclusive region were exhausted.

Although 64 solutions in the first Pareto set is plenty to work with, due to the multi-dimensionality of the problem it was decided to combine the two top Pareto sets in the selection process. Fig. 2 shows position of the two Pareto sets within the solution space.

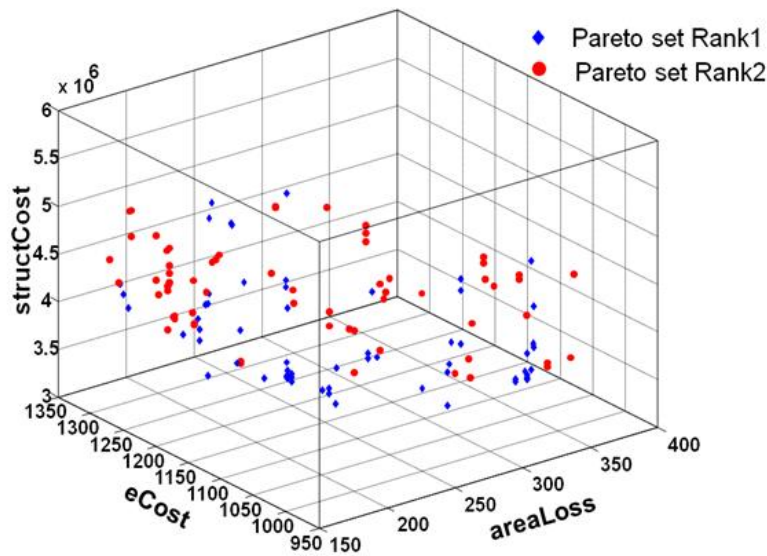


Figure 3 Position of two top Pareto sets

Identifying sets of Pareto non-dominated solutions is useful for the multi-disciplinary negotiation process. It facilitates the multi-disciplinary design team members with the opportunity to:

- Explore the interrelationship between various design parameters and objectives.
- Discover the impact of individual decisions on the decisions of other members of the team and on the overall design and hence the overall cost of the project.
- Discover a deeper knowledge of the overall design issues and knowledge of the boundaries and limitations of her/his own decisions and those of other members of the design team.

- Better appreciation and understanding of the overall design requirements and constraints, which makes it easy to compromise as the whole picture is clearer and there is little room for pushing selfish requirements as is the case in the conventional negotiation process.

Some of the benefits of using the Pareto non-dominated solutions are discussed in the following section.

Fig. 4 shows 2D plots of one objective against another. It should be noted that each plot in Fig. 4 is a 2 dimension representation of a 3 dimension object in Fig. 3. Even in a 2 dimension plot there is a clear Pareto front marked by a red line in each plot, which could be considered as the Pareto front for the two objectives that each plot represent.

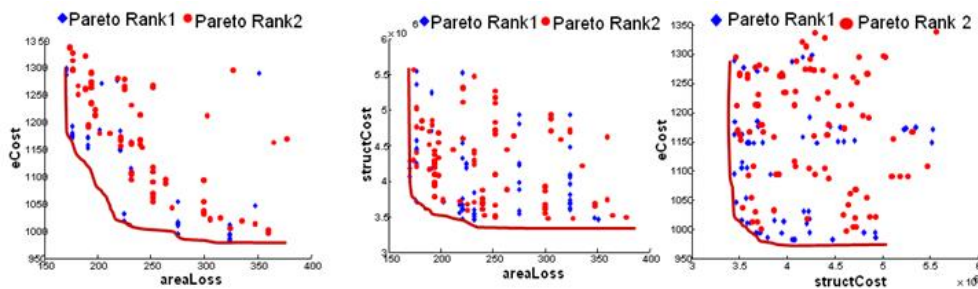


Figure 4 2D Plots of Objectives Related to each Discipline

Information presented in Fig. 4 was transferred into the IVCGA for further exploration. Fig. 5 shows samples of non-dominated solutions for lower areaLoss and/or lower energy cost.

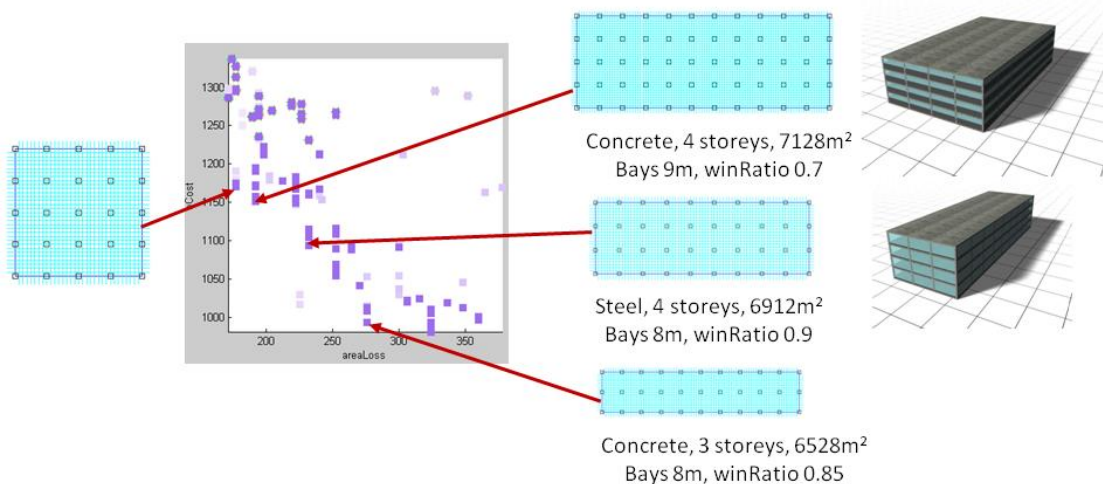


Figure 5 Pareto Designs (Building Footprints) Satisfying areaLoss and eCost Objectives

Designs adjacent to the vertical axis are those designs which have low areaLoss, but their suitability for energy usage is not optimal. Conversely designs adjacent to the horizontal axis which have low energy consumption may not fit in terms of areaLoss. Another interesting finding of the information presented in Fig. 5 is that the total letable floor areas for all designs along this Pareto front are below the required 8000m<sup>2</sup>. This may be an indication that there are no good solutions in the region of 8000m<sup>2</sup> that simultaneously satisfy both optimum energy and optimum areaLoss requirements.

Figure 6 shows samples of non-dominated solutions for lower areaLoss and/or lower structural cost.

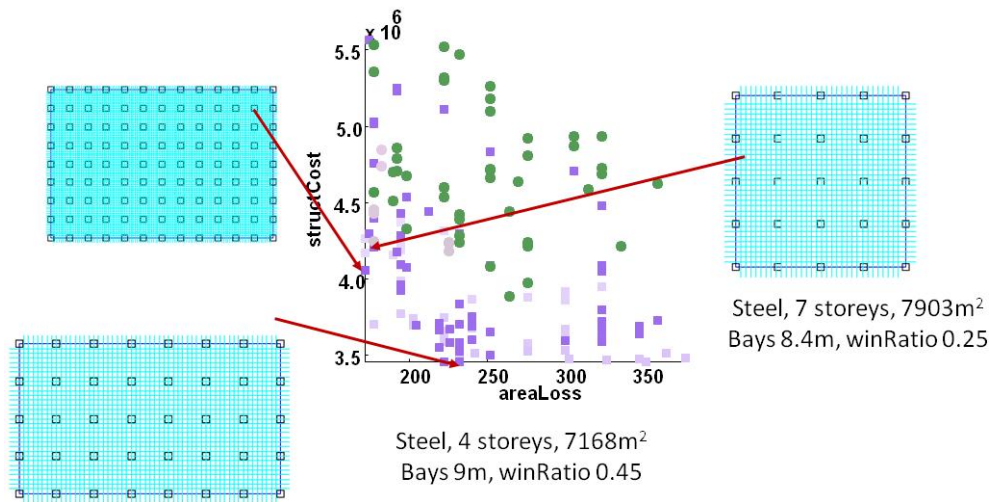


Figure 6 Pareto Designs (Building Footprints) Satisfying areaLoss and structCost Objectives

From Fig. 6 it is clear that good solutions for low areaLoss and moderate structCost having total letable areas close to the required  $8000\text{m}^2$  are achievable. Solutions with lower structural costs are either less than  $8000\text{m}^2$  or expensive in terms of areaLoss, which may not be desirable for the architectural requirements. In Fig. 6 designs belonging to concrete construction material are coloured in green.

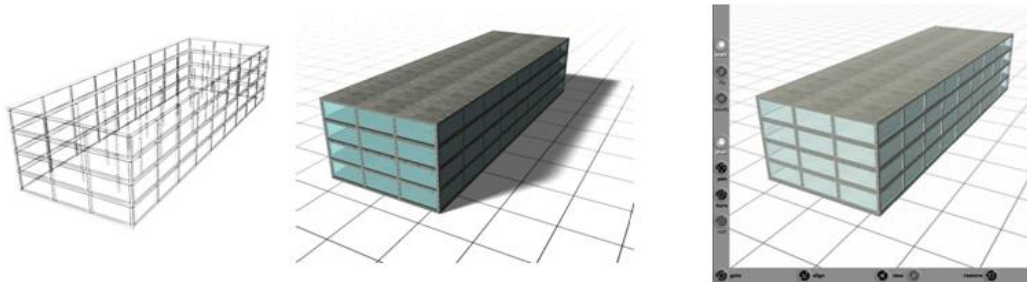


Figure 7 3D CAD model of the steel structured,  $6912\text{m}^2$ , 8m bay, 0.9 window proportion 4 storey building, with the VRML model shown on the right.

Further investigation of figure 7 revealed that most solutions satisfying both areaLoss and structCost belonged to steel frames. It was also discovered that there were no designs in concrete material that satisfy total area requirement of  $8000\text{m}^2$ .

IVCGA facilities the opportunities for designers to conduct a more focused search for each construction material or any other aspect of the design that enables them to pinpoint desirable solutions within a short time.

## 7. LINKS WITH CAD TOOLS

Although building footprint is a quick, easy and convenient way for assessing the suitability of designs, it cannot present sufficient details to justify making decisions in selecting final design solutions on its own. Three and 4D technologies are ready for use in design, construction and manufacturing areas. It may be timely to implement these technologies at the conceptual stage of the design process.

We have started preliminary trials in presenting solutions generated by the IVCGA and narrowed down using Pareto optimal techniques using 3D representation and a walkthrough inside and outside of the buildings.

It must be mentioned that although use of 3D representation and a walkthrough inside and outside of the buildings are excellent tools at the final selection stage, where only a few candidate designs are shortlisted for final selection, they are time consuming processes and use of building footprint for preliminary assessment has its own merits. This is one reason which makes integration with CAD tools at the outset of the exploration process unworkable and unnecessary. Therefore interface with CAD system at the later stage is encouraged.

Every 3D CAD system provides tools for the operator to visually assess the model in a real time interactive manner, whether that be by using specific walk through and fly through facilities or the standard panning, zooming, rotating type operations. Access to this visualisation functionality either requires an installation of the full CAD application or a compatible viewer. Certain neutral 3D model formats, such as VRML, provide means of viewing the model without the need for this specialist software. VRML also provides intuitive interactive functionality, enabling the user to easily navigate and view the model. VRML files are text based and are relatively straight forward to automatically generate. For this reason VRML has been selected to further explore suitability of solutions generated by the IVCGA to give the designer a better understanding of these alternative designs.

By interfacing IVCGA with VRML, each design selected from the solution set will be automatically be written as a VRML97 formatted file, processed and presented, giving the user an interactive first person experience of walking around the building.

## 8. CONCLUSIONS

This paper has demonstrated that IVCGA, as a powerful decision support tool, facilitates user interaction, which allows members of the multi-disciplinary design team to conduct independent exploration of the solution space in order to locate regions which better satisfy their individual design requirements. It also allows integrated exploration by all members of the design team collectively to negotiate boundaries of the mutually inclusive region of the solution space that partially satisfy requirements of all parties involved. In this process regions selected during the independent exploration are superimposed to agree on the boundaries of the mutually inclusive region. This region will constitute a framework for all future multi-disciplinary design activities. The research introduced a novel way of using a Pareto algorithm to narrow down and focus the exploration to about 10% of the non-dominated solutions within the mutually inclusive region. This would assist members of the multi-disciplinary design team to decide on a few negotiated solutions that best suit the multi-disciplinary design/client requirements.

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## BUILDING DESIGN COORDINATION: COMPARING 2D AND 3D METHODS

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Coordination of Mechanical, Electrical and Plumbing (MEP) systems among themselves and with the architectural, structural and other building systems is an important, challenging and time consuming task on the design phase of multistory buildings. Many researchers have already expressed a critical view on the most widely adopted coordination process, which makes use of transparent trade drawings overlapped on a light table for detecting conflicts. The use of a 2D CAD system is nothing but a direct replacement for paper drawings and light table, not considerably changing the method. The authors of this paper, like others, advocate the use of 3D CAD for the coordination process as a more apt tool for this spatial task. Two studies were conducted to compare the performance of a 2D CAD-based coordination method to that of a 3D CAD supported process, both in terms of efficiency and efficacy. Both methods used 2D CAD drawings as input but the three dimensional process required subsequent solid modeling of all relevant building systems. Even with this additional burden, the 3D-based method outperformed the traditional one. Results show its higher efficiency as there was a significant decrease in the time spent for detecting interferences during the development of a masonry production design in an experimental study. The higher number of conflicts revealed in the plumbing design for a multistory building demonstrated also its increased efficacy in a case study.

### KEYWORDS

design coordination, 2D CAD, 3D CAD, efficiency, efficacy.

### 1. INTRODUCTION

Design coordination of mechanical, electrical and plumbing (MEP) systems is a challenging process on complex building projects (Korman and Tatum, 2001). It may be defined as the arrangement of components of building systems into the structural and architectural envelope of the edifice and today it includes not only mechanical (HVAC and elevators), electrical and plumbing systems, but also fire protection, automation and control, CCTV, electronic security systems, video, voice and data systems, among others.

Although today not all contractors invest enough in the coordination process (Riley et al., 2005), it is considered an essential link to the successful design and construction of these systems (Korman and Tatum, 2006). Research (Riley and Horman, 2001) has indicated that investments in coordination reduce conflicts and change order costs generated on the field, paying for their cost, and producing many more benefits (less disruption of productive workflow of different trades in the field, fewer conflicts and interruptions to crews, more reliable work environments, etc.), specially in MEP intensive projects.

While Korman and others (2001, 2006) use the term “coordination” meaning only the activities regarding the (soft and hard) interferences among building systems (focus on apparatus), we prefer to call those actions “compatibility/interference analysis”, giving the term “coordination” a more global sense, which includes the first meaning, but also regards the management and harmonization of the activities of all specialty contractors among themselves as well as with other project stakeholders (focus on agents). Despite that, in this work it will stick to the expression “MEP/spatial coordination” to identify the interference analysis among building systems.

In Brazil, it is often contracted a detailed masonry wall design as part of whole systems design. The masonry designer aims to optimize the material and labor use for constructing each masonry wall, while making sure its design is correct from an engineering point of view, i.e., regarding stability, performance, durability, constructability, etc. This design is especially important in Brazil, because national structure standards permit slim concrete structures which have a considerable deformation upon walls. Also, a complete interference analysis on the building systems and other components that are constructed inside



the walls (piping, electrical ducts, structure, windows, doors, etc.) is required to reach the masonry designer goals, as optimal brick/block positioning depends on it. Soon this interference analysis turned into one of the outcomes contractors expect from them, sometimes rendered as an even more important result than the masonry design itself.

In their research in the U.S., Korman and Tatum (2001, 2006) identified the SCOP (Sequential Comparison Overlay Process) as one widely adopted MEP coordination process. In SCOP, interference checking is accomplished by plotting shop drawings from all concerned trades in translucent media (e.g., tracing paper), on the same scale, and overlaying them over a light table. Although lacking a formal study, one could say that in Brazil (Schmitt, 1999) and probably in most countries, that same overlay method is used as a primary tool for coordination, either on print media or, now more commonly, electronically with 2D CAD.

The MEP coordination process has been performed with a great deal of different technologies, from paper-based SCOP to 3D CAD, depending on the size and technological maturation of the contractor.

The introduction of 2D-CAD was an improvement over the paper-based method, as layers can be easily turned on and off, simulating a speedy overlay of tracing paper sheets over the light table. Also, expensive plotting for this process was no longer necessary, as analyses can be conducted over the computer display. Despite these advances, the 2D CAD-based process does not change considerably the paper-based method as all the drawbacks of a complete manual analysis are still present, requiring a recurrent mental effort for reconstructing tridimensional entities from a 2D representation.

On the hi-tech end of the spectrum today are tools based on object-oriented, parametric 3D models. Tatum and Korman (2000) pointed out, some years ago, that capturing the knowledge of diverse trades and integrating them on software customized for the needs of MEP coordination was a major challenge in this field. The recent development of BIM (Building Information Modeling) software may now be providing a more straightforward landscape for such undertaking.

An intermediate process between 2D-CAD and object-oriented/parametric 3D-CAD is standard solid modeling. This technique allows performing hard interference checking (Neggers and Mulert, 1993) as long as all components from relevant trades are modeled.

Riley and Horman (2001) have stated the promise and suitability of 3D/4D CAD for coordination in the future, but mentioned building contractors perceived it to be too costly for widespread use, at that time. Korman and Tatum (2006) advocated a revised process for integrating a knowledge-based tool in the MEP coordination practice: a 3D CAD file would be generated and forwarded to a central location by each specialty contractor. Those files would then be integrated and analyzed by a MEP coordination tool, which checks and corrects the detected interferences.

Since 1992, one of the authors of this work has used 3D CAD for interference checking while developing detailed masonry designs (also in 3D). This activity was performed within a traditional setting, where all the other project agents (architect, specialty contractors, and structural engineer) worked with 2D drawings both as input and output for their tasks. Therefore, a complete 3D model had to be produced from 2D-CAD files and the final design had to be represented as plan and section views for delivery. The business success of this approach led us to believe that, although the solid modeling of all building systems was a significant burden, the total time of this 3D-aided process was reduced compared to the 2D-CAD overlaying method and its efficacy was, at least, the same.

The aim of the work presented in this paper was to compare the performance of a 2D CAD-based coordination method to that of a 3D-CAD-supported process, both in terms of efficiency and efficacy.

## **2. SPATIAL COORDINATION METHODS**

The following sections summarize the main characteristics of the two methods compared in this study.

### **2.1 TWO DIMENSIONAL CAD COORDINATION METHOD**

Manual or paper-based and 2D CAD coordination methods have essentially the same framework, as stated before. These methods are based on the use of bidimensional graphics representations (floor plans, sections and views) as a tool to analyze and, at the same time, represent the designed solution. A lot of design time is spent on inferences about the real 3D space. The spatial information is registered into the designer and other stakeholders' minds demanding abstraction and good operational memory from them. Ferreira and Santos (2004) have shown that traditional 2D design (including 2D CAD) implies recurrent interpretation of graphic representation, mental analysis, codification of graphic solution (into an abstract and often partial format), followed by checking and correcting activities. This cycle demands from the designers experience, spatial abilities and acquaintance with the technical representation. Even seasoned professionals may make mistakes in complex situations, in projects with many or dense building systems and/or unconventional designs. Within this method, design processes and solution documentation take

place at the same time. Little design automation is possible with this method. Even drafting aid is small, compared to the fully automated drawing of plan and section views enabled by 3D CAD.

## **2.2 THREE DIMENSIONAL CAD COORDINATION METHOD**

With the 3D-based method, designers and other technical stakeholders analyze the objects in space through solid models. Interference detection can be done visually or automatically using the intersection boolean operation.

The solid modeling process itself allows the designer to promptly detect clashing components and design inconsistencies. Those problems are immediately corrected or marked to be forwarded to the appropriate professional. Furthermore, because the representation is not as symbolic and abstract as that of the 2D process, the demands on the designer regarding training, spatial visualization ability and knowledge of technical drawing are much lower. As a consequence, it is expected fewer mistakes to be made and more design problems to be early detected than with 2D-based methods.

In this method, the final design documentation produced is similar to the 2D CAD output, although their generation processes are quite different. When using 3D CAD, the software creates floor plans, sections and views automatically from the solid model, usually at the end of the design process. Dimensions, notes and sheet layout are done manually, eventually with some small automation routines, like in the 2D CAD method.

In both the studies in this report, the 3D CAD package was augmented with some LISP routines to increase efficiency of repetitive activities, as well as of sequences of commands frequently used.

## **3. RESEARCH METHODS**

Two research strategies were adopted in this investigation. Firstly, a controlled experiment was set up to compare the efficiency of the 3D-CAD method to that of the 2D-CAD coordination process. Then, a case study was conducted to investigate their efficacy, regarding detection of interferences and constructability problems.

The first experiment was conducted in the first semester of 2004. The case study was observed during 2007.

Both phases in this research involved the production of detailed masonry designs as, in Brazil, this is the activity supposed to detect most of interferences among building systems, structure and masonry itself.

### **3.1 EFFICIENCY STUDY**

For comparing the efficiency of 2D and 3D methods, an experiment using a real case was structured. An arrangement was made with a traditional masonry design office (Office A), which agreed to participate in this study as well as one of its clients. A project from this client (a major contractor) was selected for close monitoring. All the activities of the design office members related to this project were registered in a time sheet. Designer name, date, start time, end time, task name and a short activity description were recorded whenever some task related to the target project was performed. The team members were instructed to register their doings each time they started, interrupted or finished an activity on the selected project.

Three professionals from Office A worked directly in this project: one design coordinator and two trainees. The coordinator was a 22-year-old engineering student, graduated as a building technician four years ago. He took this position two years before, after working for two years as a trainee in the company. He reports directly to a manager who supervises the design work. The trainees were 18 and 19 years old and were graduated 12 months ago from medium level courses. The coordinator works, on average, on three different projects at a time, while trainees work on a single one.

The design process at Office A is the one described in section 2.1. The tool used was AutoCAD R14. The company had been designing masonry for seven years.

About the same time, using funds from a research grant for this study, another masonry design office (Office B) was hired to develop exactly the same project. This second office belongs to one of the authors of this paper and had more than a decade of experience in producing detailed masonry design using 3D tools. This office does not have permanent employees and temporarily hires designers who were previously trained in its premises for working with 3D CAD, on a demand basis. Starting as trainees in this office, these professionals learned not only to model in 3D, but also the particular internal processes (Ferreira, 2007) developed to enable efficient design work coordination as well as to use the custom CAD routines created to automate some of the recurring tasks of masonry design.

This office used the process described in section 2.2 and adopted AutoCAD R14 and AutoCAD 2000 as primary tools, along with some custom AutoLisp routines.

For this study, only one designer was involved with the project, assigned exclusively to this task. She was a 26-year-old architect, graduated about two years before, who worked previously as an apprentice in this office for 30 months.

The same time-recording procedure was adopted in this case. No document or information was exchanged between the two offices. Their members did not have any kind of contact during this study and the designers had never met before. To avoid any information leak, the author who owns Office B and who normally acts as a design manager, did not work in this project, which proceeded without management interaction with the designer. This was not critical, as this job was hired only for this study. Because of that, and also because time spent on management activities, including team meetings, are difficult to compare fairly, it was not computed in any of the offices. Also, the time spent in modification tasks resulting from decisions made by management was also excluded.

The designer in Office B received the same documents Office A was provided by the contractor, i.e., architectural, structural and building systems designs in 2D CAD format. Change orders from the client to Office A were also forwarded to Office B.

The construction project used for this experiment was a twenty-story multi-family apartment building with 6 units per floor. Only two basic apartment floor plans were designed as 4 units were mirrored versions of one layout and two units were rotated versions of another one. The total number of distinct walls in the typical floor plan was 69 from a total of 148.

### 3.2 EFFICACY STUDY

Although the project used in the experiment for the efficiency study could also, at first, be used for efficacy comparison, data analysis showed no significant differences in the number of interferences detected by both methods applied to that project. The reason for this is probably due to the fact that the architectural and building systems design solutions adopted in that project are very well known to all designers in offices A and B as it was repeated with minor modifications, in several projects they worked on before. Kim and Wollemon (2003) have studied the sources of complexities on the new product development environment. One of them is the technological newness. One could characterize the complexity of the first project as very low, because it was not new at all, dismissing any special help the better visualization provided by the 3D methods could provide to the designer. Therefore, a more complex project was selected to comparatively evaluate the efficacy of the 2D and 3D methods.

A case study strategy was used for comparing the efficacy of 2D- and 3D-based methods. A more complex project from a major Brazilian building contractor, which included masonry detailed design, plumbing assembly kit design and façade detailed design, was observed. These three subsystems were analyzed using the 3D-CAD method described in section 2.2 for coordination purposes.

The Office B (the same from the previous experiment) developed those designs using AutoCAD 2005 and 2007, with AutoLisp routines, modeling the subsystems components as 3D solids.

The residential building of this case study has 29 apartment floors, 3 basement floors for garage, a common area at the street level with gardens, swimming pools and other leisure equipments. There are also 3 upper floors used to shelter a water tank and the elevator equipment. The project area totals 17,400 m<sup>2</sup> for the building construction in a 2,500 m<sup>2</sup> urban lot.

During design, the specialist registered the detected interferences, so that they could be solved later by the other systems specialists and the design coordinator.

## 4. ANALYSES

### 4.1 EFFICIENCY STUDY ANALYSIS

More than 200 records were registered in the time sheets by both design teams.

Trainees' activities accounted for 72% of the total development time at Office A. The coordinator was responsible mainly for checking and finishing activities, including correction of mistakes. In Office B, of course, the only designer performed 100% of all activities.

A number of activities were identified from the data collected. These were grouped under generic denominations, as shown on Table 1, due to the difficulty for discriminating the time used in each process of a single activity. For example, the generic activity "2D Design" includes both the time it took the designer to analyze a problem as well as that for drawing its solution. In the same way, "3D Design" encompasses the time for modeling, analyzing, checking, and correcting the design, because all these activities are done iteratively, in a continuous flow of operations, which could not be registered independently by the designers.

Some activity names were reported in both the 2D and the 3D methods, although in practice they reflect very different procedures. The times for every individual activity of each generic group were added up. Totals for each activity group as well as for the whole design work for both methods were obtained and compared.

Table 1: Description of Generic Design Activities

| GENERIC ACTIVITY          | DESCRIPTION                                                                                                                        |
|---------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| <b>Transcription</b>      | Activities concerning the conversion of the originally supplied 2D drawings into a format adequate to the internal design process. |
| <b>2D Design</b>          | Analysis + 2D Drafting (floor plans and views).                                                                                    |
| <b>3D Design</b>          | 3D modeling + Analysis + Model checking + Model correction.                                                                        |
| <b>2D Checking</b>        | Geometric and conceptual compatibility analysis + Checking.                                                                        |
| <b>Correction</b>         | Correction of geometric and conceptual errors.                                                                                     |
| <b>2D output</b>          | Dimensions, notes and sheet layout activities.                                                                                     |
| <b>Quantity Surveying</b> | Counting of masonry bricks and other wall components.                                                                              |
| <b>Design changing</b>    | Revisions due to change orders from the owner.                                                                                     |

Some activity names were reported in both the 2D and the 3D methods, although in practice they reflect very different procedures. The times for every individual activity of each generic group were added up. Totals for each activity group as well as for the whole design work for both methods were obtained and compared.

#### 4.2 EFFICACY STUDY ANALYSIS

The analysis method consisted in studying the records of the interferences detected between building systems and architectural, structural, and other building systems. Each interference record was assessed to determine if the problem could be detected using a 2D representation and the overlaying method or if it was only perceived because a 3D environment was used.

After classifying all interferences and constructability problems detected by the designer, total counts of both groups were produced, and percentages over the total amount derived.

#### 5. RESULTS

This section presents the results obtained from the analyses over the data collected in both studies.

##### 5.1 EFFICIENCY STUDY RESULTS

Data collected from Offices A and B in the controlled experiment were analyzed and summarized in the following graphs. Figure 1 illustrates total time for generic/aggregated activities, comparing the 2D and 3D methods.

The (2D and 3D) design, checking and correction activities had to be aggregated because many records in the Office A time sheet referred to mixed checking and correction activities, without separating individual times, making impossible to compute the total time for each of these activities. Also, the “3D design” activity includes checking and correction activities besides modeling and analysis and were also aggregated so that they could be compared to their 2D counterpart.

It can be seen in Figure 1 that, in 4 out of 5 general/aggregated activities, the 3D method took less time than the 2D method, resulting in 28.7% total time savings.

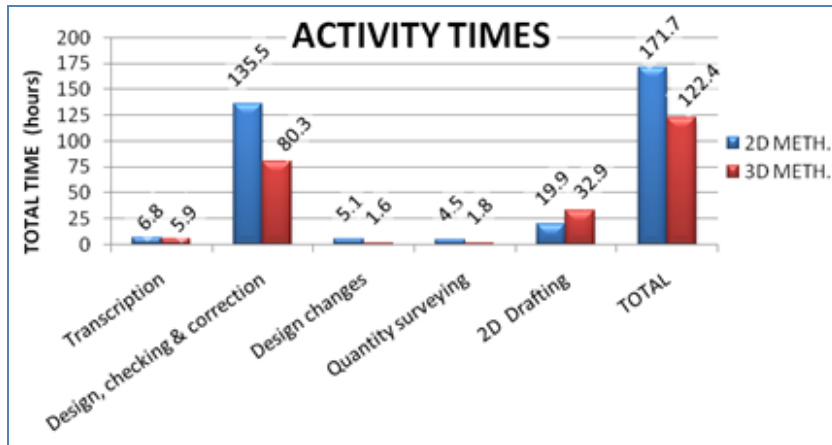


Figure 1: Total time for generic/aggregated activities for 2D and 3D methods

The activity time breakdown for the 2D Method (see Table 2) shows that checking and correction activities accounted for more than 1/3 of the total time in this method. It is important to remember that these activities do not aggregate value to the design process. Note that, in Table 2, the “2D Design” activity includes some tasks related to the “2D Drafting” activity.

Table 2: Percentage of total time for generic activities of the 2D method.

| GENERIC ACTIVITIES*   | % TIME 2D METHOD |
|-----------------------|------------------|
| 2D Design             | 45.3%            |
| Checking & Correction | 33.6%            |
| 2D Drafting           | 11.6%            |
| Transcription         | 3.9%             |
| Design changes        | 3.0%             |
| Quantity surveying    | 2.6%             |
| <b>TOTAL</b>          | <b>100.0%</b>    |

\* See table 1

Table 3 shows a breakdown of the recorded activity times for the 3D method. The “3D Design” activity concentrates most of the time spent on the design development. From an interview conducted with the Office B designer, it could be inferred that this activity also includes frequent checking and correction tasks mingled with modeling and analysis tasks with are the core of the design process. Nonetheless, there is a significant reduction on the total time spent on checking and correction activities, which are usually carried out by a higher-graded professional.

Table 3: Percentage of total time for generic activities of the 3D method.

| GENERIC ACTIVITIES* | % TIME 3D METHOD |
|---------------------|------------------|
| 3D Design           | 61.4%            |
| 2D Drafting         | 26.9%            |
| Transcription       | 4.8%             |
| Correction          | 2.9%             |
| Quantity surveying  | 1.4%             |
| Checking            | 1.3%             |
| Design changes      | 1.3%             |
| <b>TOTAL</b>        | <b>100.0%</b>    |

\* See table 1

Some other observations can be made from these data:

- Design changes were performed much more quickly with the 3D method than with the 2D one:* this is straightforwardly explained by the fact that changes in the solid model are easily done while changes in 2D imply changing drafted views, which is more complex in cognitive terms.
- Little time explicitly spent on checking and correction activities in the 3D method:* most problems related to geometry are immediately identified and solved during modeling by the

designer because they are easily spotted. On the other hand, the 2D Design activity requires some complex or attention-demanding steps, like drawing correctly and precisely section views from floor plans and transferring wall linking points that are not necessary on the 3D method, increasing the chances for making mistakes. These errors are usually only detected later on, during the checking phase. Then they are corrected and checked again.

- c. *Quantity surveying is faster in the 3D method:* using 3D CAD, brick counting is an automatic and precise task. The selection of blocks can be made by using filters. It is never necessary to count them manually, as it is, often, the procedure used with 2D techniques.
- d. *Total design time is shorter with the 3D method than with 2D:* it seems the time spent on checking and correction activities on the 2D method is much longer than with the 3D method. In the last, spent time concentrates on 3D modeling and analysis. At the same time, the automation routines are more powerful when operating on 3D data as the computer has much explicit information that, in 2D, are implicit or whose link is only in the designer's mind, like floor plans and section views or wall and brick thickness. Therefore, the computer can aid the designer more effectively.
- e. *The production of the final drawings took longer with the 3D method:* as this result is unexpected, we believe it is due to the way data was collected and do not reflect the reality. This activity time can be precisely accounted for in the 3D method, as it is done exclusively at the end of the whole design process for documenting purposes only. In contrast, the 2D approach uses drawings as a tool for design analysis and solution coding. Therefore, as stated before, it is difficult to clearly separate design actions from documenting actions and to record their times in different groups. As drafting is an automated task in the 3D method, it is likely that it will be much faster than in the 2D method.

## 5.2 EFFICACY STUDY RESULTS

Twenty nine interferences were reported during the design phase and coordination analysis. From those, 19 were assessed as only detectable using a 3D visualization method. Figure 2 shows one of those situations where the 2D view was not enough to detect the interferences between plumbing and ceiling (purple) or between sewage (brown) and cold water (yellow) pipes. The interferences are rather evident in 3D (see Figure 3).

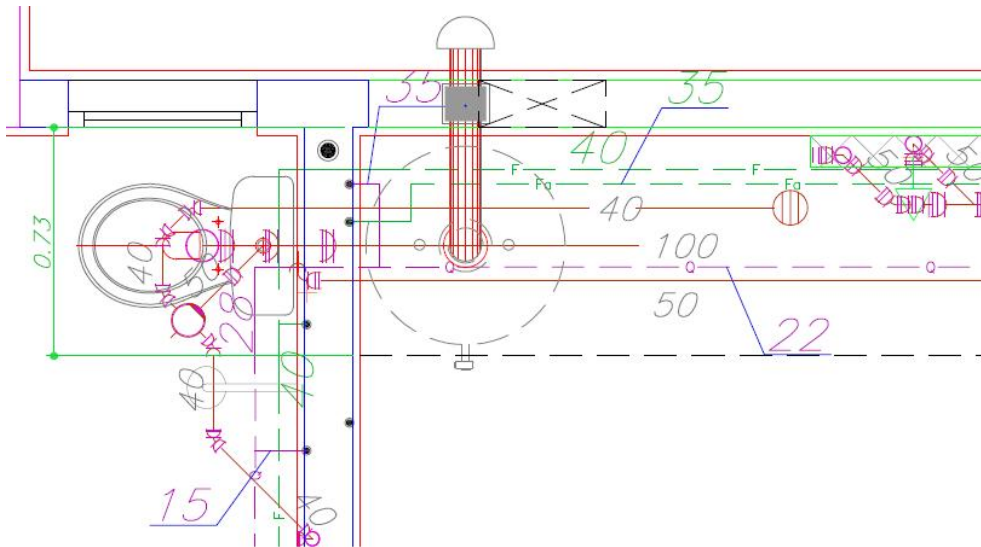


Figure 2 Some interferences that could not be detected in 2D.

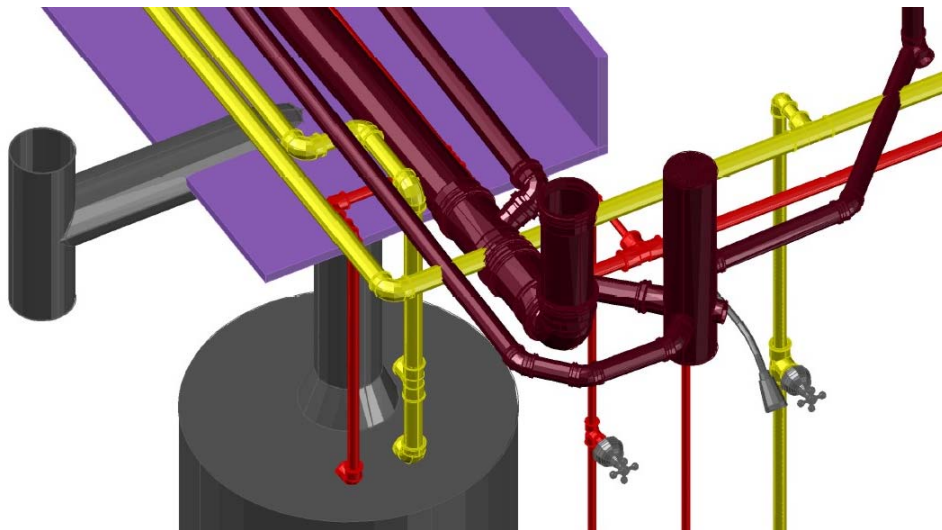


Figure 3 Interferences in building systems represented in figure 2 are evident in 3D

## 6. CONCLUSIONS

Although the conclusions that can be taken from this study are limited as it dealt with only two projects, one can say that it provided compelling evidences of the greater efficiency and efficacy of the 3D approach over the 2D-based method for design coordination.

Overall, the 3D-based method was almost 30% more time efficient than the traditional 2D-CAD process. Furthermore, only a small fraction of its time is devoted to the non-value-adding checking and correction activities while with the 2D method those amount to about 1/3 of its total time. Since Lean Thinking seeks to eliminate all non-value added steps (Soto, 2007), this fact is worth considering when it comes to optimizing construction design processes. The required amount of time in these activities is probably due to the abstract nature of the 2D representation which demands longer times for its interpretation. Also, it is more error-prone requiring corrections and further checking.

Quantity surveying is done quicker in 3D because this task is easily supported by the software. Design changes are also performed faster as they do not require modifying 2D drawings, which are produced only at the end of the 3D design process.

Regarding efficacy, the study reported here shown that the improved visualization attainable by the 3D method allowed much better results than 2D for detecting interferences. Most of the problems which could only be identified in 3D were related to deficiencies of the 2D representation itself, categorized by Ferreira and Santos (2007) in 5 types (see Table 4).

Most of these limitations are not inherent to the 2D representation itself, but they occur as a consequence of the current professional practice. In the 3D method used in this study, all components are modeled at their true size and adequate level of detail for detecting relevant geometrical interferences. By doing so, no symbols are used and hard interferences manifest as intersections among solids. No fragmentation takes place as the 3D representation is unified. All that contributes to increased interference detection efficacy.

Table 4: Deficiencies of the 2D representation

| 2D DEFICIENCY         | DESCRIPTION                                                                                                                                                                          |
|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Ambiguity</b>      | The same representation may be interpreted in different ways.                                                                                                                        |
| <b>Symbolism</b>      | A component is represented by a symbol whose dimensions are not related to the object it represents.                                                                                 |
| <b>Omission</b>       | Information is omitted from the drawing as a way to make it cleaner or because such information could be presumed.                                                                   |
| <b>Simplification</b> | A representation is a simplification of the object it stands for. It is similar to Symbolism, but its shape preserves some true dimensions (like pipes represented by single lines). |
| <b>Fragmentation</b>  | Occurs when the information necessary to fully understand the geometry is                                                                                                            |

scattered in several separated views (sometimes even in different sheets) like floor plans and sectional views.

Another worthwhile observation regards development costs. Although data about this matter was not collected in this study, it is supposed that the detailed masonry design and coordination cost about the same with both methods. This is because, even though the total design time is shorter with the 3D method, it demands a higher-wage professional and more expensive and powerful computer equipment (software costs are the same, as 3D capacities are available on the software typically used for 2D-based design). On the other hand, the costs of rework and diminished productivity due to interferences being detected later or even only on site because of the lower efficacy of the 2D method for spotting them on the design phase are much higher.

We hope mainstream AEC design may soon evolve to 3D environments, the only way the full potential of Information Technology can be realized in this realm. The adoption of BIM tools may be a perfect shortcut to reach this much needed condition.

## ACKNOWLEDGEMENTS

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## **FUTURE INTEGRATED DESIGN ENVIRONMENTS**

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### **ABSTRACT**

We are facing a probable great change in the way we carry through design in future ICT supported environments. The main driving forces are the digitalization of information handling leading to a paramount paradigm shift when information storage and access media are separated, building process and product systems are formalized in digital models, user environments are provided with rich multimedia access to virtual models, virtual collaboration rooms established, and new efficient and effective ICT tools defined and implemented.

There are though some barriers putting strains on the development. Among the most important are missing ontologies both on business and Web/Internet service levels as well as their interrelations, poor user involvement in needs and requirements formulations on new ICT tools and continuous user involvement in design and evaluation of new user environments, and lack of interoperability within building process/product models. The general competence level and preparedness for organizational and work change due to global paradigm needs to be increased.

The paper presents a system development approach to future development of Integrated Building Design Systems (IBDS) with efforts to specify needs and wishes on future system and resources to support system development. Examples are picked from ongoing global efforts as well as finished and ongoing research at Building Informatics, Aalborg University.

### **KEYWORDS**

Integrated building design, future, ontologies, models, user driven, innovation.

### **1. INTRODUCTION**

We are facing a probable great change in the way we carry through building design in future ICT supported environments. The main driving forces are the digitalization of information handling leading to a paramount paradigm shift when information storage and access media are separated, building process and product systems are formalized in digital models, user environments are provided with rich multimedia access to virtual models, virtual collaboration rooms established, and new efficient and effective ICT tools defined and implemented.

There are though some barriers putting strains on the development. Among the most important are missing ontologies both on business and Web/Internet services levels as well as their interrelations, poor user involvement in needs and requirements formulations on new ICT tools as well as continuous user involvement in design and evaluation of new user environments and ICT tools, and lack of interoperability within building process/product models. The general competence level and preparedness for organizational and work change due to global paradigm shift going from the art of writing via art of printing to the art of communication needs to be increased. There is also a need for better methods and environments to establish a more user driven innovation process and capture of user needs and requirements on future building functional systems.

We are entering a very complex society where competences typically are distributed among people in problem solving efforts. For example the old Building Master is now a team of collaborating building design specialists. We need partly new fundamental human values, tools, and methods to effectively and

efficiently act in these complex settings. A general competence level raise and preparedness for organizational and work change due to global paradigm shift is also needed.

The paper presents a system development approach to future development of Integrated Building Design Systems (IBDS) with efforts to specify needs and wishes on future system and resources to support system development. Examples are picked from ongoing global efforts as well as finished and ongoing research at Building Informatics, Aalborg University. Most research results are achieved in beneficial collaboration with building industry companies.

## 2. HISTORIC DEVELOPMENT AND ENABLING ICT

Information and Communication Technology (ICT) tools have been a powerful driving force in development of the way we work and handle information. During 1950-60 large computers were used typically for batch processing over night in custom made applications, and the results presented on heavy-duty line printers. Classification systems were used to structure documents. During the 1970s building models with abstraction hierarchies were introduced as well calculations on 3D models. The relational databases were introduced, CAD/(CAM) systems were deployed on main frame or mini-computers, and the time sharing operating systems were implemented. During the 1980s the personal computer was launched (1981) and the terminal rooms were slowly substituted with desktop accessible (not portable) computers. We got high-resolution raster graphics and windows in operating systems. Object oriented building modeling systems (mid 1980s) became available as well as the Internet and practical use of email. It became popular to develop Knowledge Based Systems. As a follow-up to the Initial Graphics specification (IGES, 1979) the Product Data Exchange Specification/Standard for Exchange of Product Model Data (PDES/STEP) work commenced in 1983, see also (NBS-DATA, 1988). 1989 the first version of a global operating systems, namely the World Wide Web (WWW), was formulated. During the early 1990 we could efficiently share applications on personal computers over the Internet, and video communication over the Internet was also possible, Figure 1. The first demonstrations had been made already 20 years before when Doug Engelbart 1968 demonstrated distant collaboration over the net with document sharing and video communication. <http://vodreal.stanford.edu/engel/17engel200.ram>. Biographical Sketch. Douglas C. Engelbart. Bootstrap Institute.



Figure 1: Left; Experimental set-up at KBS-Media Lab, Lund University, 1991, with video communication and screen sharing using Timbuktu from Farallon. Right; A hypermedia workstation developed 1988 at KBS-Media Lab, Lund University with video display of images and films stored on video disk integrated with the hypertext based program HyperCard from Apple computer. From (Christiansson 2001b).

It started to be meaningful to talk about virtual workspaces as complement to meetings performed in physical rooms. Virtual Workspace Definition from (Christiansson, 2001a); "The Virtual Workspace, VW, is actually the new design room designed to fit new and existing design routines. VW may well be a mixed reality environment. The VW will host all design partners from project start with different access and visibility (for persons and groups) in space and time to the project, and will promote building up shared values in projects. The VW thus acts as a communication space with project information support in adapted appearances. VW gives access to general and specific ICT-tools". A Virtual Space (VS) may also be characterized as a mixed reality environment optionally involving many physical spaces and many virtual spaces. A VS may be set-up within one building or many buildings placed in the local

community or on the other side of the world. A VS does not have to be stationary but can e.g. follow a person defined as the immediate surrounding of that person.

Today we can decide on how close we want the connection between the physical and virtual world to be. Real and virtual worlds can be merged to a Mixed Reality. We can augment the reality (Augmented Reality) or augment the Virtual Reality (Augmented Virtuality) (Milgram et al., 1994) depending on service relevance and surrounding constraints. See also Figure 2.

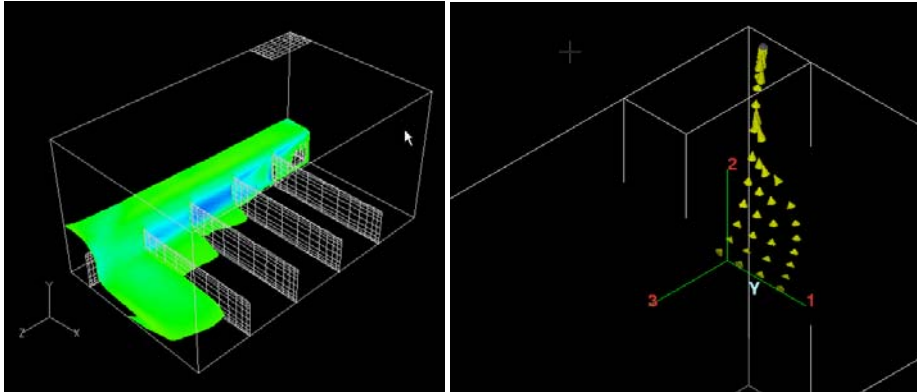


Figure 2: Dynamic interactive 3D visualization of airflow in a livestock building. The CFD (Computational Fluid Dynamics) simulation results were displayed and analysed with the visualisation software VU (Pic and Ozell) in a panorama and a six sided CAVE environment at VR Media Lab, Aalborg University. (The VU system was launched in 1993 and adapted for VR environments 1998.)  
From (Svidt et al., 2001)

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 for more than 40 years been engaged in building formalized digital descriptions (models) 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 2001. The Resource Description Framework (RDF) from 1997 paved the way for handling metadata on the WWW and The Semantic Web, see (Christiansson, 2003).

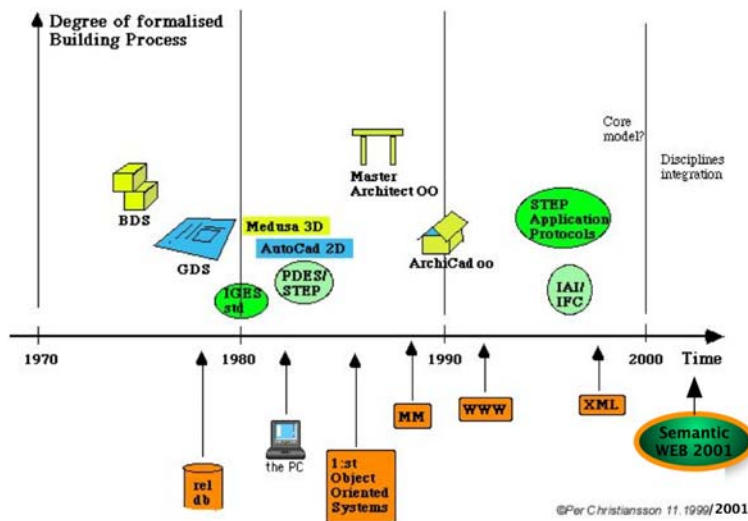


Figure 3: Building Product models development have during the latest decades had periodic focus on achieving a highly formalized non-redundant building product model, Virtual Building, VB. From (Christiansson & Carlsen, 2005).

Comments to Figure 4. A) Today's storage in CAD systems, where building models are developed and stored in CAD systems and transferred between CAD systems typically used by different disciplines. B) The ideal case, where discipline models can be merged into the shared IFC Building Model, <http://www.iai-international.org/>, either direct (simultaneous work on the building model) or via model file transfer. C) A possible situation of today, where building sub-models are extracted from the model server, checked and stored locally by e.g. Solibri modelchecker, <http://www.solibri.com/>. D) A rare situation today, where even changes on simplified VR-models (often surface models) can be transferred back to discipline models in CAD systems and further to the IFC Model server for merging. VR models are made due to lack of computer resources and low network bandwidth to allow direct interactive work on large building models. These VR-models may typically be used for design brief and design review. E) Is the same as D) but updates on the VR-model has to be manually transferred from VR-model to discipline models.

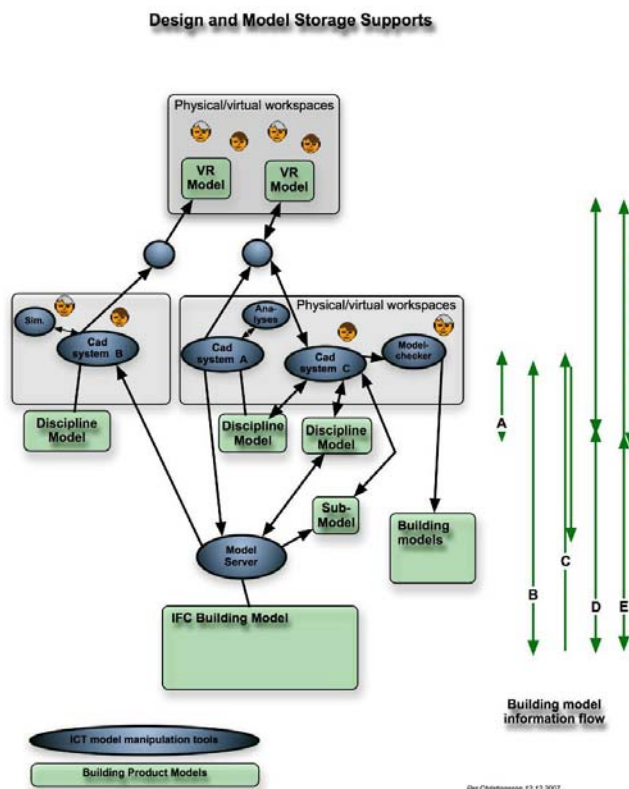


Figure 4: Building product model can be stored shared and distributed.

### 3. SCENARIO AND VISION

In the following a short scenario is sketched describing a future Integrated Building Design Environment (IBDE) from the user perspective: A client contacts a client advisory system on the WWW to learn more about the prospects on a new office building he is going to build. He contacts an architectural-engineering company and starts the project. The client involves a group of building end-user representatives in an early user-driven creative design process. He also includes the contractor in the early decision process to secure constructability.

After that alternative building solutions, expressed as Component Building Systems (CBS) and Functional Building Models (FBS), are evaluated by end users against needs and external requirements. A FBS may for example be a comfort system to provide personal living and working quality, a personal transport system, a load carrying building system, an escape system, or a communication system (collaboration, knowledge transfer, mediation, virtual meeting). Functional building systems may be improved through embedded ICT-systems to help in making the building more intelligent and responsive to end user needs, usage context and surrounding constraints, see also (Christiansson, 2007). Before a client end-up with a requirements specification on a building and its services, the design team has to recurrently traverse the end user needs capture and consolidation process. The end-users of a building are typically building inhabitants, external service providers, operations & maintenance (O&M) personnel, and building administration. They may in many cases have conflicting wishes and expectations on building performance optimizing from their world of discourse. Wishes and needs on the functionality of the final building have to be formulated with common mutual understanding in a collaborative process we can call co-creation, see (Pralhad & Ramaswamy, 2001) and (Christiansson et al., 2008).

The design process is then partly carried through in virtual spaces with access to the building product model on different detailing levels (volume, space, building element etc.) and can be browsed in geometric and time coordinates (4D).

The client early specifies representation, content and functionality of the building model to be delivered after construction is completed. He also demands to get a model where he can acquire design rationale on different alternative solutions and rich multimedia access to as-built documentation on component building systems.

#### 4. NEEDS ANALYSES

We are now prepared to start formulating needs on the future Integrated Building Design Environments (IBDE). The IBDE should be able to provide new functionalities, new services, new ontologies, new human computer interaction environments, and be useful in different business environments supporting new business models, collaboration forms and less dependence on today's often phase locked process.

Practical experiences on how to organize and carry through collaboration on digital building models (Virtual Building, VB) should be (publicly) accumulated and contribute to the future implementation of tools for collaborative design using digital models of buildings and associated processes (BIM, Building information modelling).

What important trends can we observe today?

- Local business is becoming global local-like business.
- Business models are changing. We have today business models very much based on locally optimizing value chains, see also Figure 5.
- Innovation in building is a challenge (fax and mobile phones were real hitters).
- Virtual Organization is more often brought into play.
- Moore's law will be valid for at least another 20 years (memory, speed, ubiquitous computing).
- Extended development and use of meta-data marked www-accessible information (e.g. semantic web based solutions). See also (Lai, 2006).
- Clients get instruments to formulate better requirements on buildings, see also Figure 6.
- We are introducing, also in practice, the time dimension (4D) in Virtual Building models, see e.g. (Fischer & Kam, 2002).
- Virtual building (VB) models access is getting more standardized through use of the IFC standard, <http://www.iai-international.org/>.
- Efforts under way to create International Framework for Dictionaries (and Ontologies) (IFD), <http://dev.ifd-library.org/>
- Intelligent products and buildings with embedded sensors and actuators are again in focus.
- Energy optimization and ecological building is gaining importance.
- We should be in a continuing reflective development process aiming at moving goals.

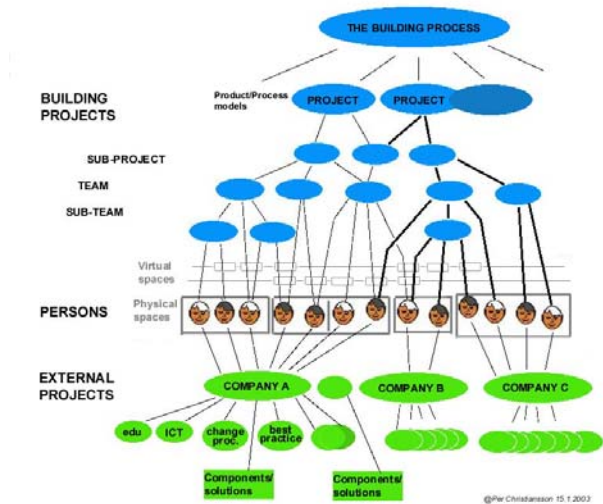


Figure 5: Organizational view on internal and external building project actors, activities and attached information containers. (Christiansson, 2003).

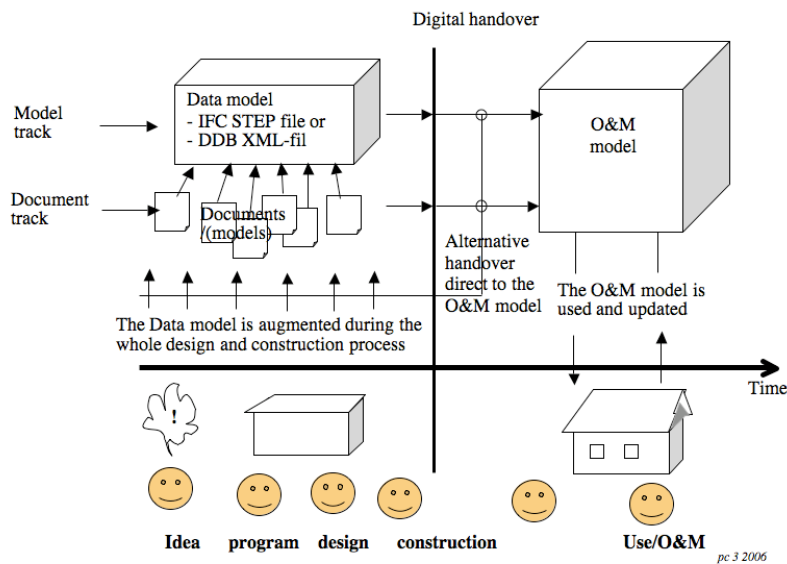


Figure 6: The newly released, January 2007, Danish digital construction requirements let public clients put requirements on the content of the digital models of the building handed over to the client after finalised construction. (DDB, 2006). From (Christiansson, 2007)

Needs list (that could and should be revised and extended)

- Quality Assurance (QA) on building process to minimize errors in the final product.
- Important decisions to be taken early in the process.
- Better interactive process models for simulations with automatic update possibilities of VB.
- More user-friendly design tools supporting use of thin flexible screens, haptic feed-back, ubiquitous access).
- Efficient distributed collaboration on Virtual Building models in virtual spaces.
- Common ontologies at least on business meta level, see also Figure 7.

- Ontologies for functional building systems (FBS) such as comfort and personal security systems, see also Figure 8.
- Landmarks (on high business and ICT levels) to aim at during long-term research, development, and organizational and work method change.
- Increase in general competence level and preparedness for organizational and work change due to global paradigm shift, going from the art of writing via art of printing to the art of communication.
- Increased possibilities for user driven innovation and co-creation in the design process.
- Motivations and tools for open ontologies and open business models development.
- More building informatics related education on university level and ICT supported learning, see (Christiansson, 2004)

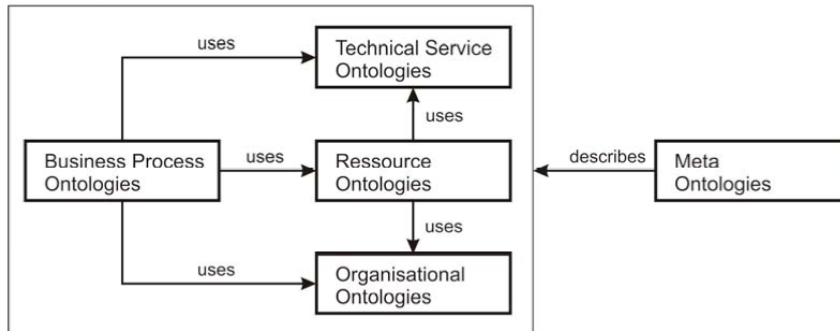


Figure 7: Overview of meta building ontology domains and their relations. From (Sørensen et al., 2008)

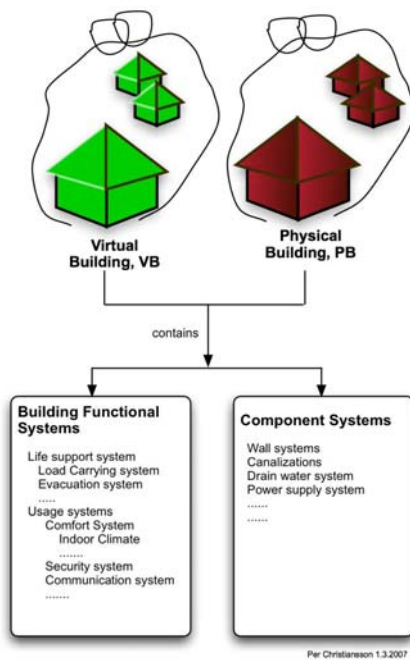


Figure 8: The Virtual Building (VB) model should be a digital copy of the real building, the physical building (PB), even before it is built. (Christiansson, 2007). In (Christiansson & Svidt, 2006) it is further described the relation between functional building systems (FBS), and Component Building Systems (CBS) and detail levels of VB descriptions.



## 5. SYSTEM DEVELOPMENT

### 5.1 INTEGRATED DESIGN SYSTEM

In the real world, see Figure 9, we identify activities, things, processes, context, and persons. The real world building can be described as (interrelated) building systems (FBS) (no de-facto structure is available today) to accomplish different functions e.g. a comfort system to provide personal living and working quality, personal transport system, load carrying building system, escape system, and communication systems (collaboration, knowledge transfer, mediation, virtual meeting). The systems are modeled in context and more or less formal conceptual models, and later data models in formal representations, are designed. The data models are implemented in computerized information handling systems, and the ICT systems performance is (continuously) evaluated and usability tested, (Christiansson, 2007).

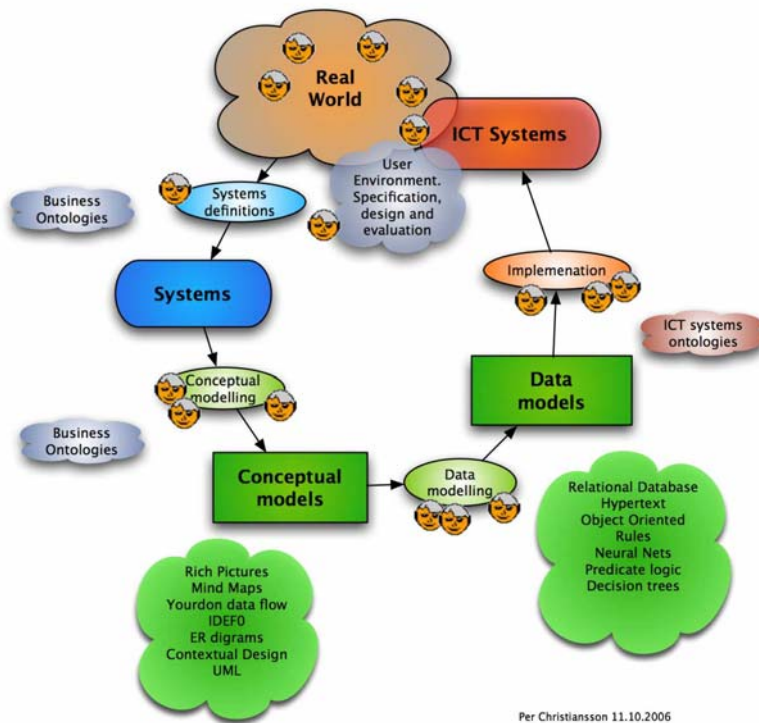


Figure 9: Real world systems supported by ICT systems. The Systems may in connection with Integrated Building Design Environments (IBDE) characterize a building or the design process.

Needs and requirements formulation from end users leads to specific requirements on the building functional systems and their implementation as a physical building. The traditional functional building systems may be improved to help in making the building more intelligent and responsive to end user needs, usage context and surrounding constraints. From (Christiansson, 2007)

### 5.2 AMBITION, RESOURCES AND TIME

During the last century the so-called 'industrialism' has been the ruling paradigm. We are now in the phase of changing to something new, which we could call 'globalism' ('the global village') or 'organism' (from organization and organic). During the industrialism there was a need for man skill in the realm of logics to make known processes more effective. Today we need more non-parametric studies and creative thinking to formulate and try out sometimes totally new processes on all level in our society, (Christiansson, 1993).



The higher the degree of formalization the more effective and efficient the computerized models of building product and processes will be and less flexible to changes, see Figure 10. It is of course a question about optimizing in a set of constraints, (Christiansson, 1993). These constraints may be dictated from external needs and access to resources (such as workforce, material, money resources) and available time as well as type of building product. During the 1960s there was probably another set of constraints than today.

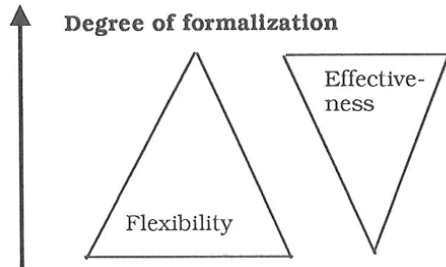


Figure 10: There might be a negative correlation between effectiveness and flexibility for different representations. From (Christiansson, 1993)

### 5.3 USER DRIVEN INNOVATION

Figure 11 shows the basic layout for a user driven innovation and design system developed by two main engineering and architecture companies in Denmark , Rambøll A/S and Arkitema A/S, and Aalborg University, Civil Engineering department. See also (Christiansson et al., 2008).

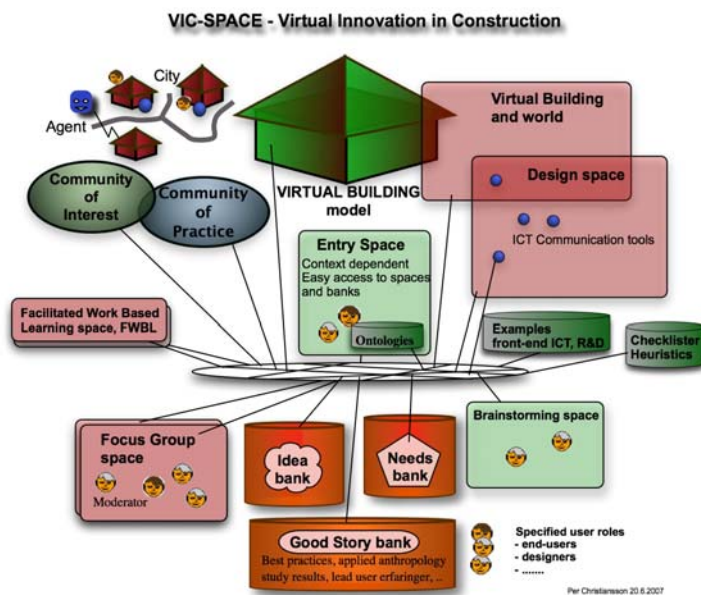


Figure 11: The Virtual Innovation in Construction methodology, VICMET, will house a number of spaces suited for different activities. From (Christiansson et al., 2008).

### 6. CONCLUSIONS

We are in the middle of a great change process concerning development of Integrated Building Design Environments. Design activities and design competences collaboration are increasingly carried through in a global context in more or less virtual spaces using rich multimedia interfaces, and digital virtual building and process models. We are in fact accomplishing an innovative creative design of future design

tools and buildings, requiring significant end-user involvement usability engineering. Ontologies and dictionaries have to be further developed especially on business and meta levels to secure effective systems interoperability, and information handling. Functional Building Systems have to be categorized and the client needs capture and requirements formulation and modeling be further advanced. There is a great need for increased efforts within building informatics education to secure needed competences for leading and carrying through the future research, development and innovation activities.

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## COOPERATIVE DIGITAL STUDIO IT-SUPPORTED COOPERATION FOR AEC STUDENTS

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### ABSTRACT

Teaching cooperation-related issues to AEC (Architecture, Engineering and Construction) students is a major stake nowadays. There are many reasons for that: construction projects become more and more complex and cooperation practices are evolving in both organizational and IT-based ways. It is notably for these reasons that the issue of IT is addressed in most of the AEC-oriented schools and universities. Traditionally IT is taught to support the tasks of each specific construction field (e.g. CAD for architects, simulation tools for static engineers etc.). The Digital Cooperative Studio, presented in this article, considers IT as a support to cooperation and especially its communication and coordination dimensions. Moreover, we describe here a living lab involving students, teachers and researchers. This strong link between research and teaching allows both the students to be “analysts” of their real project situations and the researchers to experiment their development in real project situations.

### KEYWORDS

Education, Architectural Design, Cooperation, IT-Services

## 1 INTRODUCTION

Construction projects become more and more complex, involve many actors, who are heterogeneous and work together for short-time periods. The professional practices are constantly evolving. The increasing number of actors involved in projects and the new needs of expertises are changing the cooperation practices in an organizational way. Moreover, these new practices are often based on the benefits of IT. New ways of working are enabled, such as representing the project or simulating its different aspects, but also supporting the cooperation practices through more transparent, described and managed flows of tasks and documents.

In the AEC educational curriculums, teamwork exists and students are often placed in collective situations, working in group on architectural/urban project design. These situations are close to the ones existing for example in architecture agencies, where some collaborators have to share tasks and documents to answer a client's demand. This form of collective working is generally driven by hierarchy and procedures. But this type of group work is too limited and we think that students are not enough prepared to the collective and multi-disciplinary dimensions of construction projects. In such situations heterogeneous actors have to work together in unpredictable and changing environments. Furthermore, the participants of projects are often distant and they work at different time periods.

In this context, the use of IT tools is necessary to simply enable the collective work. Nowadays architecture and engineering schools students are familiar with numerous IT tools, useful to design, simulate and merely represent their architectural projects. But, once more, we notice that they are not aware of IT-based tools supporting cooperation between participants of a project (i.e. groupware tools).

For all these reasons we setup the Digital Cooperative Studio: an experiment of collective architectural design between distant teams of students. In this article we present firstly a brief state-of-the-art of other

digital studios. Then, we describe the 07-08 SDC aims, the organization of students' work and the IT-tools setup to enable cooperation activities.

## 2. VIRTUAL STUDIO OF ARCHITECTURAL DESIGN

### 2.1 ICT EDUCATION FOR AEC PROFESSIONALS: A STATE OF THE ART

For many years now, ICT has become a full-fledged field of education in the AEC-related curriculums. Following the professional practices changes regarding to ICT, schools and universities have integrated new courses to prepare the students to the use of these emerging tools. For example 2D CAD, largely used in practices nowadays, is also largely taught in the architecture and engineering schools (Hannu 2003).

An interesting topology of ICT in architectural design education has been established by (Sariyildiz et al. 1998). It distinguishes between three types of traditional tools: information processing tools, communication tool, and visualization tool during the creative design process. It includes also three types of emerging tools: knowledge integration tools, decision support tools and design tools. One can observe that the latest research innovations are also applied, often in experimental ways, in some AEC-related teaching fields: decision support tools and 4D simulation (Sampaio et al. 2007; Wang et al. 2007), architectural and morphological design tools (Prokop et al. 2005) or analog to digital conversion tools issues.

In parallel, the issue of cooperation is becoming more and more essential in the construction projects practices. In education many interesting cooperation-related activities also emerged. It is the case of the topics of knowledge integration, search and retrieval of information (e.g. educational), especially in cross-media ways (Fruchter 2007). The topic that interests us very much is the one of cooperation between members of a construction project. Moreover the research activities that we carry out are deeply anchored in the multi-disciplinary cooperation issues. The fundamental aspect of cooperation in collective projects has been defined by (Kvan 2000) and (Benali et al. 2002).

In the Virtual Design Studios, numerous aspects of cooperation have been described:

- The roles' distribution approach (Van Leeuwen et al. 2005),
- The scenarios to build project-organizations, to favour trust relationships, especially between geographically distant students (Cheng 1998; Donath et al. 1999),
- The cross-disciplinary approaches, placing an "AEC expert" (i.e. an architect, an engineer, a technicians...) in the need to cooperate with another "AEC expert" (Forgber et al. 1999; Fruchter et al. 2007).

Finally, the recent successes of the virtual worlds concept interested the teachers. Some experiments of co-design have been done in such virtual contexts, such as the eCAADe world (information storage & presentation, landmark in 3D/immersive Internet environments, experimentation on virtual collaboration and interaction) (Brown et al. 2001; Schnabel et al. 2001).

### 2.2 COOPERATIVE DIGITAL STUDIO (SDC): A FR/BE/LU INITIATIVE

In 2007-2008 the Digital Cooperative Studio was the result of an association between two academic institutions (Architecture School of Nancy & University of Liège) and three research laboratories from France (CRAI), Belgium (LuciD Group) and Luxembourg (Public Research Centre Henri Tudor). The educational curriculums are closer: a Master Degree in Nancy<sup>5</sup> and 2nd/3rd year of Architecture/Engineering studies in Liège<sup>6</sup>.

These partners are complementary by the study curriculum but also by the research projects that they carry out, both in the topics of Computer-Aided Architectural Design and of Assistance to Cooperative Activities in Construction.

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<sup>5</sup> <http://modelisation.nancy.archi.fr>

<sup>6</sup> <http://progcoours.ulg.ac.be/cocoon/en/programmes/AIICAR01.html>

## 2.3 PRINCIPAL AIMS

For some years, at the Architecture School of Nancy, the initial objectives of our pedagogical experiments are to sensitize the students to the cooperation issues in Architecture. In 2004 our first studio put together French and Thai students to design an exposition of research works (Kubicki et al. 2004; Bignon et al. 2007). Since 2005, with the Architecture School of Versailles we have run several experiments of co-design with little groups of students, and using collaborative tools (Bignon 2007).

In these Digital Cooperative Studios (SDC) our principal aim is to put together students from different geographical origins and from different skills in shared design projects. The scenario of these projects is: working distantly (mixed teams from Liège and Nancy), involving different skills (curriculums are different in the different schools), in both synchronous and asynchronous ways.

This cooperative scenario is the ideal situation to sensitize the students to the use of cooperative IT-tools to communicate, to share tasks, to setup coordination... In one word: to co-design.

## 2.4 07/08 PROJECT

The 07-08 cooperative studio involved 29 students from Nancy and Liège. The architectural project consisted in designing a "House of Environment" (3000 m<sup>2</sup>), comprising a conference centre, a library and a cafeteria. The site was in Nancy, France.

The environmental issue was chosen by the pedagogical team for many reasons. Firstly, it is a contemporary topic, emerging from current considerations (e.g. on climate changes, energy savings etc.), which is attractive for future architects and engineers. Secondly, this issue was interesting in stimulating cooperation between students. In fact sustainability in building should only be raised by collaborative teams of experts, bringing their forces together to address its numerous dimensions. Finally, in their master's curriculums, the students acquired competencies in diverse computer simulations. It was interesting to re-use it to perform sustainability assessments on the projects: 3D modeling, natural/artificial light evaluation and energy efficiency.

## 3. SDC ORGANIZATION

### 3.1 TIME MANAGEMENT

Three essential steps had marked out this Digital Studio:

- The kick-off meeting in Nancy allowed all the students to meet, to visit the project's site and to constitute the working teams. This "Kick-off one-day workshop" allowed interpersonal relationships to become established. This way of working has been demonstrated in the past year and applied by other pedagogical teams (Elger et al. 2001).
- The intermediate projects' presentation in Web conference was the moment to point out the critical options on the projects and to reinforce the roles of each student in the projects.
- The final presentation in Liège, where all the four projects were presented by the students and evaluated by the teaching team. This presentation consisted of both an architectural/technical/environmental description of the projects and a critical analysis of the cooperative dimension of the studio.

### 3.2 TEAMS

The teams were composed of 6-7 students from Nancy and Liège. The duration of the studio was quite limited in time (3 months from October to December).

The teaching team has defined 7 particular roles that the students had to take personally: architectural composition, interior spaces design, environmental quality responsibility, natural and artificial enlightening, structural engineering, special engineering techniques, and energy management.

Based on our previous virtual studio's experiences we thought that giving each student a particular responsibility was essential to stimulate them. It was all the most important since 1) the duration was limited and 2) the teams was quite big.

### 3.3 THEORETICAL COURSES

The pedagogical inputs consisted both in a supervision of the architectural projects' design and in a set of theoretical courses.

Weekly supervision in Nancy and Liège consisted in guiding the students in their projects. Architectural and technical options were guided by the teaching team in order to choose forms (morphology) and techniques favouring the involvement of the different roles and the necessity of exchanging information.

Theoretical courses was taught both in Nancy and Liège through Web conferences. They addressed some topics related to cooperation in design activities and were strongly inspired from theoretical research results. The metamodel of the cooperation context that we have developed (Kubicki et al. 2005) is particularly adapted to introduce to the students the essential concepts related to cooperation: actors (e.g. organizations of actors), activity (e.g. tasks coordination, project management), documents (and especially the ones supporting coordination) and finally the assistance tools (taxonomy of tools supporting cooperation).

The notions of actor organizations and task coordination are especially focused in these courses. In addition we insist on examples applied to the design and construction collective activities in AEC. We also taught issues related to object sharing. The standardization of building's object description was introduced through the concepts of digital mock-up and the description of the IFC format.

### 3.4 COOPERATION PROCESS

In 2007-2008, SDC had taken place from October to December, during 13 weeks. In order to perform the work and to realize the project, a cooperative process (Figure 1) was defined with the students. This exercise was based on the main concepts related to cooperative projects taught in the theoretical courses.

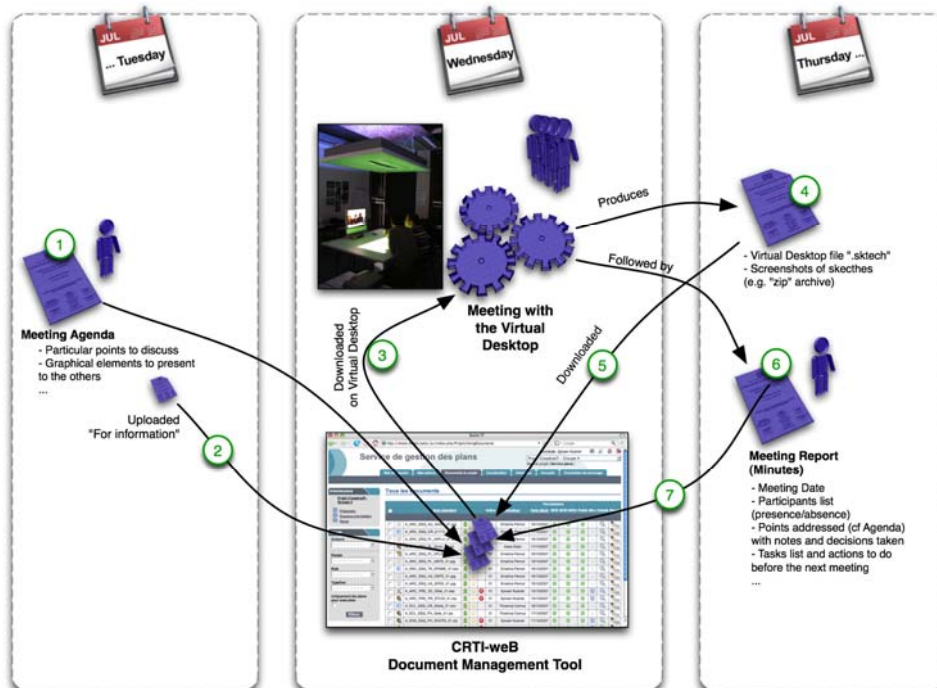


Figure 1: The cooperative process in SDC 07-08

The main idea of this standardized process was to sensitize the students to the necessary management of exchanges and interactions that they had to setup in order to facilitate cooperation and to enable coordination of their tasks. At this step they had to decide who could handle the coordinator's role in each group. We will discuss below in part 4 the tools represented in the Figure 1.

The cooperation process could be described in three weekly stages. The central stage was the Wednesday synchronous team meeting. Each part of the teams virtually meets at the same time in Nancy and in Liège. This coordination meeting was the essential stage enabling to share ideas, to debate and to take decisions.

Prior to this meeting (each Tuesday) the meeting preparation task consisted in preparing the documents to be discussed. It was also demanded to prepare a meeting agenda ensuring to structure and optimize the meeting time.

And after the meeting a task of meeting report consisted in writing what had been decided. This essential document was the “written trace” of the exchanges and of the taken decisions. This meeting report had to be approved by all the members of the team.

#### 4. A SET OF INNOVATIVE COOPERATION-SUPPORT TECHNOLOGIES

More than a Master course, SDC is also a real “living lab” to experiment IT-services resulting from our research projects. We introduced strong relationships between the work process (Figure 1) and the tools made available to the students in order to facilitate their cooperative distant work. The use of a document management system (§4.1) and of a Virtual Desktop for sketch sharing (§4.2) led the students to be sensitized to the benefits of IT to support their cooperative practices.

##### 4.1 CRTI-WEB: A DOCUMENT MANAGEMENT SYSTEM

The document exchange server “CRTI-weB” is a Web platform<sup>7</sup> (Figure 2) developed by the Public Research Centre Henri Tudor in Luxembourg. It consists of a shared project space, available for all the participants of a project from every computer connected to the Internet. It allows the project’s members to upload the documents that they produce in order to design the architectural project, and to share them with the others. The aim is to centralize the documents and to trace their updates and modifications. Moreover it enables also to notify the users when a document is available, and to assign task (requests), such as validation tasks or reaction demands. The reaction functionality is a real “discussion forum” between project members about a specific document.

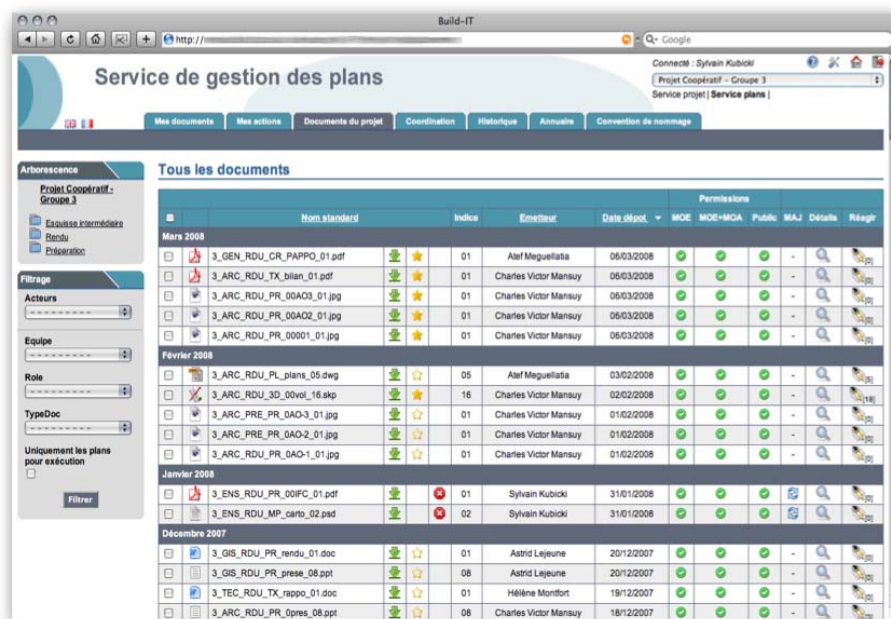


Figure 2: CRTI-weB document management server

<sup>7</sup> A demo access is available at <http://demoged.buillit.tudor.lu> (login: “demo”, password: “demo”)



#### 4.2 SKETCHA: A VIRTUAL SKETCHING TOOL

The Virtual Desktop (Figure 3) is a tool developed by the University of Liège, in Belgium (LuciD Group laboratory<sup>8</sup>). During a distant project meeting, it allows its users to draw and sketch on a shared virtual workspace.

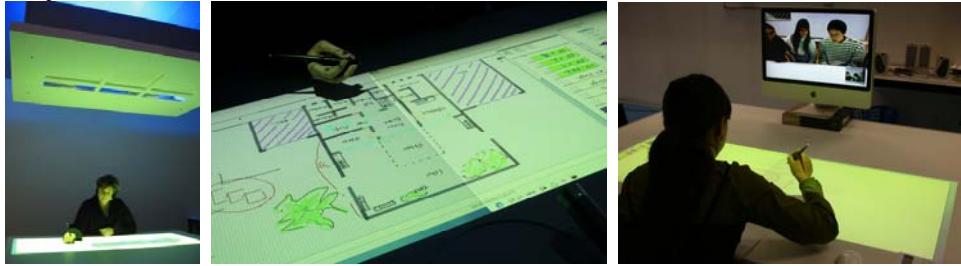


Figure 3: The Virtual Desktop and its software, Sketsha

This tool comprises both a software part and a hardware part. The desk itself is composed of a large tactile table with which the user interacts with a stylus. Two video projectors display a Mac OS X computer environment.

The software “Sketsha” completes this hardware. It allows the users to draw on the table with the stylus, manage sketch layers and the imported reference images. Sketsha displays the sketch on the two distant screens and manage coherence and changes in real time. The users can then co-edit the project while he discusses in real-time with the Web conference system (iChat).

### 5. DISCUSSION

#### 5.1 STUDENTS’ FEEDBACK

The students’ feedback was largely favourable to the pedagogical approach in this Digital Cooperative Studio. At the end of the semester the overall student’s belief was that traditional curriculums do not prepare them very well to the cooperative dimension of construction projects. In this way, the theoretical courses associated to the real design project situation were an interesting living lab, where “theories could be applied to real projects”. However students noticed also that too theoretical courses were hard to understand/apply. They asked for applied examples to communicate organizational or coordination-related theories.

The unbalanced work-planning between Liège and Nancy students had been also noticed. This has lead to difficulties related to different engagement levels in the projects. This problem intensified another one related to the roles’ distributions. In fact the engineers sometimes felt confined to a “verifier” role in charge of validating design choices. It was probably due to the unbalanced work-plannings, to a certain lack of teaching instructions, but also to the communication difficulties (due to the geographical distance between students).

Concerning the tools, the feedback had been also globally positive. The use of innovative tools motivate the students. We think that the feeling of participating to the tools’ specification/development/improvement is important to stimulate their use. Remarks concerning tools-related feedbacks are developed in parts 5.3 and 5.4.

#### 5.2 PEDAGOGICAL RESULTS

The short duration of the studio (3 months) has been an obstacle for the students in delivering a well-detailed proposition of their architectural projects. Nevertheless we observed that if the overall projects were not well-defined, the role’s allocation allowed the students to detail and improve some specific aspects related to their role.

Thus, for each project (Figure 4), a structural study has been performed, natural enlightening simulation guided the facades’ design, or the energy loss evaluation oriented the choice and assembly of materials.

<sup>8</sup> <http://www.arch.ulg.ac.be/Lucid>



Figure 4: The four architectural projects designed

An interesting remark is that these roles have been addressed by the students as complementary. It means that they understood that one role had to receive the work of another one, to validate it and to send back a validation or not, in a sequential process. The teaching team tried during the semester to change this “collaborative” way of working and to favour a more “cooperative” way of working. The results were interesting. In a team in particular an iterative attempt/error/redesign scenario has been setup and guided to very interesting results. In this approach, the technical roles were not limited to a verification role, but they had a real place in the design process, e.g. suggesting solutions and compromises. Figure 5 (realized by the students themselves) presents this cooperative process applied to the stages of the façade design.

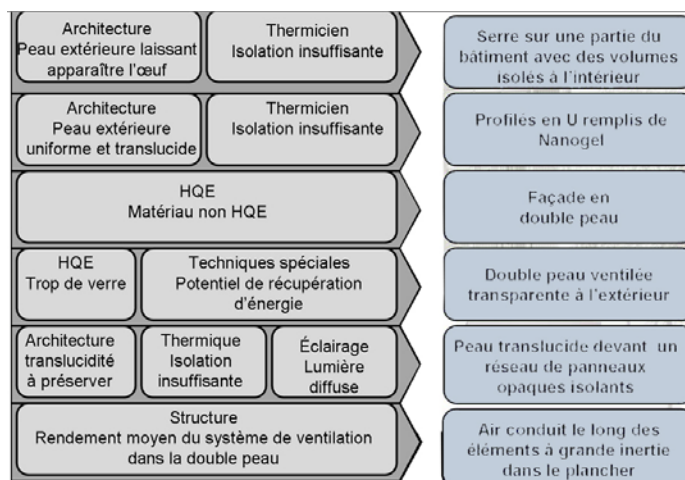


Figure 5: Cooperative process, as applied by one group on the facade design choices

### 5.3 TOOLS EXPERIMENT FEEDBACK

The use of the research-issued tools led us also to assess on their use in real project's cases. The Virtual Desktop designed as an easy-to-use, sketch-based tool has proved its ability in sketching in a natural way (horizontal table). Moreover its cooperative sketch display was useful in sharing ideas and in co-

sketching (2 hands on the same sketch). The students noticed the need to initially understand how it worked, and after that the use was easy and efficient.

The document management server was also assessed during the SDC. The critical point in its use was the definition and implementation of a standard naming for the documents. This point was quite hard to understand for students who were not familiar with the difficulties related to document exchanges between heterogeneous groups of actors. But we can see in the Figure 4 that it was not a problem in the use of the tool. It had constantly been increasing from October to December.

Figure 6 shows the increasing number of documents uploaded to the server. This number was quite homogeneous between the four groups of students.

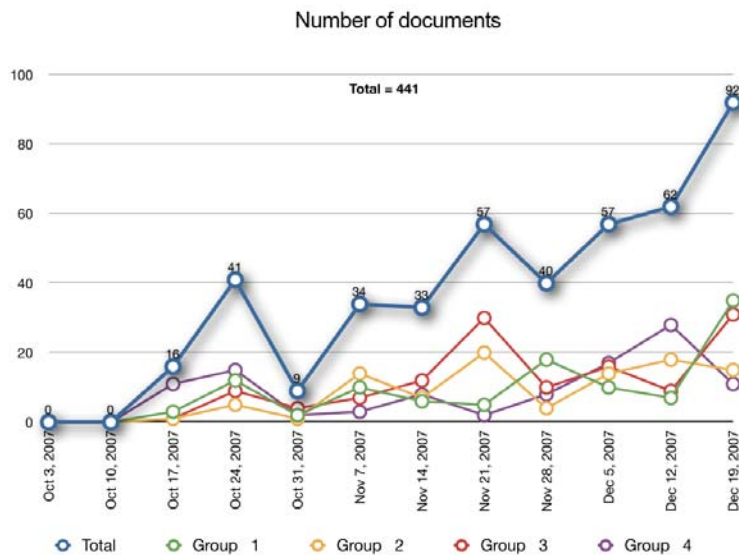


Figure 6: Number of documents uploaded on CRTI-weB server

Figure 7 shows the number of reactions sent by the students about the documents. In this case we can notice that the use of this functionality is variable between the groups. In fact, some groups had used the tool to communicate and other groups used instead other external communication tools (as MSN messenger).

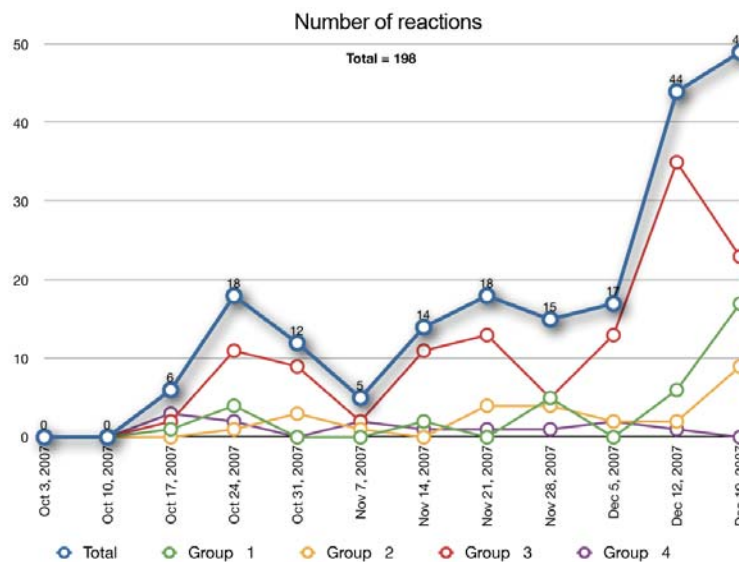


Figure 7: Number of reactions about the documents on CRTI-weB server

#### 5.4 TOOLS IMPROVEMENT IDEAS

During the studio and in the final enquiries we were interested in the feedback about the use of the experimental tools by the students. The difficulties have been mentioned above. But many improvement ideas also emerged. So far as we could, we have tried to take the remarks into account in real time, and to improve and update the tools during the semester. A new release of Sketsha delivered new functionalities to manipulate the sketches (move, rotate...). The CRTI-weB document server was also updated many times, especially to repair the bugs discovered by the students.

In terms of improvement, we noticed the idea of integrating a discussion forum or a chat service in the CRTI-weB server. The notification function was also criticized and should have to be improved through customization options. Some ideas related to visualization of the documents were also formulated, such as preview of pdf documents, or ideas related to the documents' list Human Computer Interface.

Another interesting idea has emerged. It consists in integrating the two tools to offer new possibilities such as importing a document directly from the CRTI-weB server to Sketsha, or saving a sketch to the server. This interesting idea will probably be envisaged in future research cooperation.

#### 6. CONCLUSION

Projects and experiments of collective design are essential in AEC curriculums. Future practitioners have to be sensitized during their studies to the cooperation mechanisms, methods and tools facilitating their future practice.

One challenge for pedagogical teams is to transmit the theoretical concepts related to cooperation and coordination to the students who are often focused on their project design exercises. In SDC we privilege a mixed approach both conceptual and applied. Theoretical courses coming from research developments are immediately applied in the project teams through a standardized basic process (Figure 1) built with the students themselves. The cooperation was also stimulated by the subject itself: a house of environment. The project had to be designed according to sustainable development criterions and each student wore an organizational role related to a specific criterion.

Beyond the organizational aspects of cooperation we also have to make students aware of the emerging technologies supporting cooperation. A strong link existing between our research projects and the pedagogical studio allows students to experiment innovative IT tools (i.e. groupware). These "living lab" projects are interesting both for the students, future users of cooperation-support tools, and for the researchers, to get feedback from the use of their experimental tools.

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**UNDERSTANDING ADOPTION AND USE OF ICT IN CONSTRUCTION PROJECTS  
THROUGH THE LENS OF CONTEXT, ACTORS AND TECHNOLOGY**

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**ABSTRACT**

In the literature on construction related ICT no distinction is usually made between ICT use in the permanent organization and the temporary organization forming the building and construction projects. By drawing on the rich body of literature on organizational and managerial aspects of ICT the aim of the paper is to investigate how the interplay between contextual elements, actors' frames of reference, and the ICT influence the adoption and use of ICT in building and construction projects. This objective will be pursued by an analysis of an ongoing study of ICT use in the Swedish building and construction sector, including semi-structured interviews and an ethnographic inspired study of a partnering project worth 50 million €. It is concluded that project based mode of organizing, with the prime focus on time and costs, creates a conflict with the process of introduction and development of ICT use that is characterised by ambiguity and indefinite duration in time that goes beyond the termination of a project. Unless immediate benefits are perceived by the adoption and use of an ICT application, it will not be used. This conflict can probably not wholly be solved, instead the industry has to learn to live with it and create spaces for innovation of ICT-mediated changes.

**KEYWORDS**

ICT, adoption, use, organizational change, building and construction industry, temporary organizations,

## 1. INTRODUCTION

Today large building and construction companies use ICT to the same extent as companies in other industries in order to co-ordinate and manage their internal information flows (see e.g. Molnár et al, 2007). However, in construction projects the use of ICT for intra- and inter-organizational coordination and information exchange in the planning-, design- and production processes has been limited even if it is claimed to be a recognized potential (see e.g. Wikforss and Löfgren, 2007). Among the explanations for the limited adoption and use of ICT are: fragmentation of the industry and lack of integration between design and production process (Dainty et al, 2006); a focus on solving technical problems, at the same time as the organizational context is overlooked, as well as problems of existing ICT solutions to incorporate interests of varying professional groups (Wikforss and Löfgren, 2007); which in turn is grounded in a varying set of principals, rules, knowledge domains, etc in professional groups leading to difficulties in co-operating (Söderholm, 2006). Moreover, in the literature on construction related ICT there has been a focus on construction companies, and no distinction between ICT use in construction “parent” organization, the permanent organization, and the temporary coalition of actors forming project teams (Rowlingson, 2007). Accordingly the central issue analyzed and discussed in this paper is how an enhanced understanding of the adoption and use of ICT in building and construction projects can be gained.

By drawing on the rich body of literature on organizational and managerial aspects of ICT, the crucial point of departure is to understand adoption and use of ICT as an emergent change process embedded in an organizational and societal context (Kling, 1980; Markus and Robey, 1988; Orlikowski, 1992). In order to analyse the processual and emergent nature of ICT adoption and use, the interrelationships between contextual elements, actors’ frames of reference and the role of the ICT itself need to be analysed (Constantinides and Barrett, 2006). Given this background the aim of the paper is to investigate how the interplay between contextual elements, actors’ frames of reference, and the ICT, influences the adoption and use of ICT in building and construction projects. This objective will be pursued by an analysis of an ongoing study of ICT use in a major Swedish construction company, including semi-structured interviews and an ethnographic inspired study of a partnering project worth 50 million € over two years.

## 2. THE PROCESSUAL AND EMERGENT NATURE OF ICT ADOPTION AND USE

The importance of taking the organization and its context into consideration when ICT adoption and use is studied has in IS-research been recognized by for example Lucas (1975). He stated that one reason for failures of ICT implementations was a focus on the technology, whereas it was neglected that a new ICT should be integrated in an organization where people would be affected by the new technology. This view was further developed in the seminal articles by Kling (1980) and Markus and Robey (1988) who challenged the views on change, tending to overemphasize the rationality of managers directing change and the capability of ICT to create predictable changes of organizational processes. Instead they suggested that research should analyse the processual and emergent nature of ICT-mediated change. The process of ICT adoption and use can be described as social process involving a wide array of actors (see e.g. Newman and Robey, 1992; Robey and Bourdreau, 1999). This social process is linked to intra organizational and broader contexts, so called multi-layered contexts, emerging from a series of historical, organizational and economic circumstances (Walsham, 1993). The context can be understood as broader socio-political structure in which the adoption and use unfolds, including industry characteristics, political agendas and power relations (Pettigrew, 1985). Further the context is also understood as an organization’s cultural characteristics including particular formal and informal rules of behavior enacted by organizational members (Martin, 1992). When changes triggered by the adoption and use of a new ICT it is very likely that programs of action inscribed in the ICT challenge existing cultures, structures and power relations in the organization (see e.g. Orlikowski, 1992; 2000).

The contextual elements can also be seen as entities reinforcing actors’ frames of reference. By drawing on stocks of knowledge, norms, formal and informal rules constituted by the contextual elements, humans interpret and give meanings to events and behaviours to achieve meaningful interaction (see also Giddens, 1984). In this vein a new ICT is interpreted and given a meaning, but the interpretation and sense making of ICT should not be viewed as static. Even if the technology may appear to have objective forms and functions at one point in time, these can and do vary over times due to there being different contexts and different users assigning varying meanings to technology (Pinch and Bijker, 1987; Orlikowski, 1992; Linderot and Pellegrino, 2005). Thus, actors frames of reference are continuously

constructed and refined in practice through inferences of past experience, as well as the obtainment of new knowledge emerging from for example added features to a technology, or a redefined use of a technology (op cit).

## **2.1 THE ICT AS SHAPER OF THE PROCESS**

When studying adoption and use of ICT in organizational contexts, it is of crucial importance to include the ICT in the analysis of outcomes of the interaction between the technology and the organizational context (see e.g. Monteiro and Hanseth, 1996; Orlikowski and Iacono, 2001). However, in the analysis of interactions between ICT, social settings, and their contexts, ICT often tend to fade away, be taken for granted, or assumed to be unproblematic when it once has been designed and installed (Orlikowski and Iacono, 2001). However, in contemporary research there is a well known slippage between designers and managers intentions, and users actual deployment of technology labelled as drifting, meaning that original goals and aims with a new ICT-system often drifts away from its assigners, regardless of who defines them (see e.g. Ciborra 1996; Hanseth & Braa 1998). The drifting can be seen as a process where interactions between a not totally 'disambiguated' technology (Ciborra 2000) and multilayered contexts (Walsham 1993) trigger knowledge development and learning concerning the further deployment of a technology (see e.g. Rosenberg 1982; Andersson and Linderöth, 2008).

The heterogeneity of ICT can be seen as a result of patterns of action, or programs of actions, inscribed in technological artefacts, which originate from technology designers' assumptions about the potential user and the context for use. These inscribed programs of action delegate roles and competencies to the components of a socio-technical network, including human and non-human entities of the system (Akrish 1992, Latour 1992). When a program of action is inscribed into a piece of technology the technology could become an actor imposing its inscribed programs of action on its user (Monteiro 2000:77). However, the concept of inscriptions should not be viewed from a technology determinist perspective. Instead, inscriptions in technological artefacts can govern programs of action in strong or weak modes (Hanseth & Monteiro, 1997), and inscriptions are strengthened in a process of translation where different actor groups, indispensable for the change, need to be enrolled into a network carrying out the change (see also Latour, 1991). Depending on roles and relationships delegated to the socio-technical entities in the network carrying out the change, different challenges arise for the permanent organization when outcomes from ICT-mediated change processes would be managed and transferred (Linderöth, 2007). By taking the technology into consideration when ICT-mediated change processes are analysed, it can be concluded that the process is ambiguous, fluid and long term consequences are hard to predict (see e.g. Ciborra, 1996; 2000; Orlikowski, 1996; Orlikowski and Hofman, 1997). Taking these conditions into consideration, it can be realized that the management of an ICT mediated change process in the organizational form of a project with set boundaries, will imply a number of challenges for the permanent organization (see also Bresnen, 2006).

Accordingly, in section four, the context and actors' structures of references will be analysed from the perspective of features of ICT described in this section. In order to enhance the knowledge on adoption and use of ICT in building and construction projects, a special focus will be on to the ambiguous and indefinite duration ICT-mediated change processes.

## **3. DATA COLLECTION AND CASE DESCRIPTION**

The data collection has been undertaken by two main methods: semi-structured interviews and participant observations, where data has been interpreted against a theoretical frame of reference. The approach chosen implies that a straight account of the respondents' answers to questions, or observations made will not bring any deeper knowledge about the process. Instead does the interpretive approach chosen enable an organizational member and/or a researcher to see his or her world with new eyes (see also DiMaggio, 1995). Therefore the results should be organized in a manner that is based on the researcher's interpretations. Interpretative case studies are a recommended method when the researcher is seeking to understand an emerging process of organizational transformation through IT (see e.g. Markus & Robey, 1988; Orlikowski & Baroudi, 1991; Orlikowski, 1992; Walsham, 1992; Robey & Azovedo, 1994).

In total 13 interviews are conducted with actors on different hierarchical levels in a major Swedish construction firm. Interviewed persons are for example the CEO of the company, the head of a regional unit, the head of a business district, site managers, one ICT-manager, one projecting manager and managers in R & D departments. The data collected by participant observation has been collected by



presence at 31 meetings, encompassing 58 hours, in a construction project worth 50 million € over two years, and run as a partnering project. The meetings participated in have been:

- Production meetings at the main contractor's production site involving the site manager, vice site managers, foremen, and representatives for construction workers.
- Projecting/design meetings with representatives for including the main contractor, the subcontractors and their consultants, and the client representatives.
- Meetings of the quality group with a responsibility for internal quality audits.
- Internal "check meetings" by the main contractor including the site manager, vice site managers, purchaser, cost accountant, projecting manager, planning manager.

Additional data has been collected by following a vice site manager during one day at the construction site, and by access to all meeting minutes from the internal meetings and accesses to the projects document database.

The main purpose of the data collection has been twofold. First we wanted to get an overview of the use of ICT in the studied company, belonging to the top three in Sweden regarding number of employees and turn over. Second, in all research on the adoption, implementation and use of ICT in an organizational context, it is of crucial importance to create an understanding of the context in which the ICT deployment unfolds (see e.g. Barley, 1986. In order to do this, interviews has focused on getting an in-depth understanding of the building and construction industry and what kind of ICT that is used, and how it is used. In order to deepen the understanding of the industry, and especially of the context of building and construction projects, an ethnology inspired study of a project is undertaken. The project studied is the rebuilding and expansion of a public multi activity arena. The existing building contains indoor swimming pools and an arena for indoor sports like basketball and handball. The expanded arena will contain an adventure pool, new swimming pool, a gym, and a bowling ground.

#### **4. ICT ADOPTION AND USE IN THE PERMANENT AND TEMPORARY ORGANIZATION**

In accordance with Molnár et al. (2007) this study confirms that large building and construction companies use ICT to a large extent in order to co-ordinate and manage their internal information flows. In the company studied there are 60 different systems with a range of users from one to four thousand. The large majority of systems are used in accordance with the common idea reinforcing IS-implementation initiatives: To integrate all information into a system in order to reduce fragmentation and increase efficiency (see e.g. Monteiro, 2003). One crucial dimension of this, in the building and construction industry, can be claimed to be monitoring and control of projects. Since this, according to a head of a region, is one of the core control issues in building and construction companies. Accordingly, the large majority of ICT can be seen as means for the permanent organization to control, monitor, and to some degree provide the temporary organization, the project teams, with ICT facilitating monitoring and control of activities in the project context. For example does a business district manager state that it is very easy for him to have an overview of the performance of the projects. Examples of these kinds of ICT applications in the studied organization are systems for: planning and control of projects, estimating costs and constructing project budgets, following up costs and consumption of resources on different levels in a project. However, ICT applications supporting the production process in a project are rarer. In the project under study the ICT-applications supporting the production process is mainly a database for sharing documents among contractor, sub-contractors and client; digitized survey; an e-commerce system linked to major suppliers; and of course e-mail and mobile phones these are the most common ICT applications. Furthermore 3D based building information models are emerging as ICT application with a potential to transform processes in building and construction projects. Nevertheless, compared to other industries, for example banking, manufacturing, or travels, the building and construction industry can still be regarded as a late adopter with regard to the use of ICT in the process of producing and delivering the products. However, what role contextual elements and actors' structure of reference plays in the interactions with ICT and the potential adoption and use of ICT in construction projects is still needed to be elaborated upon.

##### **4.1 CONTEXTUAL ELEMENTS ROLE OF SHAPING USE OF ICT**

In contemporary research a number of factors have been identified as explanations for the adoption and use of ICT in the building and construction industry. For example competitive advantages, external and internal forces, management support, user's individual characteristics (see Mitropoulos and Tatum, 2000; Peansupap and Walker, 2006; Rowlingson, 2007). We agree that these factors can explain the adoption

and use of ICT, but we want to bring the analyses further by highlighting one of the most distinguishable industry characteristic, namely the way building and construction activities are organized: by projects. The building and construction industry used to be mentioned as one of the industries with the longest tradition of organizing the activities by projects. With regard to the often individual and unique character of the outcomes of the production processes, the project has been the most appropriate form for organizing activities. But on the other hand, the project as organizational form for organizing activities can be claimed to be a factor constraining the adoption and use of ICT in building and construction projects. It can be argued that the focus on time and costs in projects are direct counterproductive for the adoption and use of ICT, if it is taken into consideration that positive outcomes from ICT implementations emerge through processes of knowledge development and learning these require a time span that often goes far beyond the termination of a project. I.e. the indefinite duration of ICT mediated change processes (Orlikowski, 1996), stands in sharp contrast to the well defined duration of a construction project. Furthermore Bresnen (2006) points at a number of inherent conflicts, or key differences, between the underlying logics of project management on one side, and on the other side the underlying logics of organizational change and learning. Thus, unless immediate benefits from an ICT-implementation can be showed with regard to the central dimensions of time and cost, it will be hard to convince project actors to adopt a technology. If the realizing of benefits from an ICT-implementation requires changes of work structures and a process requiring knowledge development and learning, which most often is the case in ICT implementations, project stakeholders incentives for adopting a new technology would probably be rather low.

One argument for adopting ICT is that a company can remain, or be more competitive, by for example reducing costs, or improving the perceived quality of goods and services delivered. However, the question be raised if the characteristics of the “competitive landscape” in the industry has reinforced the use of ICT in order to improve competitiveness? It can be claimed that the immobility of the products, implying a local situatedness of production processes and actors involved in construction projects, has not reinforced the use of ICT in order to stay competitive. Even if the major Swedish building and construction companies are active on an international market, for small and medium sized projects they operate on local markets competing with locally based competitors. This picture is confirmed when the CEO of the company studied is interviewed. He refers to an internal survey with 85 managers of local business districts, 54 % of them pointed out a locally based company as the hardest competitor. This condition implies that a locally based company can compete successfully with the three major companies when it comes to small and medium sized projects. It can be claimed that the limitation of the competition to local markets has held back a competitive pressure reinforcing innovation of the organizing of production processes, and implicitly an adoption and use of ICT as a mean for renewal and development of production processes. This condition can be compared with the situation in the manufacturing industry, where we have get in touch with small companies, with around 100 employees, who compete on international markets (see e.g. Andersson and Linderöth, 2008). For these companies the competitive pressure is harder and all means, including ICT, are needed to be taken into consideration in order to remain competitive.

Another contextual element that partly can constrain the adoption and use of ICT in the production process is the lack of standardization. In an interview with a R & D manager, working on standardization issues linked to the introduction and use of 3D-based building information models, states, for example, that it exists more than 3000 types of windows on the Swedish market. Maybe 300 would be enough for satisfying the need in the market, he rhetorically asks. A site manager also mentions windows as an example when lacks of standards are discussed. He states that on each and every construction site there is always a search for special solutions when it should be made watertight between windows and other building components. He adds that this is just one example of maybe hundreds. This lack of standardization of building components can also be to the origin of the lack of standardized working procedures. This problem is highlighted in an interview with a head of a business district, when he mentions the commonly used abbreviation “LPA” that can be translated to “to be solved at construction site”. When ICT is used as a support in production process there is an unconditionally need for varying degrees of prescribed components and activities. Just consider a fully automatized production line in manufacturing, or when a package travel is booked on the Internet. Thus, the lack of standardized procedures in the industry can be claimed to be another factor restricting the potential use of ICT in the production process. However, a gradual change might evolve. The need for standards is highly visible in the launch of 3D-based building information models. The managers concerned with the development and use of these models state that there is a heavy workload of inscribing standardized components and work methods into these models. However, some of the sub-contractors’ consultants, in the project studied,

already work with 3D-based tools. For example, the ventilation consultant stated that he draws everything in 3D, and about 90 % of components needed are available in 3D and supplied by material suppliers. Furthermore, he also stated that the material suppliers have realized that they do not have a future if they cannot deliver components in 3D for computerized models. However, he finally concludes that the use of 3D-technologies in a project is an issue of client's and contractors' possibilities to use the technology.

The use of 3D-based building information models in the production process is, however, an application with a potential to transform the production process (see e.g. Jongerling, 2006; Robertsson et al, 2007, Boland and Lyytinen, 2007). In the company studied 3D-based building information models are already used in some project's projecting phase and the company recently decided that 3D-based building information models should be used in all projects under own management. The R & D managers interviewed, states that some sub-contractors involved in these projects were highly sceptical at the outset, but after the implementation of the projects, parties involved have had rather positive attitudes towards use of the 3D-based models.

#### **4.2 ICT USE AND THE ROLE OF FRAMES OF REFERENCES**

When the actors' frames of reference are analyzed, the frames can be claimed to be reinforced by the contextual elements and especially the project based mode of organizing construction processes. In this mode of organizing there is a special focus on time and cost, two factors always present on the agenda in construction projects. As already discussed, for managers on different levels the monitoring and control of time and costs in projects is the ultimate task. However, even for the workers the focus on time is of crucial importance, which the following episode illustrates:

At a weekly production meeting, held each Monday morning, a carpenter is suddenly coming into the meeting room, furious because there are no lifts available and the vice site manager has to fix one NOW. The manager calls the local outlet of the machinery and equipment rental firm. 45 minutes later the lift is delivered. After the incident the manager says that he thinks that it is good that people are engaged in their work and always want the process to move forward. However, when we just after the delivery discover another lift on the floor below where the lift was needed, he adds that people sometimes need to spend some extra minutes and communicate with each other in order to find out if the missing equipment is somewhere else at the site.

This episode could be seen as an expression for engagement in the project's progression, but also as an expression for how the structure of wages shapes the sense making of events and reinforce certain behavior. In the Swedish construction sector, piece wages are dominating, which implies that all occurrences and activities these not are included in the piecework can be regarded as real or potential threats to the achievement of high wages. This implies that the potential adoption and use of ICT-applications among workers will be heavily affected by the wage structure. I.e. if the ICT is perceived to bring immediate benefits regarding time consumption or not.

A controversy caused by the use of a new ICT-application and related to the time dimension, was digitized survey. Early in the project it was decided that there would be no measures on the drawings. Instead should all measures for the components in the building be surveyed by the digitized system. This implies that the surveyor downloads the measures from the subcontractors computerized models into his digital device, and then survey them at the right places on the site. The advantage with this system, as stated by the site manager and the projecting manager, is that all measures are surveyed correctly from the beginning, instead of that drawings are interpreted and measures are surveyed with a folding rule or measuring tape, implying that errors occur and are transferred. However, not all parties affected agreed on the benefits. This was mainly caused by the surveyor's from time to time heavy workload, depending on delays in the projecting stage. For example did the construction workers representative complain at a number of production meetings, that the workers needed measures surveyed for the progress of the work. At one occasion the digitized survey was even blamed as a reason that workers did not get enough drawings, but this depended on heavy delays by the architect firm. One of the vice site managers emphasized, however, that the construction workers needed to think in advance and communicate where they wanted the measures surveyed, in order to ease for the surveyor to prioritize what to do. Another vice site manager did also from time to time complain that survey risked delaying his part of the building and he wanted to use the folding rule and the measuring tape. But the projecting manager stated that this would not be the case, because of the risks of transferring measure errors.

There is however one group in the project context that has been heavily influenced by ICT, the site managers. The site managers interviewed confirms that they are more tied to the computer today than a decade ago. Also other interviewed confirm this picture and states that the role of the site manger has changed during the last decades. From a focus on building, to someone who has the responsibility for production, logistics, planning, economy and staff issues. These responsibilities can be seen as the force that has tied the site managers closer to the computer. However does the head a region say that there is a process going on where more competence is moved out to the construction sites in order to provide more support to site managers. Regarding the ICT used by site managers, applications these are perceived to cutting time are appreciated, and vice versa. For example did a head of a business district state that many site managers were sceptical to the introduction of electronic invoices, but after the implementation the opinions were positive. On the other side are site managers sometimes sceptical towards the web-based purchasing system, because it can be hard find the right items and information. When it comes to the voluntary adoption and use of ICT, applications perceived cutting lead times are adopted. For example, digital cameras are used for taking pictures of building components and attached to e-mails when a quick answer on a question is needed from a subcontractors or other actors concerned. Or when some information is needed about for example assembly an instruction, Google is often used in order to fast find the information needed.

## 5. DISCUSSION

By the analysis of the interaction between contextual elements, actors' structures of reference and the ICT itself it is possible to draw some conclusions regarding adoption and use of ICT and distinguish the permanent organization and the temporary organization. By taking the ICT into consideration, it is obvious that the introduction and development of ICT use in an organization in order to achieve renewal and change, requires a process of knowledge development and learning that goes beyond the termination of a project. By including the context into the analysis, the project organization with a prime focus on time, reinforced by for example contractual regulations and incentives encouraging a reduction of time consumption, a conflict between the mode of organizing and the features of ICT-mediated change has clearly come up to the surface. Furthermore is the focus on time reflected in actors' frames of reference which is expressed when an event or a new phenomenon is interpreted and made sense of. This focus on time makes it hard to find the slack necessary for experimenting with new ICT, unless the ICT-application brings immediate benefits for the actors concerned. Usually a project is used as an organizational form when ICT mediated changes are implemented in organizations. The project is an occasion for reflecting over how the ICT and the organization can be adapted to each other and to develop knowledge of how organizational process can be renewed. At the same time, the projects definite duration in time makes it necessary to find organizational arrangements these facilitate the transfer of ideas from the project to the permanent organization (Linderoth, 2007). But when operations in it self are organized by projects it will be a challenge to find the slack necessary developing the ICT use. This argument can furthermore be supported when the rather encompassing use of ICT in the permanent organization is taken into consideration. In the permanent organization slack resources for the development of ICT is easier to find. Consider for example that a number of people in the organization studied working on issues connected to the development of ICT use. Furthermore the adoption and use of ICT in the permanent organization is reinforced by the priority of monitoring and controlling projects. Accordingly, since ICT-applications are to be developed by R & D departments, a deep knowledge is needed regarding context specific conditions in projects, facilitating and constraining the adoption and use of ICT.

Despite the problems caused by the organizing of operations by projects, ICT-applications are indeed adopted and used in building and construction projects. As stated, perceived immediate benefits are one condition that facilitates adoption and use. But another important condition, if actor group have various perceptions of the benefits, is the possibility to make the ICT into an obligatory passage point (OPP) (Callon, 1986, Linderoth, 2007). I.e. actors concerned by the change should not have any alternative than passing the ICT-application on their ways to their goals. One such example is the digitized survey. The removing of measures from the drawings is a conscious or unconscious attempt by the management to force actors to await the digitized survey. But it is also important to bear in mind that organizational routines are to be adapted in order to facilitate the use of the new technology (Linde and Linderoth, 2000; Linderoth, 2002). Furthermore is actors' possession of power another key to whether ICT is adopted and used. This means that one actor in the project need to have power enough to force other actors indispensable for accomplishing a task to adopt and use an ICT-application. The use 3D based building information models in projects under own management, can be seen as one such example. In this case the contractor has full control over which actors should be included or excluded from a project. For example

can use of 3D based building information models be stipulated if a subcontractor wants to be included in the project. Furthermore, projects under own management can be a good opportunity to test new technologies and organizational arrangements, since contractors themselves on one hand take the whole risk, but on the other hand are they freer to innovate.

Even if the organizing by projects is claimed to be one the main sources for the relative low rate of adoption and use of ICT in building and construction projects, this organizational form would probably not be replaced in the nearest future, or probably not at all. Therefore the industry has to learn to live with the disadvantages of the organizational form and create alternative spaces for innovation where for example new ICT can be tested and experimented with. By some occasions ICT can be implemented into a project setting if it is possible making it into an obligatory passage point and developing organizational routines supporting technology use. By other occasions, where it is necessary to experiment with processes of operation due to the use of new ICT, projects under own management, might be the best forum. However, important to keep in mind in that case, is that actors engaged in these projects should not draw on their old frames of references regarding how a project would be organized and managed.

## 6. CONCLUSIONS

By taking the context, actor's frames of references and the ICT itself into consideration when adoption and use of ICT in the building and construction sectors is analysed, it can be concluded that the project based mode of organizing, with the prime focus on time and costs, creates a conflict with the process of introduction and development of ICT use that is characterised by ambiguity and indefinite duration in time that goes beyond the termination of a project. The focus on time in projects, reinforced by for example contractual agreements including fees for delays and structures of wages, creates a basic conflict with the ambiguous and indefinite duration of ICT-mediated change processes. Unless immediate benefits are perceived by the adoption and use of an ICT application, it will not be used. This conflict can probably not wholly be solved, instead the industry has to learn to live with it and create spaces for innovation of ICT-mediated changes.

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## ASSESSING INDIVIDUALS' RESISTANCE PRIOR TO IT IMPLEMENTATION IN THE AEC INDUSTRY

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### ABSTRACT

Ever increasing technological capabilities exist in the architecture/engineering/construction (AEC) industry. Email, project specific websites, Computer Aided Drafting (CAD), animations, and Building Information Modeling (BIM) are but a few information technologies adopted in recent years within the industry. The change methods used in the adoptions suggest a focus on technology, yet the technology itself is seen as a primary barrier to successful implementation.

In general, the AEC industry is extremely slow to embrace available information technology. Companies often have difficulty with technology implementations because technology is the driver of change, rather than an enabler of change. Resistance of people is the primary reason for failure of any organizational change, including an information technology change. Technological changes will be more successful when researchers develop a fundamental understanding of how people change. Studying individuals and their change processes is essential to improving implementation of technology change, yet change management theories present processes and guidelines for changing organizations and tasks with limited emphasis on individuals involved in change. This research uses a people centered paradigm for developing technology implementation models, placing technology in a change enabling position rather than being a driver of change.

This research investigates individuals' resistance to change brought about by new information technology implementation in the AEC industry. Resistance to change is a combination of three factors: cause of resistance, level of resistance, and manifestation of resistance. Previous work investigated the importance of specific behavioral characteristics indicative of resistance to change and correlated these characteristics to the level of resistance in individuals. This paper discusses methodology continuing this work, which aims to confirm the previous work, as well as to develop and validate new predictive tools to identify potential resisters prior to an information technology change implementation. The results from analysis of preliminary data are also discussed.

### KEYWORDS

Resistance, Change Management, Information Technology, Technology.

### 1. INTRODUCTION

Ever increasing information technology capabilities exist in the AEC industry. Email, project specific websites, Computer Aided Drafting (CAD), animations, and Building Information Modeling (BIM) exemplify technologies adopted in recent years within the industry. In general, the AEC industry is extremely slow to embrace available information technology (Emond 1999; Gambatese et al. 2007; Rosenbaum and Schriener 2000; U.S. Department of Labor 1988). Executives often delay investing in new technologies, hoping that the rate of technological growth will stabilize, reducing long-term investment costs. According to Moore's Law<sup>9</sup>, stabilization is unlikely to occur in the next several years (Intel Corporation 2008). This places financial implications on new technology adoptions, limiting their introduction into the AEC industry (Allen et al. 2005).

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<sup>9</sup> The press coined the term, Moore's Law, which is based on an observation made by Gordon Moore in 1965 that the number of transistors per square inch on integrated circuits would double every year. This has been modified slightly to a doubling every 18 months, which is the accepted definition at this time (Intel Corporation 2008). In common usage, it implies that information technology development continues to dramatically improve at an exponential rate.



Even when financial issues are disregarded, a successful implementation process must meet the technical requirements of the problem, satisfy the organizational needs and desires, and address any worker-related challenges (Parsons et al. 1991). Management is usually preoccupied with the technical aspects of implementing a new technology and ensuring that it meets the organizational needs. Unfortunately, the worker-related issues are regularly neglected (Parsons et al. 1991; Steier 1989).

On the whole, unsuccessful information technology adoption originates from too much emphasis on technology and too little focus on people. Throughout history, changes in technologies and the inventions of new machines have altered the skill requirements, tasks, and relationships among workers. Improvements in industrial technologies profoundly change organizations (Kingsford 1964). The telephone, while initially thought to be only for the elite, has changed global communication. The Internet, first thought of as a curiosity of academics and government researchers, is fundamentally changing the global economy. The impact of technological changes is often vastly underestimated.

When information technology changes such as email, project specific websites, CAD, or BIM are implemented in an organization, they affect the way work is done. “[C]hanges in *Technology* will alter the nature of the *Tasks* and *vice versa*; changes in the tasks to be done will affect the *People* and *vice versa*; changes in people change the *Organization* and *vice versa*” (Sutton and Sutton 1990). Frequently, when new information technology is introduced, communication modes are altered. The power structure of the organization may change and become flatter than it was before the implementation. The people involved form opinions and ultimately choose to accept or reject the change.

Change theory provides a theoretical framework for investigating individual resistance to the implementation of information technologies. Current change models present processes and guidelines for changing organizations and tasks, with limited emphasis on individuals involved in change. However, resistance of people is the primary reason for failure of organizational change (Maurer 1997). Within the AEC industry, Peansupap and Walker (2005) reviewed 24 recent IT adoption studies. Nearly all were noted to have issues with what they termed ‘individual and social issues’ and ten studies specifically mentioned issues with individuals resisting the IT change. Cultural issues such as these continue to be a major barrier to IT implementation in the AEC industry (Rojas and Locsin 2007; Ruikar et al. 2005), yet they are predominantly unresearched within the building and construction industry (Cleveland 1999; Ford et al. 2000; Mitropoulos and Tatum 2000; O'Brien 2000; Songer et al. 2001; Thorpe and Mead 2001; Todd 1996). The existing change models have limitations, particularly with respect to cultural issues. These limitations have a direct effect on the successfulness of implementation of information technology changes in the AEC industry.

To address these challenges, this paper discusses a plan of work aimed at identifying resisters prior to the implementation of an information technology innovation. Working closely with industry organizations, this research investigates adoption of information technologies by individuals in organizations within the AEC industry and studies the impact of the adoption on communication, productivity, and processes through analysis of existing models of implementation. The project promotes a realignment of cultural and technological implementation issues through the development of prediction models aimed at identifying technology resisters prior to technology adoption, a step towards developing new organizational change models.

## 2. OBJECTIVES

The goal of this research is to develop new knowledge in the areas of social implications of information technology, change management, and attitude-behavior theory. This work integrates and extends previous research in cultural aspects of information technology implementation. Specific research objectives for this project include:

- Isolate attitudes, fears, and beliefs that are indicative of resistance to information technology change within individuals in the AEC industry;
- Estimate the intensity of resistance an individual is likely to exhibit using the personality traits and behavioral characteristics identified;
- Identify any variances that exist between different demographic groups based on the estimates of intensity of resistance likely to be exhibited; and
- Predict likely resisters prior to technology adoption based on demographics.

## 3. PLAN OF WORK

A typical construction project involves three parties: owners, designers, and constructors. Owners often require designers and constructors to use specific information technologies when working on their project, such as a project website or a specific CAD program. This seemingly simple owner's

requirement forces multiple organizations to comply and adopt what is often a new technology for them. This, in turn, trickles down to the employees of these organizations who now must adopt the new technology, often without having any say in the decision process – a less than ideal situation. Identifying which employees are likely to resist this adoption and addressing their resistance immediately is crucial to successful implementation of the technology, but can also be crucial to the success of the project as a whole. The AEC industry is ideal for studying this resistance, as it has a reputation of not being particularly receptive to the introduction of new information technologies.

This research examines AEC projects with owner-required technologies. The employees of multiple organizations involved in each project are surveyed to benchmark their initial level of resistance at the beginning of the project. These individuals are tracked longitudinally to ascertain the type of resistance (passive or active) exhibited and whether their resistance increases, decreases, or is constant over time. Resistance levels are measured with the Resistance to Change Index (Davis 2004; Davis and Songer 2008) and are validated through qualitative methods, including interviews and direct observations. Using the level of resistance and basic demographic information regarding each individual, regression analysis enables the prediction of likely resisters prior to technology adoption.

The plan of work is comprised of two phases: (1) Assessment, and (2) Analysis & Prediction. The first phase assesses, documents, benchmarks, and validates individuals' likelihood of resistance and its intensity. The second phase analyzes the relationships between social variables and demographics of the individual to identify relationships that exist, enabling prediction of resistance. Phase II also develops and validates new predictive tools to enable more successful information technology implementation in the AEC industry.

### 3.1 PHASE I: ASSESSMENT

Phase I addresses the first two objectives of the study, which are (1) to isolate attitudes, fears, and beliefs that are indicative of resistance to information technology change within individuals in the AEC industry and (2) to estimate the intensity of resistance an individual is likely to exhibit using the personality traits and behavioral characteristics identified.

The Social Architecture Factor Model illustrated in Figure 3 and developed by the researcher (Davis 2004) guides the investigation into individual change with a focus on the cultural aspects. The initial framework of the model, shown in white, represents the basic change process: one or more parties initiate a change, the change is later introduced to other parties, and individuals and organizations choose to accept or reject the change along a continuum. The behaviors of individuals in the process influence behaviors of the organization and vice versa. It is general enough to represent nearly any type of change, but can be specialized for specific types of change by supplementing it with additional information, as appropriate.

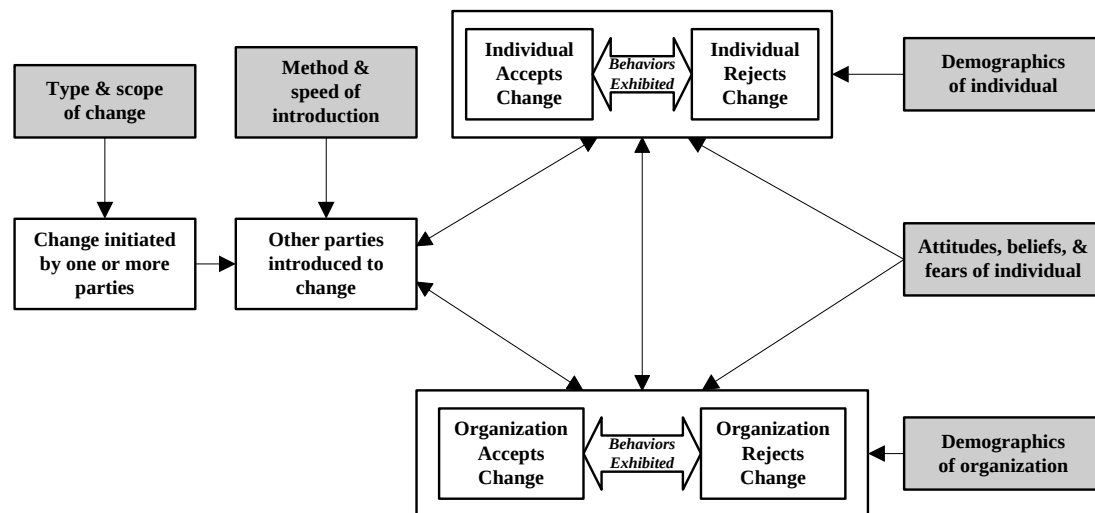


Figure 3. Social Architecture Factor Model

The basic change process model was augmented through a rigorous literature review identifying aspects that affect an individual encountering an information technology change. This augmentation resulted in the creation of the social architecture factor model (all of Figure 3). This model illustrates the change process from an individual perspective.

When a change is initiated, the type and scope of change are significant to the continuation of the change process and can indirectly affect an individual's response. As the change is introduced to others, the method and speed of the introduction affect its success. Individuals and organizations exhibit behaviors indicating acceptance or rejection of the change, with the behaviors of one interacting with, and quite possibly altering, the behaviors of the other. Each individual brings their own demographic characteristics with them, as well as their attitudes, beliefs, and fears, all of which may influence their behavior towards change. Organizational demographics and the influence of individuals' attitudes, beliefs, and fears on the organization also influence reactions to change.

The broad categorical measures indicative of individuals' resistance to information technology change represented in the model are: type and scope of change; method and speed of introduction; demographics of individual; attitudes, beliefs, and fears of individual; and demographics of organization. An in-depth discussion of the specific factors for technological change identified in each of these categories and the associated literature is available in Davis (2004).

Using the social architecture factor model, a prior study (Davis 2004; Davis and Songer 2008) created and tested a Resistance to Change Index (RTCI), providing estimations of the intensity of resistance an individual is likely to exhibit during an information technology change. This project uses the Resistance to Change Index to measure the level of resistance during an information technology change. Phase I of the project collects data from the established relationships of resistance to change (the right side of Figure 4) and validates the level of resistance (the center of Figure 4). Phase II investigates the hypothesized relationships between the demographic variables (the left side of Figure 4) and the Resistance to Change Index (the center of Figure 4) and uses these relationships to predict resisters. Existing data indicate that these relationships do exist. For example, prior work (Davis 2004; Davis and Songer 2004) found that individuals do have a different likelihood of resistance based on their profession, gender, computer understanding and experience, and awareness of past or future changes occurring in their company. Relationships between the RTCI and other demographics including age, education level, and personality type, were either not supported or were inconclusive, in part due to the size of the study. Data from this work also supported predictions of RTCI from demographic variables, although no prediction models were created.

### 3.1.1 BACKGROUND – RESISTANCE TO CHANGE INDEX

The Resistance to Change Index is made up of seven factors that represent nine variables (the right side of Figure 4): Attitudes towards computers and information technology, Motivation to use new technology, Readiness for change, Irrational ideas, Defense mechanisms related to the behavior of an individual during change, Perceived interpersonal power, and Perceived support for change. The relevance of each factor included in the Index and the process by which these factors were combined to create the RTCI (the center of Figure 4) is discussed below.

Attitudes towards computers and information technology emphasize “feelings about the impact of computers on society and the quality of life, and their understanding of computers” (Heinssen et al. 1987). Attitudes towards computers is measured with the Computer Attitude Scale (CAS) (Loyd and Gressard 1984). Three types of attitudes are represented in this scale: computer anxiety, computer liking, and computer confidence. A positive attitude towards computers is an indication of lower resistance towards technological change and vice-versa.

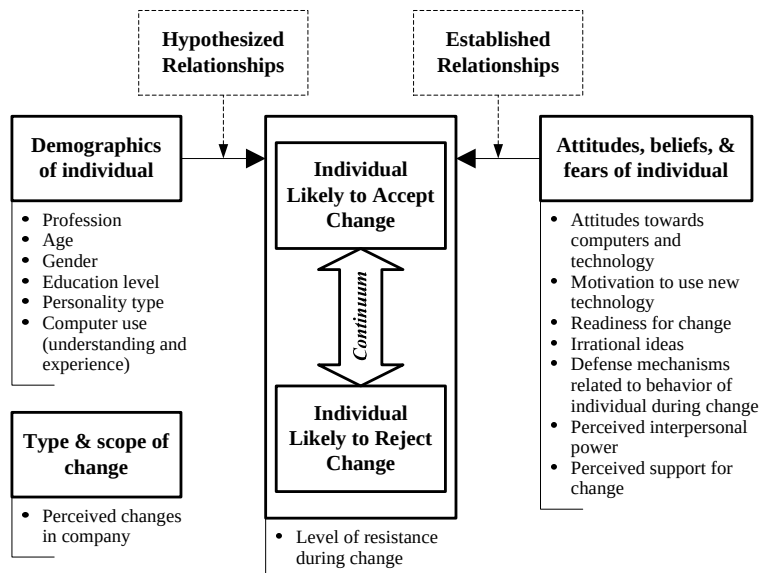


Figure 4. Level of Resistance to Information Technology Change

An individual's motivation to use new technology will affect their reaction to the implementation of new technology. A strong motivation to use the new technology can overcome many difficulties, whereas a strong motivation not to use the technology can cause an individual to erect additional barriers as protection. The researcher developed the questions used, as no existing measures of this factor were located in the literature.

Readiness for change is an individual's attitude towards change. Two metrics are used: the Change Scale (Trumbo 1961) and the Reaction-to-Change Inventory (De Meuse and McDaris 1994). The Change Scale indicates that "individual differences in attitudes toward change may reflect differences in the capacity to adjust to change situations" (Trumbo 1961). A high score indicates a "favorable change attitude", which is interpreted to mean low resistance to change. A low score is interpreted to mean a high resistance to change. The Reaction-to-Change Inventory measures an individual's perceptions about change. Higher scores indicate stronger support for change, whereas lower scores indicate stronger resistance to change (De Meuse and McDaris 1994).

Individuals often have irrational ideas about change and they create their own interpretations of how the change will occur. The Irrational Belief Scale (Malouff and Schutte 1986) is used for measurement. The level of irrational ideas has shown a statistically significant positive correlation to resistance to change (Bovey and Hede 2001b).

The defense mechanisms of the individual during change are generally unconscious responses of the individual to perceived danger (Bovey and Hede 2001a). Defense mechanisms include adaptive mechanisms such as humor and anticipation of change and maladaptive mechanisms such as acting out, denial, dissociation, isolation, and projection. The measure of defense mechanisms included is the adaptive portion representing humor from the Defence Mechanisms scale (Bovey and Hede 2001a). The adaptive mechanism of humor showed a statistically significant negative correlation with the level of resistance to change (Bovey and Hede 2001a).

There are five types of interpersonal power: legitimate, reward, coercive, expert, and referent (French and Raven 1959). When a person has one or more of these, they can influence decisions and use manipulation to successfully resist changes. The Emotional Intelligence EQ Map subscale indicating Personal Power (Cooper and Sawaf 1997) is included as a measure of the individual's perception of their referent power. A higher level of referent power indicates a lower level of resistance to change. The other types of interpersonal power are indirectly measured by the individual's level in the organization, obtained using questions created by the researcher. An individual with a higher level in their organization will exhibit less resistance to change because they have a more powerful position and are more likely to be able to influence changes to satisfy their needs.

The metric included for measurement of an organization's support for change is the Support for Change Questionnaire (Maurer 1996). This questionnaire looks at how the individual perceives that their

organization supports or opposes change. Lower scores indicate higher likelihood of resistance to change and vice-versa.

These seven factors (representing nine variables) were combined to create the Resistance to Change Index (RTCI), representing the likelihood of an individual to accept or reject information technology change. Since each variable was collected independently from its own set of questions, there was no common scale for all of the variables. The scale of each variable was algebraically modified to a common 1 to 10 scale indicating resistance to information technology change in a common direction. One (1) is representative of a low resistance to change and ten (10) is representative of a high resistance to change for each individual variable in the common scale.

Regression analysis and factor analysis were evaluated to establish weighting of the variables and both failed to provide an appropriate method. Therefore, each of the variables was given equal weight in the RTCI. The index takes the average value of the nine variables, after the algebraic modifications to a common scale and common direction are performed. RTCI is expressed on a continuous scale from 1 to 10 with one indicating a low likelihood of resistance to information technology change and ten indicating a high likelihood of resistance to information technology change.

### 3.1.2 TASK 1 – DATA COLLECTION

The first phase of this project involves extensive data collection. Data collection techniques include self-report surveys, individual structured interviews, researcher observation, and document analysis. Table 2 depicts the general data collection techniques, whether they are assessing the individual or the organization, how they relate to the Social Architecture Factor Model (Figure 3), and the purpose and expected outcome for each collection activity.

Self-report surveys are used to benchmark the initial level of resistance at the beginning of a construction project that has an owner-required technology using the Resistance to Change Index. The sample includes employees of architecture, engineering, contractor, and construction management organizations involved in the project that are affected by the technology. All positions and all levels within each AEC organization affected by the change are included in the sample, as technological changes in the industry can affect all employees within an organization. To validate the appropriateness and accuracy of the initial self-report survey, individual structured interviews will be performed with random members of the sample population. These interviews also allow the researcher to gain additional information regarding the anticipated change beyond that measured in the self-report survey. To date, preliminary data collection using self-report surveys has been completed.

Table 2. General Data Collection Techniques

| <b>Data Collection Activity</b>  | <b>Assessing?</b> | <b>Target Area of Social Architecture Factor Model</b>                                                                  | <b>Purpose/Expected Outcome</b>                                                                                                                      |
|----------------------------------|-------------------|-------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Self-report surveys              | Individuals       | Demographics of individual;<br>Attitudes, beliefs, & fears of individual;<br>Expected behaviors exhibited by individual | Provides a sense of how each individual perceives the change and how they believe they will handle it                                                |
| Individual structured interviews | Individuals       | Attitudes, beliefs, & fears of individual;<br>Expected behaviors exhibited by individual                                | Provides a sense of how each individual perceives the change and how others are perceived to change. Also verifies or refutes the survey information |
| Researcher observation           | Individuals       | Attitudes, beliefs, & fears of individual;<br>Actual behaviors                                                          | Provides a general sense of the environment and verifies or refutes                                                                                  |

| <b>Data Collection Activity</b>  | <b>Assessing?</b> | <b>Target Area of Social Architecture Factor Model</b>                                                                                                                                     | <b>Purpose/Expected Outcome</b>                                                                                                                                     |
|----------------------------------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Individual structured interviews | Organizations     | exhibited by individual<br>Expected behaviors exhibited by organization                                                                                                                    | the interviews and surveys<br>Provides a sense of how the organization perceives the change                                                                         |
| Researcher observation           | Organizations     | Actual behaviors exhibited by organization                                                                                                                                                 | Provides a general sense of the environment and verifies or refutes the interviews                                                                                  |
| Document analysis                | Organizations     | Type & scope of change;<br>Method & speed of introduction;<br>Demographics of organization;<br>Expected behaviors exhibited by organization;<br>Actual behaviors exhibited by organization | Provides explicit information about the environment in terms of rules, regulations, and acceptable behaviors and standards. Also verifies or refutes the interviews |

Individuals will be tracked longitudinally to ascertain whether their resistance increases, decreases, or is constant over time. Resistance levels will again be measured with the Resistance to Change Index and will be validated through qualitative methods, including interviews and observations by the researcher. The interviews and observations also allow the type of resistance (passive or active) exhibited to be determined. Data will be collected from the sample population approximately every 3-4 months for a minimum of one year.

To ensure that the influence of organizations is recognized in the change process, data collection will also be done at the organizational level. Individual structured interviews will be performed with company executives, owners, and IT staff from each participating organization at 3-4 month intervals to collect data regarding their impressions of the status of the technology change, their opinions regarding the success of the change at that point, and any lessons learned to date. Observations by the researcher will validate these interviews.

Finally, document analysis will be performed, beginning with the change initiation, to track the change process from the organizational perspective. The type and scope of the change, the method and speed of the introduction, and the demographics of each organization involved will be included in the document analysis. The type and scope of the change is dictated by the owner and is therefore the owner-required information technology on the project. The method and speed of introduction will vary from one company to the next within the scope of the project and will need to be assessed for each participating organization. Organizational demographics will likewise vary from company to company and each will be assessed individually. Additionally, within each organization, specific aspects that will be sought include training available, the reward and punishment system used, and any support provided by the organization (as perceived by the organization). These aspects help establish the corporate culture and management style of each participating company. The document analysis also provides validation of the organizational aspects measured through the interviews of executives, owners, and IT staff.

### 3.2 PHASE II: ANALYSIS & PREDICTION

Phase II addresses the third and fourth objectives of the study, which are (3) to identify any variances that exist between different demographic groups based on the estimates of intensity of resistance likely to be exhibited and (4) to predict likely resisters prior to technology adoption based on demographics.

Using the results of the Phase I data collection, which benchmarks individuals' likelihood of resistance and its intensity, Phase II consists of two tasks. Task 1 analyzes the data to examine patterns and relationships between social variables and demographics of the individual. Task 2 is the development and validation of a new prediction tool to identify likely resisters prior to technology adoption. Such a prediction tool will be invaluable to organizations when planning and implementing change models. Additionally, a comprehensive understanding of individual resistance levels is critical prior to investigating group, project team, and organizational change models and resistance.

### **3.2.1 TASK 1 – DATA ANALYSIS**

This task within Phase II investigates the hypothesized relationships between the demographic variables (the left side of Figure 4) and the Resistance to Change Index (the center of Figure 4). The demographic variables under consideration are: profession, gender, age, personality type, education level, computer understanding and experience, and perceived past and future information technology changes. Statistical tests compare the RTCI values obtained from different demographic groups represented in the sample population.

The main statistical methods used are ANOVA, t-tests, and correlation tests. One-way ANOVA methods are used to compare the mean RTCI values of the different professions to determine whether any groups differ and the method is most appropriate for tests involving three or more groups. If a statistical difference is found (i.e., at least one group differs), Tukey's multiple comparison test is used to compare each group with each of the other groups to determine which groups differ on the mean RTCI value. The t-test is used to compare the RTCI values for several of the demographic groups to determine if any groups differ. While similar to ANOVA, the t-test provides more concise information when only two groups are involved in a test. Specifically, the t-test is used to compare mean RTCI values for demographic variables with two categories such as gender (male/female) and perceived changes (change/no change). The t-test can also provide information on which mean value is larger and which is smaller, if a difference exists. The remainder of the demographic variables use correlation tests for testing possible relationships with RTCI. Correlation tests discern the level of dependence/independence that two variables have with each other. Continuous variables, such as age and computer use, are tested by using Pearson's correlation test. Ordered variables, such as education level, use Spearman's correlation test.

Based on preliminary data collected, demographics that indicate high likelihood of resistance to IT change are gender (female), computer understanding and experience (low), past IT changes (none experienced), future IT changes (not aware of any planned), and profession (construction trades). Individuals in these demographic groups appear to be more likely to resist IT changes than individuals who are not a member of any of these groups. If an individual fits into two or more of these groups, it is expected that their likelihood of resistance would be higher than an individual only fitting into one group, though this has not been tested to date. Demographics that indicate low likelihood of resistance to IT change are gender (male), computer understanding and experience (high), past IT changes (at least one experienced), future IT changes (aware of at least one planned), and profession (management or architect). These individuals are less likely to resist IT changes than individuals who are not a member of any of these groups. Likewise, if an individual fits into two or more of these groups, it is expected that their likelihood of resistance would be lower than an individual only fitting into one group. Age, education level, and personality type have no relationship with resistance to IT change based on the data collected to date.

Additional data analysis includes an examination of the data from a longitudinal perspective and will be a more qualitative analysis. Individuals will be analyzed longitudinally to understand how their resistance may have changed over time, the type of resistance they presented (passive or active), if any, and whether that is related to organizational aspects, such as the corporate culture, management style, training provided, rewards and/or punishments enacted, and support provided by the organization.

### **3.2.2 TASK 2 – PREDICTION TOOL**

Following completion of further data collection and analysis, a prediction tool will be created to enable more successful information technology implementation in the AEC industry. This task within Phase II develops and validates this new predictive tool. Using the level of resistance and basic demographic information regarding each individual, regression analysis will be performed to enable predictions of likely resisters prior to technology adoption.

Based on the results from the data analysis in Task 1, appropriate demographic information regarding each individual will be chosen and included in the regression analysis. Likewise, demographic information which does not appear to have a relevant relationship with the Resistance to Change Index (based on the analysis discussed above) will be excluded from the regression analysis. Additionally, the model should not only address the demographic information of the individual, but also any relevant organizational modifiers (i.e., corporate culture and management styles), as determined from the qualitative data analysis.

Depending on the final demographic variables included, an appropriate modeling technique will be used in the development of the prediction tool. Linear regression modeling is a fundamental technique relating independent variables ( $X_1, X_2, \dots, X_{K-1}$ ) with a dependent variable ( $Y$ ) in a linear fashion. If the relationship is not linear, a nonlinear estimation is a more general modeling technique that can be used to relate independent variables with a dependent variable. If the independent variables are categorical and include more than two options, an ANOVA linear model is more appropriate than a regression model.

Using the preliminary data collected, a linear regression test was performed with an ANOVA linear model to determine if a prediction was possible using the demographic variables discussed above. Based on this test, prediction of RTCI is possible ( $p\text{-value} = 0.0006$ ).

To validate the prediction model that is created, additional survey data sets will be collected and input into the optimum model. The results will be analyzed to compare the two populations. The method for testing the model involves entering data from these test cases into the equations and comparing the actual results to the predicted results. The model is considered valid if the predicted values are within an acceptable range for practical application. It is not crucial that the model predicts with 100% accuracy, but rather that it conveys meaningful information to organizations regarding individuals' resistance to information technology change. Although the model need not be 100% accurate, it still must be accurate enough to make reasonable predictions.

#### 4. CONCLUSION

Identifying likely resisters prior to the adoption of a compulsory technology innovation aids organizations in accommodating the resistance as it occurs. The predictive tools that will result from this work promote sustainable implementation of IT within AEC organizations and multi-organizational project teams. By understanding how individual participants resist and adapt to change, their resistance can be better accommodated by the organization in the adoption of new information technology within the AEC industry. This enables both researchers and practitioners to understand how new technologies should be introduced within organizations. Additionally, providing companies in the industry with the ability to identify their potential resisters using more than stereotypes is the first step in helping ensure that new IT implementations succeed. This, in turn, enhances the responsiveness of AEC organizations to market needs and global competitiveness. Therefore, the research, at its completion, will significantly impact individuals and organizations within the AEC industry.

Once complete, the work will add to the theories related to adoption and diffusion of innovations, as well as to attitudinal-behavioral theories. Additionally, the process and predictive tools outlined in this study are scalable to all organizations involved in complex, multi-participant, project driven domains.

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## **COST DATABASE SYSTEM APPLIED TO REFURBISHMENT OF SOCIAL HOUSING IN BRAZILIAN CONTEXT**

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### **ABSTRACT**

In Brazil, low income people haven't a good way or help to preview the budget to their projects, especially concerning to build or refurbish their houses. Moved by this lack of opportunity, this paper describes briefly the work carried out to give to this public a system prepared in Internet basis which help them to calculate more precisely the necessary funds to implement this kind of investment.

Some questions emerge: How to communicate data to the Database System related to the planned build or related to the changes desired to be applied in a house existed? The Database System needs to keep cost data of new constructions and data of refurbished constructions since the costs are very different due to the different nature of the job? How to update costs of lots of items turning the system reliable?

These and other critical questions will be answered along this work and we hope that, starting from a small and specific problem we spread the possibilities of this system, reaching a level of having real helpful tools. Reaching this level, the material produced can turn a seed of more complete and helpful systems.

Computational technological support of the purposed system will be IFC, PHP and MySQL.

### **KEYWORDS**

IFC, Building Cost, Building Budget, Building Modeling

## 1. INTRODUCTION

More accurate cost evaluation of financing houses is very important for low income homeowners, financial agents and construction supplier companies. With the most possible exact calculated cost, these actuating personalities on building construction can minimize their margins of uncertainty in gains and maximize their opportunities of success in the entire process. This means: if build and homeowner data are reliable and easily evaluated: (1) financial corporation will process data quickly and accurately, saving specialists time and effort (2) homeowner will have a better program of construction tasks, including quantity, and clear credit payment information (3) suppliers will work with safe buyers, will have assured ordering and, therefore, can offer better prices.

Homeowner and financial agent need to have a better anticipation of the amount of money which will be employed in the construction planned, the most near of real cost better. From the viewpoint of homeowner this forecast will help to prevent against the danger of evaluate above or under the amount really required to complete the planned construction. From the viewpoint of financial agent the advantage of a good forecast is to prevent against the necessity of deep adjustments in original credit which, if didn't made very carefully, can lead to homeowner defaults.

A computational system which interoperates with these three agents and helps in such matter is justified. A research effort was started and intended to understand all the technical implications and how to give support to actors interoperability. The first movement was the characterization of actors and data. The second movement was the characterization of relationship between actors and between actors and data. Once these steps were complete, we search for the technology that can map them in computational terms harmonically, and utilize this technology to implement the system.

## 2. ACTORS CHARACTERIZATION

Three are the major actors contemplated in the scene: Financing Corporation, Homeowner and Suppliers (material, equipments, services, etc.). Here a brief characterization of each one:

### 2.1 FINANCING CORPORATION

Currently in Brazil house finance market is growing (Folha Online, 2007) and becoming very accessible, with lots of banks offering money at diverse interest conditions. Despite this development, government bank persists the most advantageous way to get credit for the low income people.

The larger fraction of low income people legalized new realty corresponds to a small and inappropriate dwelling, purchased through financing programs based on workman compulsory social insurance contributions managed by the government. Every workman with regular work documentation must contribute. These programs can finance 100% of realty and can reach 30 years of loan term. It is common the homeowner desire to refurbish and expand their houses to adjust as better as possible to appropriate condition. This means search for new money offering and there are similar financing programs of government bank focusing these issues. In these programs the term of the construction must be until 12 months and the credit limit \$42300 USD.

The main steps in the process to get credit in Brazilian government bank are, in a simple manner (Caixa Econômica Federal, 2008):

- Determine the total budget to refurbish, expand or conclude the house.
- Collect all documentation about ownership, familiar income level, construction plans, city hall permissions, etc.
- Evaluation of previous data: budget and documentation.
- Emission of a Credit Approval Letter: documentation certifying conditions to get credit in the bank, valid for 15 days. It is possible that part of total amount stays out of the credit granted, and homeowner must be in charge of it.
- Evaluation of the realty by a bank engineering team.
- Setting up of the financed value and amortization term which will be contracted.
- Make the contract.

There are credit lines dedicated to other income range, to material acquisition only, and some specific ones. All of them have similar central technical characteristics, like homeowner budget evaluation and realty specialist verification are common.

### 2.2 HOMEOWNER

To be an applicant to get credit actually in Brazilian government bank, the homeowner must have, roughly, familiar monthly income of \$230 USD up to \$1800 USD and total value of building under

refurbishment of \$42300 USD. The loan term increases as homeowner income decreases reaching 120 months regularly or 360 months in fiduciary alienation case.

### 2.3 SUPPLIER

There are at least three kinds of supplier, but the most recurrent in construction case are the material stores. Service and equipment suppliers are more specific and can be described using almost the same characteristics used to describe material supplier.

Low income people in Brazil use to buy construction material in pieces, i.e., as the money comes, and reach a proportional amount, they go immediately to a local store to buy the next apparent useful consumables to their chaotic construction planning, in a very disordered and expensive way. Sometimes the material acquired is lost due to wrong storage conditions. With money from financing, the homeowner must plan the acquisition of consumables to extract most possible advantage of this money opportunity. The system may help to plan and to choose the better supplier in many aspects, including construction nearness.

The supplier contribution is to give to the system necessary data to evaluate the prices and conditions of payment. The system must permit the supplier to handle this information with confidentiality, security and precision.

### 3. DATA ORGANIZATION

The system will fundamentally deal with information. Data organization is the main effort in preparation of an efficient and useful system. Three are the key information sources: unit costs, building and homeowner. Pairs of them are useful for a particular actor, as shown in Figure 5. The combination of Homeowner and Build Information depicts the matter to be financed, necessary to Financing Agent. Build and Unit Cost information assembled make possible the calculation of total cost, very important to homeowner and which arrives at financing agent through him. To the Supplier, Homeowner and Unit Cost are two handled information to help gaining a new customer.

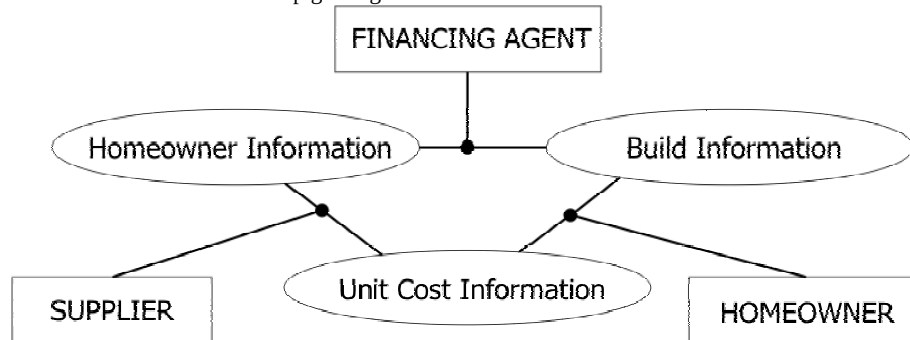


Figure 5: Information pairs useful to corresponding actors

#### 3.1 UNIT COST INFORMATION

Supplier prices are a composition of manufacturing cost, transportations cost, government taxes, marketing cost, demand, etc. They are one component of construction cost, once associated with workforce prices and indirect costs, like new government taxes and weather adversities, the result is the construction cost. These construction costs are commonly deal as unit prices times build quantity, i. e., square meter or cubic meter can be the unit measure of material, for workforce can be one hour of work, etc. One task is composed by material, workforce and equipment application. For the calculation of unit task cost we join these three prices and an indirect cost component. This shows that unit cost is not only supplier prices, but to reach the unit cost the system must handle with supplier prices, and the right composition of material, workforce and equipment application for each kind of task.

#### 3.2 BUILDING INFORMATION

As we are working with people without access to sophisticated ways of plan and represent the projected refurbishing, the system can give this support through a viewer and an editor of building information. This is not a simple job, but currently we have technology to develop interactive applications, running on Internet basis, linked with a very complex and complete data model managed by a robust machine and by expert people. One example of this possibility is presented in (Kehmlani, 2008).

To elect a build model for the system we search for the most adaptable model currently in use and found IFC (Howard & Bo-Christer, 2008). IFC (Industry Foundation Classes) Model is a proposition of IAI (International Alliance for Interoperability), have been endorsed by the International Standards Organization as a Publicly Available Specification (PAS) under the ISO label ISO/PAS 16739 (International Alliance for Interoperability, 2008). This model organizes information about the whole lifecycle of the building.

### 3.3 HOMEOWNER INFORMATION

The information about homeowner is that required by financing corporation. Supplier must require some other information, but generally with a good data form, all necessary information is captured.

## 4. RELATIONSHIP BETWEEN ACTORS

As financed values are smaller, interest payment are smaller also, and some taxes associated with total value. As the financed value depends on homeowner calculations of refurbishment needs, accurate in these calculations is essential and this is the central target of the system.

One financing step is engineering bank analysis. This analysis could be very easier and including unnecessary if the system had all necessary data since the early stage. If system is reliable, evaluation will be too. This reliability will be conquered by ne accuracy in calculations previously described.

Another relationship between actors causes the appearing of some questions:

a) How to communicate data to the Database System related to the planed build or related to the changes desired to be applied in a house existed?

IFC model will be the information standard way to organize and exchange building data, but the information about the build will reach your destination after handled through an editor embedded in the system's homeowner interface. The IFC model is very good but very complex too. This leads to a very good homeowner interface, simple but with complete tools to handle build information with accuracy.

In the case of refurbishment, the system needs to have information of two build models: one before and other after refurbish, to compare and extract information about what represent the changes, quantitatively and qualitatively.

b) The Database System needs to keep cost data of new constructions and data of refurbished constructions since the costs are very different due to the different nature of the job?

New construction costs have an intrinsic difficulty to obtain, but there are many companies dedicated to collect and calculate the average unit prices of a representative number of sources and sell the result as tables. Refurbish construction costs are much more difficult to obtain because they are classified information to the building companies and they do not publicize them, on the contrary these information are typically a competitive gap between companies. To surpass this wrong situation, a solution is to discover the relationship between unit prices of a new construction in unit prices of refurbished ones. This represents a big work and currently it is been made by a research group of University of São Paulo, collecting data from public and private buildings under construction. In cooperation with this group we are using the results to compose the unit cost database of refurbished buildings.

c) How to update costs of lots of items turning the system reliable?

A method to transform unit prices of new construction in prices of refurbished can be found, at least statistically, but the prices itself varies driven by market rules. To the system this represents the need of supplier (of material, services and equipments) involvement and commitment. The system can provide a way to edit, increase or delete items and prices updated periodically or at any time. The advantage to the supplier will be that they will receive directly ordering if the prices and conditions are better. The system foresees security of data access, so it guarantees loyal competitiveness between supplier companies. Not only lower prices are better, but availability, near distance of build place, conditions conceived by supplier for best customer in quantity and quality, etc. It can turn into an advantageous negotiation, prepared and calculated by the system.

## 5. ARCHITECTURE OF THE SYSTEM

A guide to choose the best technology to be applied in the system was that open source or freeware software has priority because we want also to show the low level investment in its implementation. In addition, popularity, good documentation, easy access and support were other criteria in that election.

IFC is an object-oriented and highly structured information building model. Building model made with IFC structure is very exchangeable and can be processed with an application capable to read the archive in IFC format.

Java is an object-oriented and Internet linked programming language. It fits very well to process IFC data. IFC viewer, editor and parser will be developed in Java.

PHP (recursive acronym of PHP: Hypertext Preprocessor) is a scripting language that is especially suited for Web development and can be embedded into HTML. PHP reveals very appropriate to make the user interface and the communication with database. It is object oriented too.

PHP works very well with MySQL database. For this reason Cost Database was mapped to MySQL and the interface with suppliers is been built to give all necessary possibilities to edit unit prices. The structure of MySQL also gives support to join information an arrangements to formulate unit costs, as presented before.

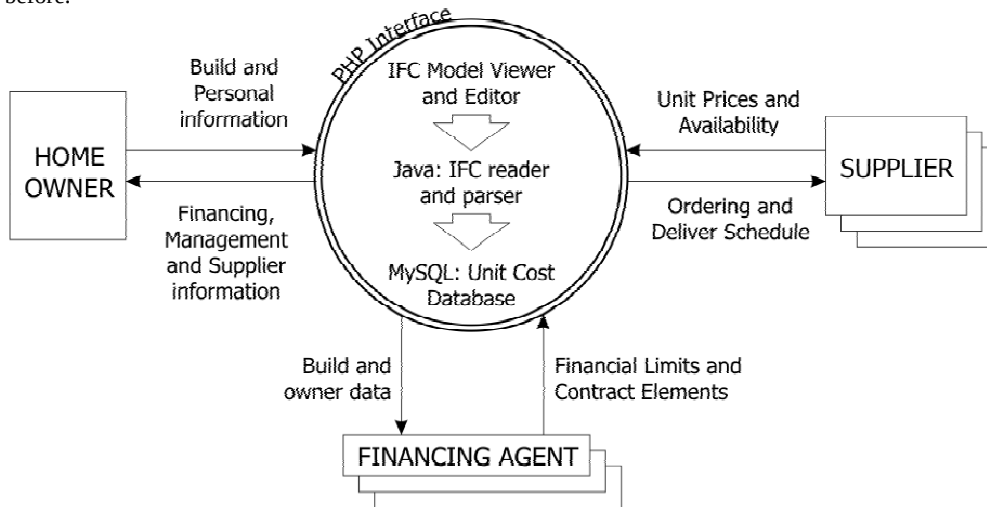
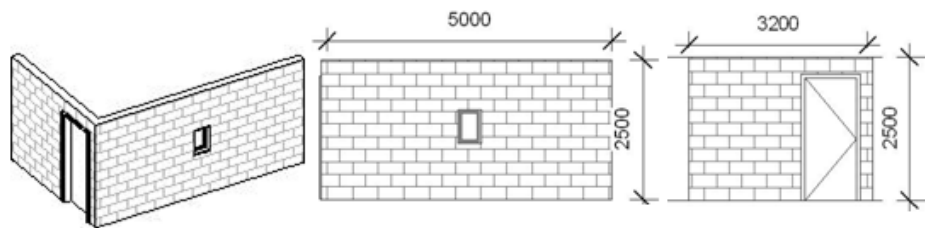


Figure 6: System architecture.

## 6. CONCLUSION

Until now we have experienced the use of all technological elections made and implemented some parts of the system: MySQL database of unit costs, supplier user interface and IFC parser are the most advanced ones. See the Figure 2 to visualize where each one in the system is. We have the intention to reach a prototype of the entire system to test conceptual alternatives. The complete system in a "commercial" stage must be done with further developments and for computer analysis specialists. Our work focuses in civil engineering and architecture views of the problem, mapping the problem and searching for the better solution. The next steps are concluding IFC parser and make the link with MySQL unit cost database, which seems to be the harder topic of the entire system. We believe this stage is critical and once surpassed we will reach rapidly the prototype and can experiment alternatives in final solution. We hope the continuity of this work can contribute expressively to low income people achievement of a remarkable economy of work and money. Providing a good help in refurbish their houses we think we are making a very good difference in the lives of this unfortunate people and for entire society.



#61=IFCWALLSTANDARDCASE('2rEa91Cb9EienByob5m3\$Z',#33,'Basic Wall:Generic - 200mm:102163',\$,'Basic Wall:Generic - 200mm:398',#45,#60,'102163');

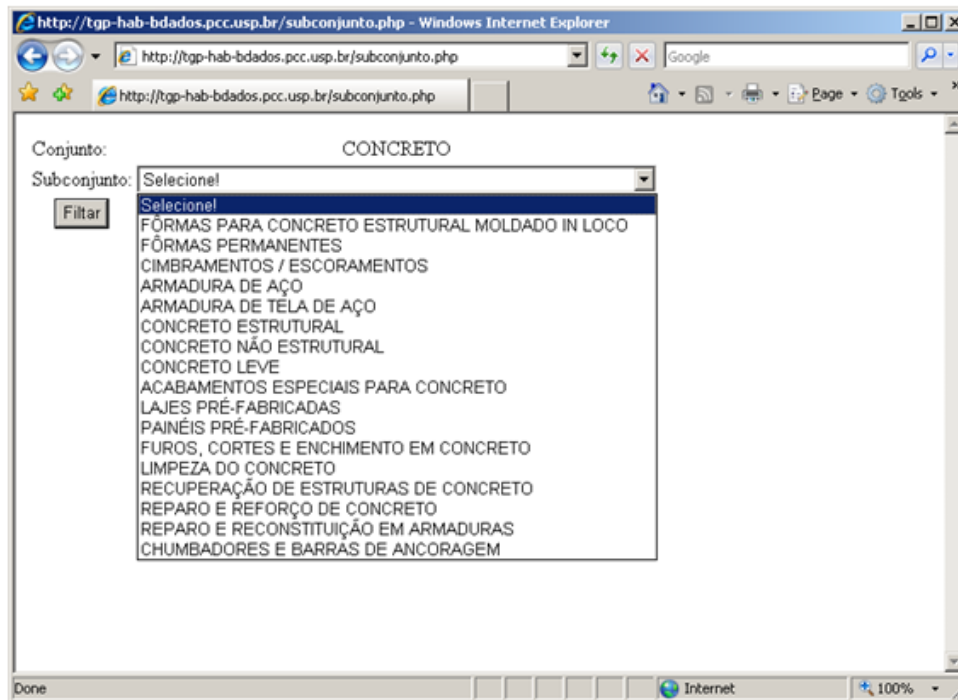


Figure 7: wall representation, IFC wall description (fragment) and supplier interface examples.

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## **REQUIREMENTS ON 3D BUILDING INFORMATION MODELS AND ELECTRONIC COMMUNICATION – EXPERIENCES FROM AN ARCHITECTURAL COMPETITION**

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Denmark

### **ABSTRACT**

In 2007 the public clients in Denmark started implementing new requirements on information handling in their construction projects. In the full implementation they will demand that all construction data on public construction projects are digitally managed and interchanged. Tendering shall be effected electronically over the Internet. Design will be based on 3D building models, which are gradually specified to reach different levels of detail. The parties involved in a specific construction project must share and interchange data and documents about the construction project on a common document management system accessed through the Internet. When a construction project is finished, the parties will hand over relevant operation and maintenance data electronically to the client. Detailed requirements have been developed on behalf of the public clients within four main areas: 3D models, Digital Tendering, Project Webs and Digital Handover. Within each of these areas, initial requirements have been tested in specific construction projects. This paper describes experiences from the test of the suggested requirements on 3D models. The requirements were used in an architectural competition on modernizing a cluster of university buildings. Four selected architects were invited to the competition. The proposals from the architects should be prepared as a 3D model in IFC format supplemented with a number of 3D visualizations chosen by the individual architects.

### **KEYWORDS**

3D building models, BIM, electronic communication, requirements, architectural competition.



## 1. INTRODUCTION

The Danish government has decided that construction data on public construction projects must be digitally managed and interchanged beginning in 2007 with a set of requirements regarding electronic communication and tendering through a web based document management system, use of 3D building models and digital handover of operation and maintenance related information to the client. The extent of the new rules depends on type and size of the construction project. Details of the rules are given in an executive order from the National Agency for Enterprise and Construction, (Erhvervs- og Byggestyrelsen, 2006) in Danish. Information in English is available at Danish Enterprise and Construction Authority (2008) and (Implementeringsnetværket, 2008).

To prepare the public clients and the industry for the new requirements, a development project called 'Digital Construction' was carried through from 2003 to 2006. The project was divided into six major work packages:

- The foundation for digital construction
- Client demands on electronic tender
- Client demands on 3D models
- Client demands on project webs (web based document management systems)
- Client demands on electronic hand-over
- Best practice

The structure of the Digital Construction programme is illustrated in figure 1. A short introduction to the programme is given in the publication "Digital Construction" by the National Agency for Enterprise and Construction (2005).

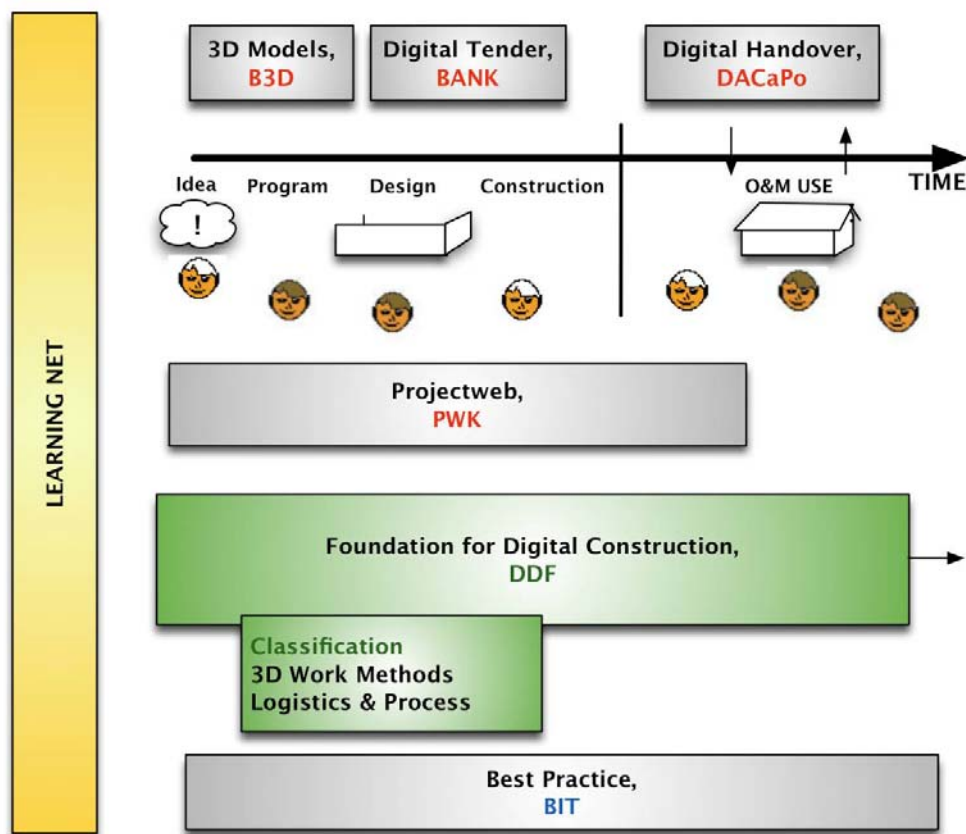


Figure 1. Structure of the Digital Construction project. From Christiansson (2005).

Six different consortiums were commissioned, through a public tender, to carry through the individual work packages. Each consortium had a number of partners typically including major consulting engineers and architects, contractors as well as university departments.

As a part of the development process, the four consortiums, that developed the client demands, were expected to test preliminary versions of the developed requirements in current construction projects managed by the public clients. The first version of the requirements regarding 3D-models is expressed in two publications (Karlshøj et al, 2004a and 2004b) describing the requirements and guidelines for using them. These publications are in Danish. For English information on related topics of the Danish Digital Construction project, please see bips (2007)

The two requirements publications describe modelling concepts and recommendations regarding agreements between the client and advisors. Modelling concepts are described to give the client and advisors common terms for describing the content and level of detail of the required models. The described modelling concepts are based on guidelines from Finland developed in the ProIT project (Niemiöja, 2003). The Danish requirements publications further give a survey of data requirements for a number of simulation and visualisation possibilities which can be based on 3D models. It is suggested that building models are exchanged in the IFC format specified by the International Alliance of Interoperability, <http://www.iai-international.org/>.

Similar requirements are in recent years being introduced in other countries. In January 2008 the U.S. General Services Administration and similar organisations in Denmark, Finland and Norway announced a "Statement of intention to support building information modeling with open standards" (U.S. General Services Administration et al, 2008). Senate Properties in Finland announced new BIM requirements (Senate Properties, 2007) and there are other initiatives going on in Norway and the United States (Kiviniemi et al, 2007).

The case, that was chosen to test the first version of the Danish requirements on 3D models, was an architectural competition on an overall plan for modernizing a cluster of university buildings (fig. 2). The

buildings were 30 years old, and the university wanted proposals to modernize the buildings so they could meet new requirements from students and employees of a modern university. Some of the wishes were:

- more daylight in the corridors, especially by roof light
- incorporation of social rooms near entrances of the buildings
- more or less covering of outdoor areas between buildings
- establishing a covered square at the main entrance of one of the departments

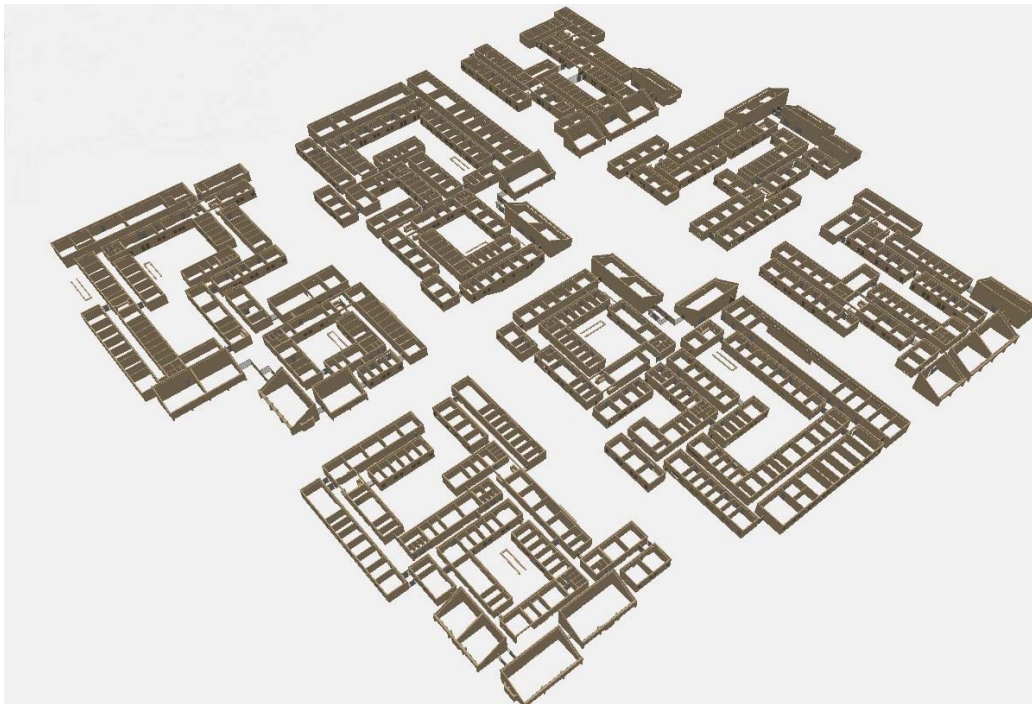


Figure 2. The test case was an architectural competition on an overall plan for modernizing a cluster of university buildings.

The client, who was the public owner of Danish university buildings, invited four selected architects to participate in the competition. The proposals from the architects should be prepared as a 3D model in IFC format supplemented with a number of 3D visualizations chosen by the individual architects.

The client had existing 3D object based models of the individual buildings for operation and maintenance purposes, and the client decided to use these models as a basis for the competition. The models had a high level of detail reflecting many construction details of the real buildings (an example of a complex wall object is shown in figure 3). The models were merged into one model including all buildings of the site, and then exported to the IFC format. This model was used as a major basis for the competition together with a sketch map of the area in the form of a 3D IFC model of the surrounding terrain and photos of selected details of the existing buildings.

In addition to the requirements on 3D models, which should be tested, the client decided to avoid any paper based communication. All information on the competition including sketch maps and photos was delivered electronically to the architects via a web based document management system, and the architects were required to hand in the entire proposal electronically to the same document management system. The proposal should include an IFC model of the modified cluster of buildings as well as traditional descriptions and visualisations of selected parts of the site. The assessment committee was given electronic access to the proposals, and the committee also decided to present all the proposals electronically with a computer projector at the assessment meetings, i.e. no traditional posters were printed to present the proposals.

## 2. METHOD

The developing consortium monitored the entire process of the competition including the client's preparation of the basis material, the architects' production of the proposals and the meetings of the assessment committee, in order to capture experiences with the use of the 3D client requirements. Two persons from the developing consortium assisted the client in the preparation of the material for the competition and they participated in all meetings with the client and architects as well as the jury meetings.

After the competition, representatives of the university operation and maintenance organisation as well as the participating architects were interviewed individually to collect their experiences. The interviews were based on the following main questions:

- *Did you experience problems in communicating the requirements to the employees who must meet the requirements?*
  - o *requirements in the specific project*
  - o *the requirements in general*
  - o *form and extent of the publications*
  - o *content and language*
- *Assuming that the requirements have been understood correctly; did you meet any problems in fulfilling the requirements with regard to*
  - o *Technological, software, hardware*
  - o *User competences*
  - o *Organisational, commercial aspects*
- *What is the profile of the target group facing the requirements in your organisation?*
  - o *role in the organisation*
  - o *competences*
  - o *existing tools*

## 3. RESULTS

The major experiences captured from interviews with the architects, the client and the jury are presented below. Further details can be found in a Danish report by (Svidt & Karlshøj, 2005).

### 3.1 ARCHITECTS EXPERIENCES

All of the involved architects had chosen to use Autodesk Architectural Desktop for the import and export of IFC files. For the visualisations, they used a range of tools for 3D modelling and image editing as they were used to in traditional projects.

A collection of statements from the interviews are presented in the following sections focusing on:

- The requirements in general
- The IFC requirement
- Competences and technology
- Working methods
- Digital information exchange
- Digital presentation

Some of the statements may be contradictory, since they originate from different persons.

#### 3.1.1 THE REQUIREMENTS IN GENERAL

- Specific requirements on visualisations may be a limitation, since architects prefer to have their own graphic profile.
- Architects will feel limited by requirements on too accurate models in the competition phase.
- The requirements publications contain too many pages, we would prefer a shorter introduction
- In fact we only needed a few pages from the requirements publications.
- The 3D building model from the client gave us a good overview of the project.

- The 3D terrain model did not help us, we would prefer a traditional map with contour lines.
- The 3D model from the client had a higher level of detail than we were supposed to deliver back to the client. This fact caused us some problems (e.g. complex wall objects as the one shown in fig. 3 made it complicated to manage simple operations as inserting windows and doors)
- The complex wall constructions in the original model made it complicated to insert new doors and windows in the model.
- We found a lot of errors in the model from the client, which disturbed our further work.

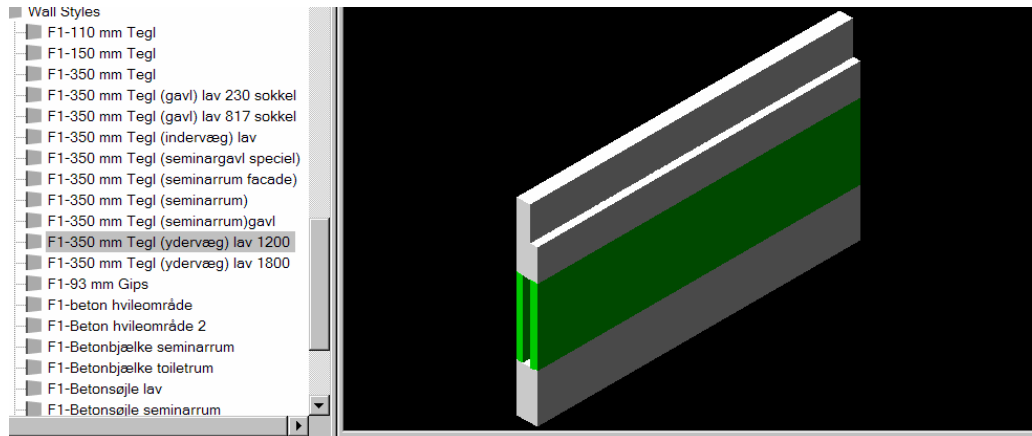


Figure 3. The model of the existing buildings included many construction types at a high level of detail. Walls with different layers at different heights caused problems for the architects modification of the model.

### 3.1.2 THE IFC REQUIREMENT

- We had never heard of IFC before.
- We had some trouble in the beginning, but now we don't see any problems in delivering IFC files.
- Other clients, e.g. hospitals owners already require object based models, normally in a specific CAD format.
- We see some immediate advantages in these models, e.g. the possibility for quantity take off.
- We had some problems with 3D objects imported from another software.
- The IFC format in itself is not a problem, but using this type of models in general would require a big educational effort to spread the necessary competences in our organisation.

### 3.1.3 COMPETENCES AND TECHNOLOGY

- Some of our employees have used object based CAD for the last three years.
- For many purposes this is faster than traditional CAD.
- One third of our CAD licenses are on object based systems.
- We need further education to have sufficient competences in the company to meet such requirements in general
- We used to work with 3D digital building models, but had never heard of IFC and the Danish Digital Construction project.
- We had problems to get teachers for an internal course, because they were employed in competing companies.

### 3.1.4 WORKING METHODS

- We made the 3D visualisations in a pure visualisation tool and built the object-based models from scratch in Architectural Desktop, no reuse of models.
- Working with 3D models in the sketching phase was more challenging than traditional 2D, but forced us (i.e. helped us) to solve some issues, which wouldn't have been solved by traditional sketching.

- We normally don't use this type of models in the initial sketching phase.
- We plan to use 3D in the detail design phase, but our engineers still prefer traditional 2D drawings.
- We did the architectural part of this proposal with our traditional tools and made the required 3D model in the last minutes before delivery.
- We didn't find that we could present our ideas through the required 3D model.
- We had some problems with the high level of details in the delivered model, and therefore decided to build a new model from scratch.
- We worked in parallel with hand sketches, object based CAD and a 3D visualisation tool.

### **3.1.5 DIGITAL INFORMATION EXCHANGE**

- We experienced no problems in the electronic communication.
- This is the first time we try a pure digital delivery.
- We find this working method interesting and would like a faster progress towards 3D models and electronic communication.

### **3.1.6 DIGITAL PRESENTATION**

- We see some interesting possibilities in making more dynamic presentations
- Presentation on a computer screen or projector give some limitations regarding a general overview of the proposal, it is often necessary to zoom in and out.
- We had to consider if the user should be allowed to navigate freely in the model or he should follow a predefined route.
- Traditionally we are supposed to present proposals on posters or other printed material and thus we are not used to make animations.
- It reduced our workload in that we should not print and send anything
- We considered several times to build physical models to support our internal design process.
- We chose to deliver the proposal as a pdf file in print quality.
- We planned, but due to limited time and resources we didn't fulfil to make an interactive model where the user could choose a number of predefined fly-through tours.

## **3.2 CLIENTS EXPERIENCES**

- The electronic presentation (projector) of the proposals was not successful in all cases since some of the received proposals were more suitable for high resolution printing than for a low resolution projector.
- It was found positive that the entire jury was focused on the same picture during presentations and discussions.
- It was concluded that the use of IFC models required special competences.
- Some uncertainty on the role of the IFC-models compared with traditional visualisations was expressed.
- Using the 3D requirements requires new competences in the clients organisation.
- The jury would have benefited from a "3D pilot" to support the navigation in the delivered 3D models.

## **3.3 THE JURY'S EXPERIENCES**

It was new to the jury members that all communication was electronic and that traditional proposals based on posters and books were replaced by a projector. The individual jury members experienced some technical problems in handling the electronically delivered materials. However, the jury emphasises the good possibilities achieved to study the proposals before the first jury meeting. Only one member of the jury brought a laptop computer to the meetings, so he could browse the proposals individually during the meetings.

## **4. DISCUSSION AND CONCLUSIONS**

A proposal for requirements on 3D models was tested in an architectural competition by the public owner of Danish university buildings. In addition to the 3D requirements, the client decided in the project to

avoid any paper based communication and thus all information exchange and presentation was based on electronic media.

It was found that the new requirements on 3D models were received positively from all parties of the project, and that the architects only had minor problems in fulfilling the requirements. All participating architects managed to use the electronically delivered material as intended to identify the buildings' mutual position on the site and their internal structure. The main part of the architects have used the required 3D models directly in presentation of their proposals. However, none of the architects have chosen to give the jury the possibility to navigate freely in a visualisation model.

In this case, there were no requirements to specific 3D visualisations or animations and there was thus a large variation in the material that the different architects had decided to deliver for presentation of their proposals. It would probably be easier for the jury members to navigate in the proposals if there had been certain minimum requirements such as specific viewpoints or specific informations to be presented in the proposals. It would also be relevant to require that the delivered documents are suitable for projector presentation if this is planned to be the main presentation medium.

The client didn't carry out any further treatment of the delivered IFC models, but chose to show the 'raw' models directly in an IFC viewer during the assessment committee meetings. By the largest models this procedure caused some viewing problems due to insufficient capacity of the computer in use. This raises some questions regarding the choice of tools for a certain visualisation purpose and the possibilities (or missing possibilities) to handle different information levels of large and complex building models.

The succeeding interviews with the architects showed a generally positive attitude to the 3D requirements and the selected structure of the competition. One of the participants expressed that the requirements forced the architects to solve some problems in the early phase, which could have caused greater problems later in the project. However, the competences to build object based models for such purposes are not always available in the team, who makes the competition proposals since these tools are more common in the detail design teams.

Experiences from the interviews and from discussions at the jury meetings show that it has been difficult for the involved parties to distinguish clearly between different parts of the requirements, e.g. 'visualisation', '3D-models', 'electronic communication' and 'electronic presentation'. Some of the participants have associated the 3D requirements with pure electronic communication and information transport over the Internet. And electronic storage and transport of the information has further been associated with presentation on a projector which has a very limited resolution compared with posters and other paper based presentations. This means that it has been difficult to keep the main focus on the 3D requirements, which was the main subject to be tested in the project.

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## BARRIERS OR CONSTRAINTS? A REVIEW OF DEVELOPMENT ISSUES AS THEY APPLY TO CONSTRUCTION IT

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### ABSTRACT

The construction industry is widely characterised as conservative in both business practices and construction methods and processes. Companies are seen as reluctant to change existing practices, despite the potential for greater efficiency and time and cost savings offered by technology now available. Supply chains are fragmented, and extensive use of sub-contacting introduces layers of management and a strong degree of autonomy in a wide variety of subgroups within a construction project team.

Many studies have focused on barriers to the uptake of information technology in construction firms, with findings often framed in terms of characteristics of the industry similar to those summarised above.

This paper presents a review of literature related to the introduction of IT in construction. It highlights a number of related issues that indicate that the construction industry might be better seen as cautious, but making progress, rather than resistant.

While there are clearly characteristics of the construction industry that hinder widespread uptake of information technology, this can be seen as only part of the story. The argument for increased application of IT to construction processes is now well established, with identified benefits of improved productivity, financial and environmental sustainability. There are clearly gains to be made from progression in the industry from low-level business applications to construction-specific IT usage, and there are indications that the industry is ready for this to take place.

To conclude the paper, the author questions why these industry characteristics often cited as barriers to innovation are not instead regarded by the proponents and developers of construction IT as constraints or design issues to be factored into the development process.

### 1. INTRODUCTION

Construction activity is an important contributor to the national economy of most countries, and improved productivity of the sector is widely touted as a key dynamic in boosting the performance of the country as a whole. Application of IT has for some time been hailed as the key to implementing such productivity gains. The fragmentation and inefficiencies in the UK construction industry identified in 1994 by the Latham report (Latham, 1994) triggered a wave of initiatives designed to lead construction in that country into the “information age”. This provided impetus for similar initiatives in other countries, and in international collaborations, which have continued in various forms since.

After more than fifteen years of this drive towards more widespread application of IT in the industry, the discussion is surprisingly unchanged (Issa et. al., 2003; Gyampoh-Vidogah et. al., 2003, Peansupap & Walker, 2005). The construction industry is still widely characterised as ‘traditional’; conservative in both business practices and construction methods and processes. Companies are seen to be reluctant to change existing practices, despite the potential for greater efficiency and time and cost savings offered by the information technology now available.

This paper confronts some of the assumptions in the literature around this perception of conservatism and unwillingness to progress within the industry, and identifies some optimistic indicators that construction IT is moving forward.

### 2. WHAT IS “THE CONSTRUCTION INDUSTRY”

From some of the literature on implementation of construction IT, there is an impression of homogeneity in the construction industry. This belies the reality, which ranges from thousands of “one-man band” builders and other trades people, to multi-national, multi-disciplinary consultancies. Depending on how inclusive a scope one takes, construction businesses include not only those active on a site to put a

building together, but the transport companies, primary producers (e.g. cement, stone etc), labour exchanges and other enterprises that contribute to the construction process. This wide variety of businesses has similarly varied needs in terms of IT. To address innovation and expectation across the whole spectrum indiscriminately and to expect a consistency of interest and uptake, would be to invite failure in the IT design process.

A key factor in the development of IT in the construction industry is that of company size and distribution. UK figures show that 79% of companies have less than 5 employees, with only 2% having over 50 employees (Office for National Statistics, 2007). Similarly in the US, recent figures show 59% of companies have less than 5 employees, with only 3% having over 50 employees (US Census Bureau, 2005). Industry distributions in many other countries are likely to follow similar patterns. This is significant, as the literature suggests that the large companies are leading the drive for IT uptake and development. Small and medium enterprises (SMEs) have a much smaller uptake and do not currently see the same benefits and opportunities from the use of IT, beyond a limited range of business applications.

A recent approach has been to address the needs of small enterprises as a particular type of construction organisation. Research in this area (Acar et. al., 2005; Sexton et. al., 2006) has identified that these companies often have more in common with other small businesses, regardless of sector, than with large organisations in the construction industry. Even within the grouping of SMEs in the industry, there are considerable variations between firms in terms of size and purposes, and this must be recognised.

Another area of diversity in the industry is the distinction between the office and site activities of a company or project. Even within a single company, performance in terms of IT may vary widely. Given the temporary nature of project site offices, it can be a difficult task to establish a workplace with an IT environment comparable to those in a permanent office (Tah & Carr, 2001).

### **3. IDENTIFIED BARRIERS**

Many studies have identified barriers to the uptake of information technology in construction firms. Stewart et. al. (2004) summarised these into three levels of barriers: industry, organisational, and project. Another way to categorise these barriers is to view them as culture or organisation based, where the barrier results from the way people work within the construction industry; and technological barriers, which result from shortcomings in the technology and its development process.

Almost all of the barriers identified by Stewart et. al. (2004) may be characterised as cultural/organisational barriers. However, it is notable that contrary to the characterisation of the industry as conservative and slow to change, respondents in that study did not consider conservatism and fear of change to be significant issues in limiting IT implementation. The most significant organisational issue identified was the limited time and money available for investment in IT, particularly for small and medium enterprises. This highlights the significant challenge that the diversity within the industry, outlined in the previous section, introduces to IT implementation.

When these multiple organisations of various sizes and specialisations come together to form a project team, layers of management are introduced. Supply chains are fragmented, with participants retaining a strong degree of autonomy and independence. The project-focused nature of the industry means that each project team is relatively short-lived. The effort involved in putting IT into practice within a project - development and implementation, training staff in how to use it, and monitoring and adjusting the processes involved - represents a huge investment in time and cost in an industry which operates on already close margins and high risk levels.

Because of the project focus, and resulting from the shared risk of projects between participants in the project team, there is often no clear beneficiary from advancement in IT. The benefits accrue to the project as a whole, but the advantages to any one participant are not as easily quantified. In addition, the savings resulting from IT usage are difficult to specify, as they manifest in terms of time savings, reduced waste, etc (Tah & Carr 2001) which may also result from a variety of other factors.

This difficulty in identifying company-specific benefits contributes to another sticking point in advancing the IT development of the industry – use of IT occurs primarily at project level, and most of the drivers for development and innovation result from project-focused needs, but it is at company level, and particularly in the small companies, that increased uptake needs to occur for the industry to continue to grow and develop in IT use (Sexton et. al., 2006).

On the technology side, the lack of interoperability between many IT tools has been identified as a barrier. The “one-off” nature of much of the industry’s work, and fragmentation and reforming of project teams and temporary organisations has hampered the development of industry standard systems, and has prompted the creation of many task-specific tools that have a limited market and so are often subject to a less thorough development process. A European project in 2000 identified over 4000 items of construction-related software (Amor et al., 2000). This quantity acts to limit the amount of conformity between tools, and means that although industry standards exist, many companies use non-standard applications that are not able to exchange data.

Even where successful tools have been created for a company or project and put into action, limitations in other aspects of IT implementation or technologies act to limit the achievements possible with the new tool (Alshawi & Faraj, 2002). There has been a considerable level of ongoing development, adaptation and specialisation required to ensure tools continue to meet the requirements of individual companies and projects, which again contributes to diversity in applications that may have started out as standard but have become increasingly bespoke.

Bandwidth has been a technological barrier, particularly acting as a hindrance in document exchange. While large companies with broadband access have increasingly adopted electronic document transfer and internet-based project portals in their operations, the speed and unreliability of dial-up have been limiting factors for smaller companies who run systems with dial-up access to the internet. Even for companies using broadband, the large size of CAD files and transfer formats such as IFC still mean that this type of transfer is not instantaneous.

Limitations in mobile computing and flexible computing impose other technological barriers. Establishment of temporary site offices is essential if IT is to be used throughout the construction process. While the computers and other equipment needed to meet construction requirements may have been around for some time (Bowden 2002), users of new technology are still experiencing difficulties with equipment that does not perform properly in the demanding environment of a construction site (Svidt & Christiansson, 2006).

That barriers exist to more advanced and more widespread use of IT in the construction industry is indisputable. Many of these barriers stem from the nature of the construction industry, and as such are difficult to overcome. Technological barriers are less intractable, with development in IT both within the construction industry and in the wider IT context serving to reduce their impact.

#### **4. DEVELOPMENT PROCESS**

While there are clearly characteristics of the construction industry that hinder widespread uptake of information technology, this can be seen as only part of the story. Where there is a demonstrated advantage, with a supported process of application and implementation, the industry has shown it is open to change in how IT is applied to both business and site activities.

There has been a considerable increase in use of information and communication technology at the office level in construction companies. For example, the construction industry was one of the early adopters of mobile phone technology, and continues to pursue further applications of mobile communication such as video phones, as well as wider application of mobile computing.

Successful use of IT in construction, as in any industry, depends on alignment between the business processes and the IT intended to support it. A mismatch in this alignment will result in rejection of the IT by the people using the system (Adriaanse et. al., 2004). While there are many shades of change possible between them, the two polar approaches to this are clear: either to use existing behaviour as the model for how the IT processes should be developed; or to change the existing processes so that the IT determines the practice.

The literature suggests that the most successful uptake of IT results from implementations that tend towards the former of these two paths. The tight margins and high risk already present in construction projects means that companies are loath to introduce more risk. Process re-engineering is a very risky approach, in terms of both time and cost, with the end result an unknown. Stepwise change represents a much smaller upfront investment, in terms of cost, time and overall risk management.

CAD is one example of how this progressive uptake has proved successful. Initially, the change to CAD was a computerisation of existing activity. There was little or no change to the business, reducing the risk of moving to this use of IT. Draughtspeople were trained for CAD in a similar way as they developed manual draughting skills, in a training organisation outside the hiring company. The process for the company involved some outlay, in terms of equipment purchase, but little in training and time. Once this first step of computerised draughting had been accepted, the way was opened for the incremental of additional processes developed from that. The current movement away from CAD as a document production tool and towards the development of 3D CAD building models can be seen as part of this gradual progress. This signifies a considerable change in the way users will develop or model a building, integrating design with product details and other modelling and visualisation tools, but it has taken place gradually over time. Users have accepted new ways of working as a side effect of the technology, rather than being forced to confront change as a result of the change in technology.

This process of incremental change also serves to develop partnerships between the many organisations and interests involved in a construction project. Fernie et. al. (2006) identifies the divisions that can grow within partnerships if change is imposed rather than progressing incrementally. The extensive partnerships and inter-organisational processes in the construction industry are unavoidable, so development and implementation of IT needs to be cognizant of this effect.

Change can often be risky and thus daunting to businesses, both for managers and employees. A gradual approach to change, integrating current practice into new processes, is a successful model that allows low risk adaptation to new ways of working, and assists companies in building partnerships rather than threatening them.

## **5. BEYOND THE BARRIERS**

The current environment in the industry is shifting towards increased adoption of IT and a wider acceptance of its use across the industry. While this change may be slow to filter down to the many micro-companies in construction, a number of factors are important in driving a swing towards IT.

Education is a significant factor in accelerating change, with young people entering the industry more comfortable with technology. This has brought a considerable shift in attitudes towards IT. For the current generation of workers entering the workforce, IT is no longer seen as a threat or a change. They expect to see and use it in their work environment, as it has become an established part of their education and home life. For companies, this reduces the risk of introducing advanced IT, as the culture change and general acceptance of IT have taken place outside of their circle of influence. The organisation can then focus more on the specific application, and the technology and processes involved.

Clients, particularly government clients, are increasingly requiring companies to move beyond generic business use of IT into the use of domain specific tools as part of the construction design and management process. This is providing impetus for even the small companies to identify appropriate IT and shift towards a more integrated approach across the supply chain (Brewer et. al., 2005). Strategic partnerships and “favoured supplier” relationships are reinforcing this move, where companies seek to become part of projects or ongoing partnerships by aligning their IT use with that of the dominant companies. As more companies use advanced IT in their operations, other companies have to adopt similar practices to work with them, compete with them, or simply to maintain their market position. This is leading towards the point where a company has to adopt a certain level of technology to participate in the industry.

Improvements in technology are also contributing to greater acceptance of IT in the industry. Increases in capabilities and reductions in price of computing equipment make establishing a project site office less of a hurdle. Improvements in telecommunications, most notably the widespread access to broadband, also assist this process. The development of industry standards for information exchange is perhaps not a strictly technological change, but this a change in the way IT is being addressed across a range of industry sectors (Amor et. al., 2001). Increased momentum in the development and application of these standards will overcome the significant and widely identified barrier of lack of interoperability in industry tools.

Many of the factors identified in the literature as barriers are themselves in a state of change. Shifts in the way the industry operates, improvements in the available technology, and changes in society as a whole

are all contributing to a reduction in importance of some of the issues that have been traditionally seen as obstructing greater uptake of IT in the construction industry.

## 6. BRIEFING FOR BARRIERS

Many of the factors that have been widely identified as barriers to the introduction of IT into the construction industry could be viewed as key design factors to be considered as part of a development brief. For example, the implementation process is almost always identified as a barrier to the uptake of unsuccessful IT projects, despite there being a widely recognised best-practice process for achieving uptake (Stewart, 2004). Shifting the focus from barriers to brief requires a recognition that part of the design process is designing for not simply a system that 'can' meet the requirements but one that can be put in place to do so.

Another barrier can be overcome through recognition that there is not a single 'client' for an IT product. By taking a cross-functional view in the brief, there is a greater likelihood that developers are able to fulfil the requirements not just of the primary user of the tool but of the many other parties who will interact either with the tool itself or the information output from the tool. As discussed above, adherence to and support for industry standards will also serve to reduce the discrepancies in information exchange for the multiple users.

Parallel to the incorporation of these barriers as design factors in the brief, is the need for IT developers to take greater responsibility for achieving successful adoption of the tools created. A relationship between developer and user(s) is necessary as part of the development process, particularly for non-standard IT applications (Svidt & Christianson, 2006, White et. al., 2002). The dynamic nature of the industry means that the use of an application may evolve across the course of a project, or change between projects and project teams. For any application to achieve long term success in this environment, the development process needs to be regarded as evolutionary rather than one-off.

Understanding industry constraints and requirements is a further onus on both the developer and industry researchers. Industry benchmarking exercises such as the IT-barometer (Samuelson 2008) provide for greater understanding of the constraints and limitations present in the industry, and thus allow factors such as limited IT-usage by sectors within the industry, or areas of planned investment to be considered as elements of the brief, instead of as barriers to be encountered later during implementation. Process modelling is another area where improved information will lead to better briefing and thus a more responsive IT development. If an activity or process is to be supported by the development of specific IT tools, scrutiny of the interactions and procedures involved will allow the systems developed to align more closely with practice.

In redefining many of these traditional barriers as factors for consideration in the development brief for new IT applications, the focus is shifted from perceived shortcomings of the construction industry. Given that many of these are fundamental elements in the way the industry operates, it seems more realistic to approach IT development with an awareness of the constraints that exist. This in turn requires IT developers to recognise and incorporate these constraints into their work.

## 7. CONCLUSIONS

Many barriers have been identified that limit the successful implementation of IT in construction. A number of these barriers stem from the demographics of the construction industry. Many participants in the industry are micro businesses that do not realise the advantages that larger specialised companies can. A recent research focus on the needs of small and medium sized enterprises is helping to tailor development to the needs of smaller companies, and the inter-organisational nature of construction projects is also acting to include SMEs in advanced applications of construction IT.

Incremental change appears to be a successful approach in the industry in avoiding many of the barriers. The multi-party, short-term, high-risk endeavours that are construction projects have too much at stake to add further risk through introducing new processes and new IT tools. Incremental development allows gradual change and potentially leads to acceptance of more advanced applications once initial changes prove advantageous.

While there are still limitations to how construction companies and project teams accept and apply IT, many of the technological barriers are losing their significance. Moves in IT and telecommunications are improving access, reducing costs and increasing interoperability. Some of the cultural and organisational barriers are also decreasing in importance. Changes in attitudes and expectations surrounding IT in society as a whole are being reflected in construction, with greater personal experience changing the way employees approach IT in the workplace.

Many of the remaining barriers are intrinsic in the way the construction industry functions. In these instances, there is a need for these to be considered as part of the IT development process. If these characteristics are regarded as part of the question, if the constraints are incorporated as part of the brief, the IT tools that result will have a greater potential for contributing to the construction processes they are intended to serve. IT developers need to work with and for the construction industry, from an understanding of the needs and challenges it faces.

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## AN EVALUATION SCHEME FOR TWO SAFETY TRAINING APPLICATIONS

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### ABSTRACT

Safety research at Virginia Tech has developed two applications to enhance the mining industry's training methods. The first application is a virtual reality training application that introduces the information to the user through a 3D model walkthrough of a conveyor belt and then tests, through task-based training, the knowledge the user has gained. The second application, a Digital Safety Manual, is designed to allow users to visualize and manipulate safety information using a non-linear interactive multimedia application.

This paper describes the details of an evaluations scheme to test the usability and effectiveness of the two applications through novice and expert input. This involved a series of site visits to different companies and potential clients to review the information being presented and to get industry feedback. After the system was revised a series of usability studies and evaluations were conducted using novice and expert users to ensure that the applications are user friendly. The feedback and evaluations were then used to revise the applications and ultimately offer a product that would better fit the needs of the industry.

### KEYWORDS

training, program, conveyor belt, evaluation, feedback

### 1. INTRODUCTION

Working around conveyor belts is inherently dangerous and causes multiple fatalities and a high cost to the industry each year. Lucas et. al. (2007, 2008) studied 534 fatalities between 1995 and 2007 in the United States surface mining industry of which 50 were related to conveyor belts. Each of these fatalities costs the industry \$1.9 million (Goldbeck 2003) (2007 equivalent value as per inflation recorded at U.S. Bureau of Labor Statistics from 1986 study). Current training practices in the industry rely predominantly on a passive approach of using slide-shows and videos in a lecture setting for training, yet the accident rate remains high. With this high annual accident rate there is a need for alternative training methods to complement current practices. New methods are also needed to train large quantities of younger miners as the current workforce is aging and nearing retirement.

The use of visualization tools for improved safety training around conveyor belts is being investigated at Virginia Tech under several research project funded by the National Institute for Occupational Safety and Health (NIOSH) and the Virginia Tech Center for Innovation in Construction Safety and Health (CICSH). Two prototype applications have been developed aid in the training of miners who work around surface conveyor belts. The first is a virtual reality application that was developed to allow the user to walk through a virtual environment of a conveyor belt where information is presented about maintenance issues, safety procedures, and hazard recognition (Lucas et.al. 2007, 2008). The user is then tested on their gain of that knowledge through task-based training (Lucas and Thabet 2007, 2008). The second application is a Digital Safety Manual (DSM); an interactive multimedia application that comprises various categories of conveyor safety information and allows the user to visualize and manipulate information using a non-linear approach (Worlikar 2008).



Compared to conventional training methods, it is the authors' hypothesis that both applications provide better cognitive learning experiences as they utilize interactive non-linear approaches to training. This allows trainees to better recognize hazards and preventive measures associated with conveyor belts and to better understand the economical impact of accidents on their organizations and the mining industry. Evaluation is conducted to answer either of the two questions: whether training objectives were achieved i.e. learning issues, and whether accomplishment of those objectives results in enhanced performance on the job i.e. transfer issues (Kraiger 1993). This paper describes an evaluation scheme intended to test the author's hypothesis and verify that the interactive non-linear learning provided by the applications can enhance current industry training methods through learning retention and knowledge transfer on the job site. Other objectives of the evaluation scheme include:

1. Insuring that the information content and training scenarios are comprehensive, realistic, and consistent with industry training standards.
2. Improving the design of the graphical user interface (GUI).
3. Minimize programming and usability problems.

The evaluation scheme was divided into three phases. Phase one involves a usability evaluation that consists of unstructured industry feedback and interface evaluation are both subjective in nature and based on person opinion. The goal of the usability evaluation is to provide feedback in development, supporting an iterative development process (Carroll and Rosson 1985; Gould and Lewis 1985). The usability evaluation phase will allow for verifying the content of the application, get input on the GUI, and fix programming bugs.

The subjective analysis phase involved a subjective analysis to document individuals' opinions on their perceptions of the usefulness of the applications as a training tool. If it is determined that the proposed training application could be beneficial a more developed application is used for the performance based evaluation phase.

The performance based evaluation phase will aim at testing the hypothesis to show a learning improvement gained from the application versus conventional training methods. This will be an objective analytical comparison.

| SUBJECTIVE –<br>Based on Opinion                             |                   | OBJECTIVE –<br>Based on Fact                                             |                                                   |
|--------------------------------------------------------------|-------------------|--------------------------------------------------------------------------|---------------------------------------------------|
| QUALITATIVE –<br>Collection of personal<br>opinions or input | PHASE 1           | PHASE 2                                                                  | PHASE 3                                           |
|                                                              | Industry Feedback | Interface Evaluation<br>Subjective Analysis – Potential Usefulness Study | Performance Based Comparison<br>(Future Research) |
| QUANTITATIVE -<br>Analytical comparison of<br>results        |                   |                                                                          |                                                   |

TABLE 1: Evaluation phases

The process of each phase is discussed in more detail later in this paper with a summary of the quantified results for the usability evaluation and subjective analysis phases.

## 2. CURRENT INDUSTRY TRAINING REQUIREMENTS AND PRACTICES

In the United States, the Mine Safety and Health Administration (MSHA) is the governing entity for policies within the mining industry. As part of their Title 30 Code of Federal Regulations (CFR) Part 46, each mining facility is to develop and implement a written training plan that includes programs for new miners, newly hired experienced miners, new tasks, annual refreshers, and site-specific hazard awareness training. Within this plan, new miners are required to complete 24 hours of training, four of which are required before the miner starts any work, the rest within the first sixty days of work. Also within the plan are requirements for new task training and requirements for an 8 hour refresher course.

Besides MSHA's requirements, some literature review and research was performed to determine what to include in a successful training plan. Goldbeck (2003) proposes four training areas for effective training programs which include: (1) general safety practices of using safety equipment, (2) guidance for performing maintenance tasks and inspection hazards, (3) information about conveyor and belt conditions, and (4) procedures for belt training or tracking.

Lastly, interviews were conducted with the industry to see how various companies fulfilled and exceeded MSHA's training requirements, see Table 2. Typically, the weekly safety meetings cover any new site specific hazards. The informal safety talks consist of discussing near misses and prevention whenever safety staff thinks it's relevant. The rewards and incentive programs are of both monetary reward and activity rewards and are intended to encourage individuals and teams to continuously practice safety.

| Safety Training Practices                         | Company 1 | Company 2 | Company 3 |
|---------------------------------------------------|-----------|-----------|-----------|
| MSHA Required Training (new employee & refresher) | √         | √         | √         |
| Weekly safety meetings                            | √         | √         | √         |
| Rewards/incentive programs                        | √         | √         |           |
| Informal safety talks                             |           | √         |           |

TABLE 2: Current industry training programs

## 3. TRAINING APPLICATIONS DEVELOPMENT

The first step of development for both of the proposed applications was background research that would give a databank of information from which to draw while developing the proposed applications. This information was gathered through literature review, on-site visits, and interviews with industry professionals. Required areas of training were identified and the information was classified into four safety categories: belt conveyors, possible hazards, preventive measures, and awareness & statistics. The two prototype applications were then developed.

### 3.1 VIRTUAL REALITY APPLICATION DEVELOPMENT

The Virtual reality application consists of two modules; an instructional based module (Lucas, et.al. 2007, 2008), is used to train the user. The second module is a task-based module (Lucas and Thabet, 2007) where the user is tested on the knowledge that they were given in the first module. Shown in Figure 1, the 3D model of the belt conveyor virtual environment was developed using AutoCAD and 3D StudioMAX (Autodesk, 2008). The model was then imported into the DeepCreator™ (Right Hemisphere, 2008) where animations were added and other information programmed. From the created environment the two modules were then created. LISP programming language was used to create scenarios and track user decisions and scores.



Figure 1: Station within instructional-based module – a hot-point is clicked and information in form of animation and text caption is presented.

The instructional-based module contains an automated walk-through that takes the user from station to station where they are given a series of hot-points that contain safety information. Lucas, et.al. (2007, 2008) describe the development of the instructional based module in detail. The task-based module is a self guided session where the user is assigned tasks that need to be completed. These include hazard recognition (a broken rail, missing guarding, and material accumulation), proper start-up procedures, and proper lock-out and tag-out procedures before performing maintenance. The user is then scored on the completed tasks and the tally can then be used to track an employee's performance and improvement. Lucas and Thabet (2007) describe the development of the task-based module in detail with sample implementation and coding that was developed in order to track the performance.

### 3.2 DIGITAL SAFETY MANUAL (DSM) DEVELOPMENT

The framework for the Digital Safety Manual (Worlikar, 2008) is based on a 3D matrix to display the four main categories of information; *Belt Conveyors*, *Possible Hazards*, *Preventive Measures*, and *Awareness & Statistics*. This 3D matrix uses a 4 x 4 grid to store the content related to each of the four categories and provides the users the necessary navigational tools to explore the graphical database. Each square tile in this grid allows access to information and the four diagonal tiles serve as the main navigational nodes to move back and forth in the matrix between the groups of information.

Each of these four navigational nodes brings up a unique combination of information based on the user's selection during the exploration of the DSM. This information is presented as color-coded 3D bars of varying heights where the height symbolizes the amount and type of information that it contains (Fig. 2). The color-coding is used to provide the visual link between the related information when it appears at different points in time on the surface of the grid. The DSM allows for non-linear interaction and the flexibility of taking unique paths to retrieve safety information. While taking a non-linear approach, the users are also provided with a tool locate themselves in the hierarchy of the DSM's information organization and to help in understanding relationship between the different categories. The matrix provides a tool to zoom in on one specific piece of information and highlight all the related information from the database at a given point in time irrespective of the categories.

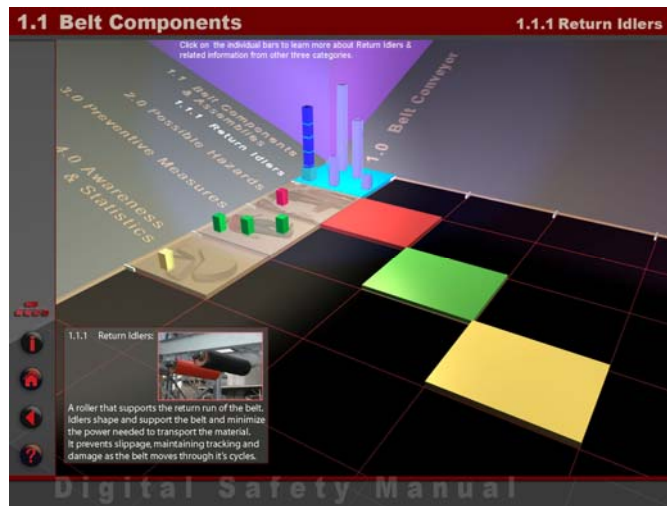


Figure 2: Screenshot from the DSM showing navigation through the 'Belt Conveyor' category

#### 4. EVALUATION SCHEME

In order to ensure that the two developed applications fit industry needs and to offer an application that is easy to use and understand the following feedback and evaluation scheme was developed (Fig. 3). The evaluation scheme is divided into three major phases; a usability evaluation phase, a subjective analysis phase, and a performance comparison phase. After each phase the two applications were revised based on the comments received. The first phase focused on the usability evaluation of the two applications and is further sub-divided into two parts, industry feedback (for information review) and interface evaluations (Fig. 4). The industry feedback part of the application evaluation (Fig. 4a) was unstructured and was performed by conducting initial on site meetings with various industry professionals to gather their reviews on the completeness and appropriateness of the information that is presented in each of the two applications. During this unstructured industry feedback session, industry professionals were given a demonstration of each application and their comments were recorded and documented to revise the prototype to its next iteration.

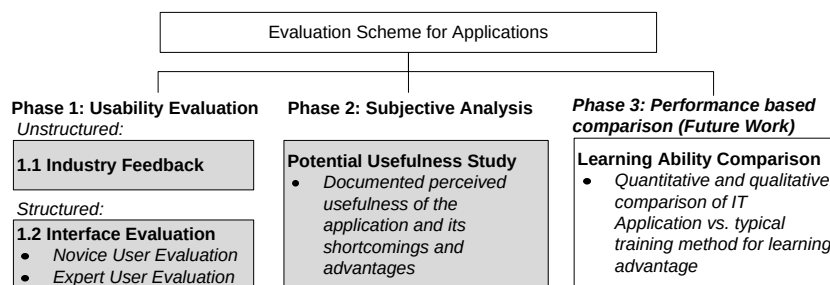


Figure 3: Evaluation Scheme

The revised versions of the two applications were used for the second part of the usability evaluation, the interface evaluations (Fig. 4b). The interface evaluations were conducted using two test groups; novice users, mostly students with various backgrounds and no prior experience with conveyor belts or mining, and industry experts or professionals who have experience with conveyor belts, mining, and are aware of conveyor belt environments. This evaluation aimed at assessing the usability of the GUI of both applications.

## PHASE 1: Usability Evaluation

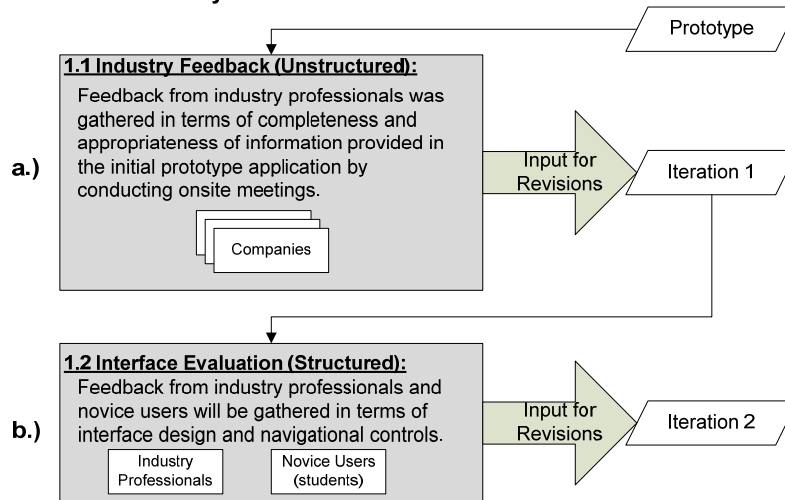


Figure 4: Details of Usability Evaluation (Phase 1)

Both groups were asked to complete an evaluation questionnaire where each participant rates their agreement with statements dealing with clarity of instructions, navigation of each application, and presentation of information. Once the findings of the questionnaires were reviewed, revisions to the applications were made and implemented in a new iteration for the subjective analysis phase.

The subjective analysis phase (Fig. 5) used both novice and experienced subjects to complete a subjective survey designed to identify the advantages and shortcomings of using the proposed training application versus typical training methods. The first group consisting of novice users was given a sample of a typical slide show presentation, videos, and written documents to examine and review. They were then presented a demo of the two applications and then were allowed to test the applications. Upon finishing examination of the typical material and the proposed application the participants filled out a subjective survey to document their perceptions. Experienced mining professionals were asked to complete the same survey based on their experience with training methods used in their facility compared to the proposed applications.

## PHASE 2: Subjective Analysis

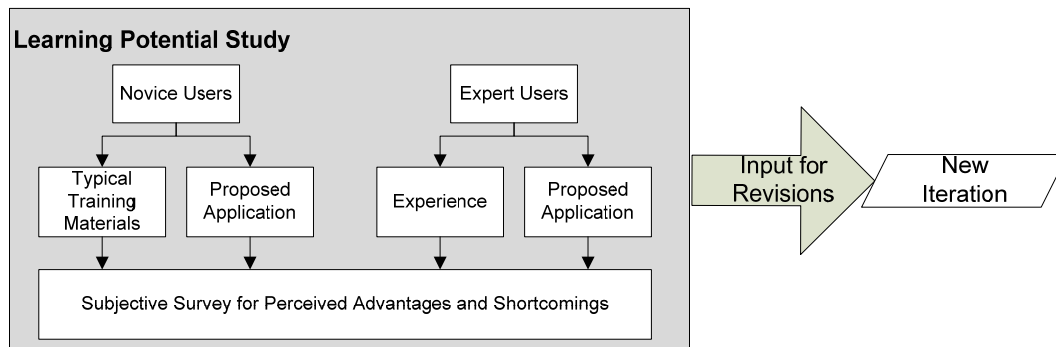


Figure. 5: Details of Subjective Analysis Phase

Once the data from the subjective analysis phase was collected and reviewed, it was used to develop the new (second) iteration of the applications to be used in the performance based comparison phase of the evaluation (future research). This two-parts assessment phase will validate the effectiveness and efficiency of the training applications. Two groups of users (non-experienced miners) will participate,

one in typical training methods of paper manuals, slideshows, and similar media, and the second in using the developed applications (Fig. 6). Both groups, once they complete their designated training will participate in a general knowledge quiz consisting of questions pertaining to safe working practices within the mining environment. The results will then be compared.

### PHASE 3: Performance Based Comparison (Future Work)

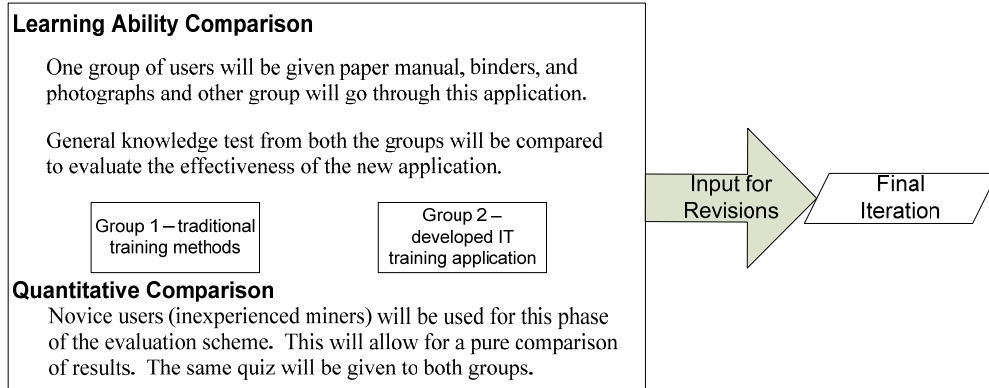


Figure 6: Details of Performance Based Comparison Phase

## 5. VIRTUAL REALITY APPLICATION: EVALUATION RESULTS

The virtual reality application followed the scheme laid out above. There were a series of industry meetings in order to check the quality and content of the information being presented followed by interface studies and a learning ability evaluation. Four meetings were held with a total of eleven professionals from the three companies. The attendees were given questions to focus discussion and encouraged to interrupt to make comments. Their comments were documented and compiled and were used in making the revisions of the application. From the meeting, 37 comments were documented for the instructional-based session, twelve of them dealt with existing information and twenty pertained to adding or revising safety information. The task-based session received 33 comments; 13 were revisions and the rest dealt with new information. After each meeting the application was revised to incorporate the new comments received. Once all meetings were complete build 2 of the application was created and used for the next phase of the evaluation scheme.

During the interface evaluation (Phase 1) 13 participants were asked to use the virtual reality application and answer a questionnaire that was broken into four sections: (1) demographics, (2) instructional-based module, (3) task-based module, and (4) general comments. The users were asked to rate their agreement on statements that deal with navigation controls, instructions, information clarity and method of presentation for both of the modules.

The participant's average age was 28, two were experienced miners, and one had previously participated in virtual reality training. For the instructional-based module the users were asked to rate their agreement with questions dealing with instructions, navigational controls, clarity of information presented, and graphics used. The average results for their agreement on a 1-5 scale (5 strongly agree) were as follows: *Instructions (4.15)*, *Navigational Controls (4.46)*, *Clarity of Information Presented (4.44)*, and *Graphics Used (4.58)*. For the task-based module the users were asked similar questions dealing with instructions, controls, task instructions, clarity of information presented, and ease of completing tasks. The results were as follows: *Instructions (3.23)*, *Controls (3.42)*, *Task Instructions (3.62)*, *Clarity of Information Presented (4.03)*, and *Ease of Completing Tasks (4.00)*.

The problems identified within the task-based session were clarity of instructions and navigational controls. Since the task-based session used mouse and keyboard controls, individuals were having difficulties getting accustomed to navigating the environment. If older miners who were not computer literate were required to participate in this training the navigational controls would be a barrier to learning. To prevent these controls from becoming a barrier to individuals who are not computer literate, alternative navigation methods with touch screen, third person navigation, joystick, or game controller

controls need to be implemented and explored. A module would also have to be developed to train the trainee on the navigation and test their ability to navigate and complete tasks before testing them on their knowledge to minimize the effect of the navigational controls on the final results of the task-based session.

Eight participants were used in the subjective analysis phase for the virtual reality application. Questions on the subjective analysis survey involved perceived advantages and shortcomings of the proposed application and typical training methods and which was perceived to be a more effective method of learning. 63% of the participants agreed that the proposed application is more effective because of the reasons: (1) the user is learning within an environment that represents real life, (2) that the prototype application provided detail steps for completing processes and then tests the user's ability in completing the processes, and (3) that the prototype application allows for an employee to interact with the environment and view consequences to actions without the result of injury that would occur on the job if the user did not participate in the training. The remaining 37% agreed that the first person interaction within the digital environment is beneficial; however, they thought the personal interaction that exist and allows for a training professional with a wealth of knowledge to answer questions is more effective. They also commented that the miners currently in the industry are more likely to be computer illiterate and that traditional methods of training cover a wider array of training methods that allow for overcoming various learning disabilities of illiteracy and reading comprehension problems.

## **6. DSM APPLICATION: EVALUATION RESULTS**

The DSM prototype follows the evaluation scheme described above in section 4. The concept of the DSM was presented to industry professionals through a series of site visits to the three companies to check its applicability and the accuracy of the information presented. These visits were followed by interface evaluations using novice and experienced subjects and subjective analysis to measure the potential of the DSM concept as a new approach to train workforce in the mining industry.

Industry feedback for information review and interface usability evaluations was conducted simultaneously using the industry experts. There was a range of personnel from different departments including safety engineers, superintendents, and maintenance personnel among others who were involved in this phase of the information review and interface usability evaluations. In the beginning, demonstrations of the application were given to all the attendees and they were encouraged to ask questions and give feedback concerning information presented during the demonstration. Attendees were then given 20 to 30 minutes to individually explore the DSM. The process was monitored by the research team so that concerns were recorded and resolved, and used in making the revisions of the application. After this exploration of the application by the attendees, all the users completed a questionnaire. This questionnaire was divided into four parts; demographics, navigational issues, design/layout issues, general issues.

During the interface usability evaluations, novice users were provided a brief introduction and a demonstration of the application before they used the application. This process was monitored by the research team to resolve any questions that users were having while navigating through the application. Another questionnaire was completed by each user and all comments and suggestions were noted and included in the next version of the DSM prototype.

The results from the interface usability evaluations helped in determining that instructions for the navigation of the DSM needed to be more clear and accessible throughout the application. The results also indicated that the color-coding used in the current version needed to be more evident throughout the DSM and needed to be included as part of the instructions. The results also helped to determine that some users had problems drawing the link between the categories of information presented on each screen and that it related to the two active categories (column and row) being examined.

The last section of the usability questionnaire asked general questions pertaining to the overall organization of the DSM, the effectiveness of the DSM's organization, and if the DSM exploration is an interesting and engaging experience. General questions pertaining to best features and shortcomings of the DSM, the applicability of the DSM concept in the construction industry, and general comments were also included in the questionnaire. Some of the features of the DSM noted were how it allowed the presentation of information, its use of videos and pictures in a multimedia environment, and its potential as a learning tool. The DSM shortcomings documented included barriers to user friendliness, its lack of

tracking system to record user performance, and that it has no defined structure. All these comments were analyzed and used to develop the next iteration of the DSM prototype.

Phase 2 measured the potential of the DSM concept. Novice users examined typical training material and then were presented with the proposed DSM application. Each user completed a questionnaire subjectively comparing the advantages and disadvantages of the typical training methods and the proposed application. Industry experts were also presented with the DSM and were asked to complete the subjective questionnaire comparing the proposed application to training methods used at their facilities.

Feedback received from the subjective analysis was largely positive. Almost 2/3 of the comments received from the participants indicated that the DSM has more advantages over the traditional training method. Comments from the remaining participants had concerns about the incompleteness of the DSM as time of evaluation and that when fully implemented were not sure of its potential.

Overall, 79% of the participants commented that there are more benefits in learning through methods used in the DSM than typical training methods. Few shortcomings were documented by the remaining 21% of participants. One main concern documented was the years of experience an instructor has is valuable and cannot be replaced by computer-based applications. 69% of the participants said the DSM is an effective way to learn training material if implemented fully whereas 31% said that even though the DSM has many advantages it can be used as a supplementary training aid with the conventional training method typically in use.

When asked about the benefits and the shortcomings of the DSM, comments received from the industry experts were equal. 75% of the comments received indicated that the DSM is an effective and interesting way to learn the training material whereas the remaining 25% of advocated the benefits of the typical training method.

## **7. DISCUSSION**

After preliminary research and initial industry discussions, it is believed that these applications would be a valuable addition to augment current training methods. The major concern of the current versions presented is user friendliness and usability, however many comments were received on how this can be improved. The final phase of the evaluation process still needs to be conducted. With the first two phases of the evaluation scheme completed and results analyzed, there seems to be considerable industry interest to further develop the applications and implement them into practice. If this were to happen, extensive further evaluation will have to be performed within the mining industry itself to test effectiveness of the training applications and their usability within the intended user group. Fully functional applications would also have to be integrated into training curricula in select facilities to allow for supervisors to record perceived effectiveness of task performance. Only then can the true effectiveness of the use of these applications be proved.

There is industry interest and belief that these applications, if further developed to fully functional application, would be a valuable addition to the current training methods. This helps support the hypothesis that these applications can be effective in learning and add to the typical training methods currently in use within the industry.

## **ACKNOWLEDGMENTS**

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## SCIENTIFIC VISUALIZATION AND VIRTUAL REALITY TECHNIQUES INTEGRATED TO CAD/CAE SYSTEMS FOR ILLUMINATION DESIGN

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### ABSTRACT

For a same project, engineers tend to use different software to perform different tasks such as geometry modeling, database management, numerical analysis and data visualization. This may cause decrease of productivity and losses of information during the conversion process between different data file formats. In, most lighting analysis tools for example, the geometry modeling and pre-processing features does not provide all the capabilities available in a CAD (Computer Aided Design) system. Also the presentation of numerical results does not allows a rich and interactive data exploration/visualization such as is provided by Scientific Visualization tools and Virtual Reality systems. The aim of this paper is to describe an lighting analysis application which is an add-in for a 3-D CAD system which integrate all CAD modeling features, algorithms for mesh generation, numerical processing and post-processing of scalar fields, management tools for fixtures database, and a VRML (Virtual Reality Modeling Language) writer/exporter. Basically the application use the workspace of the CAD system as a 3-D interface for to plan the lighting scheme (luminaires choice and positioning), to process the illumination in 2D or 3D meshes chosen by the user, and then, to visualize and explore the results through scalar field scientific visualization techniques (p.e. contours, cut, slices, color mapping). Therefore, the application developed consist of a lighting analysis tool which integrate features for pre-processing, processing and visualization of illuminance fields with rich and intuitive visual interactivity. The method used for the algorithms developments are described and two examples of application are presented, a power substation and a simple house lighting plan.

### KEYWORDS

Illumination design, Scalar field post-processing, Scientific Visualization, CAD and CAE integration, CAD3D, VRML.

### 1. INTRODUCTION

For a same project, engineers tend to use different software to perform different tasks such as geometry modeling, database management, numerical analysis and data visualization. This may cause decrease of productivity and losses of information during the conversion process between different data file formats. Important industries, such as energy, oil and gas, are looking for computational systems that allow users to view and transfer geometric models, numerical results and others data quickly and efficiently. In this sense, visualization technologies can be used as powerful communication tools. Unfortunately, many of the facilities (techniques and algorithm) provided by the Visualization Toolkits available today (e.g. VTK and OpenDX) are not yet fully exploited in most CAD/CAE systems. Some of the well-known CAD programs, such as AutoCAD, Microstation, SolidWorks, Catia and Pro-Engineer have they own file format making data difficult to exchange. Furthermore, in many cases is desirable to visualize geometric CAD models and computational simulations results simultaneously, in order to increase the understanding of a phenomenon under study. But not ever this kind of visualization model is easily constructed. Many software for numerical analysis do not support CAD format files or not allow the interaction with

numerical data simultaneously to display the CAD model. Thus, tools that can handle almost all engineer numerical procedures is expected.

On the other hand Virtual Reality and others interface paradigms have been used as support tools for communication and planning in Architecture, Engineering and Construction – AEC (Savioja et al., 2003; Bouchlaghem et.al, 2005). Visualization tools can cover the whole lifecycle of a product from presentation of initial concepts to the final stages of production and can also be extended to maintenance issues (Facility Management). The 3D visualization techniques can be indeed a powerful technique to show large amount of information compactly and, moreover, suggesting behaviour and affinity among different entities given their placement in the virtual world (Malandrino et al., 2007). Thus, virtual reality models can be used to communicate design intent, and to compare and evaluate design options.

In this paper is described an lighting analysis application which is an add-in for a 3D CAD system which integrate all CAD modeling features, algorithms for mesh generation, numerical processing and post-processing of scalar fields, management tools for fixtures database, and a VRML files writer/exporter. Basically the application use the workspace of the CAD system as a 3-D interface for to plan the lighting scheme (luminaires choice and positioning), to process the illumination in 2-D or 3-D meshes chosen by the user, and then, to visualize and explore the results through scalar field scientific visualization techniques (contours, cut, slices, color mapping, etc.). The final visualization model can be exported in a VRML. The models in the VRML standard file format facilitate the communication and transfer of 3-D content on the web because the user can visualize and navigate into the 3-D model using a simple internet browser. Therefore, the application developed consist of a lighting analysis tool which integrate features for pre-processing, processing and visualization of illuminance fields with rich and intuitive visual interactivity. We believe that the major contribution of this work is to describe a way to create a computer application that integrate differents tools, needed in differents tasks of an lighting project, using a open source scientific visualization toolkit and customizing a comercial CAD system.

The organization of the paper is as follows: section 2 presents some basic concepts of visualization technologies and tools, including the Visualization ToolKit (VTK) and Virtual Reality Modeling Language (VRML). Section 3 describes the point-by-point method used for numerical processing of illuminance field. Section 4 details the application developed. Section 5 present two examples of application. Section 6 summarises the authors conclusions.

## **2. BASIC CONCEPTS IN VISUALIZATION TECHNOLOGIES AND TOOLS**

### **2.1 SCIENTIFIC VISUALIZATION**

Using visualization humans can recognize states, objects structures and models behaviour. Different kinds of visualization are used to communicate complex content and support decision processes. In Scientific Computing, Visualization is the area interested in to transform data and informations in representative pictures. The term Scientific Visualization (SciVis) refers to the sub-area dedicated to displaying physical or scientific data, usually obtained through numeric simulations or sensors. The first definition for SciVis was introduced by McCormick et al. (1987) at the panel "Visualization in Scientific Computing" presented at SIGGRAPH Conference: "Visualization is a method of computing. It transforms the symbolic into the geometric, enabling researchers to observe their simulations and computations. Visualization offers a method for seeing the unseen. It enriches the process of scientific discovery and fosters profound and unexpected insights. In many fields it is already revolutionizing the way scientists do science."

The goal of SciVis is to enhance scientific productivity by utilizing human visual perception and Computer Graphics techniques. Therefore SciVis is a support technology that enables scientists and engineers to understand complex relationships typically represented by large amounts of data.

Many visualization techniques and algorithm have been proposed in the literature (Brodlie et. al, 1992), some may be more appropriate for scalar data others for vectors or tensors. Some techniques are based in texture others in geometric reconstruction such as line and surface contours. According to Collins (1993), some techniques of SciVis have their first records dating of the XII century, and are still used and implemented in many computational tools. Some well-known techniques for visualization of numerical data are mapping scalar values into colors (colormap) and contours (level curves and surfaces).

The process of displaying datasets usually walk through three basic steps, which are: data acquisition, transformation (filtering and mapping) and rendering (Schroeder et al., 2004). Therefore visualization techniques involve data processing algorithms, which extract the data of the sample of interest and convert into a form suitable for representation.

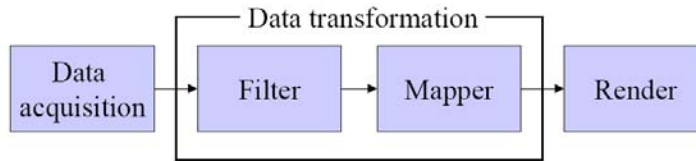


Figure 1: Data flow in scientific visualization algorithms

Visualization algorithms and applications can be more easily developed using visualization toolkits or libraries. In this work the VTK - Visualization Toolkit ([www.vtk.org](http://www.vtk.org)) was used. VTK is one of several visualization toolkits available currently but some advantages make VTK a good choice, such as are described below.

## 2.2 VTK - THE VISUALIZATION TOOLKIT

VTK is an open source, freely available software system for 3D computer graphics, image processing, and visualization. Consists of a C++ class library, and several interpreted interface layers including Tcl/Tk, Java, and Python. Some advantages of VTK is the support to a wide variety of visualization algorithms including scalar, vector, tensor, texture, and volumetric methods; and advanced modeling techniques such as implicit modeling, polygon reduction, mesh smoothing, cutting, contouring, and Delaunay triangulation.

VTK provides a variety of data representations including unorganized point sets, polygonal data, images, volumes, and structured, rectilinear, and unstructured grids. It comes with several reader/importer and writer/exporter to exchange data with other applications (including 3DS and VRML formats). Hundreds of data processing filters are available to operate on these data, ranging from image convolution to Delaunay triangulation. VTK's rendering model supports 2D, polygonal, volumetric, and texture-based approaches that can be used in any combination.

Using VTK is possible to develop visualization algorithms connecting filters and mappers through input/output process in such a way as to create a visualization pipeline or, alternatively, a visualization network. For example, we may wish to read a set of unorganized points, create a polygonal mesh via Delaunay triangulation, then display the mesh using polygonal (surface) rendering. Connections may only be made when the input/output types match.

VTK consists of two major pieces: a compiled core (implemented in C++) and an automatically generated interpreted layer. Data structures, algorithms, and time-critical system functions are implemented in the C++ core. Common design patterns such as object factories and virtual functions insure portability and extensibility. Since VTK is independent of any graphical user interface (GUI), it does not depend on the windowing system. It hooks into the window ID and event loop to let developers plug VTK into their own applications. An abstract graphics model achieves graphics portability. The graphics model forms an abstract layer above the OpenGL graphics language to insure cross-platform portability (see Fig. 2).

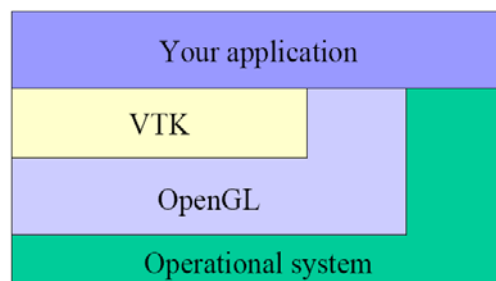


Figure 2: The VTK layer

In this work was used VTK for develop two main visualization alorithms, one for 2D scalar color mapping and image generate, and other for 3D scalar mapping and isosurface generated. Additionally a color table (lookup table) image also had to be generated, in each case, for the correct interpretation of results in the final visualization interface (3D CAD and VRML viewer).

### 2.3 VRML - VIRTUAL REALITY MODELING LANGUAGE

The Virtual Reality Modeling Language (VRML) is a non-proprietary ISO standard file format for describing interactive 3D objects and worlds. VRML is designed to be used on the Internet, intranets, and local client systems. VRML is also intended to be a universal interchange format for integrated 3D graphics and multimedia. VRML may be used in a variety of application areas such as engineering and scientific visualization, multimedia presentations, entertainment and educational titles, web pages, and shared virtual worlds (Web3d, 2008).

Three-dimensional information can be easily generated and transferred through the Internet by this technology. VRML models can be displayed in several freely available browsers and integrate with web browsers as plug-ins. Information in a VRML file is encoded in ASCII. The VRML's latest incarnation is X3D, which updates the specification to more modern standards, including additional graphics features and an XML encoding.

VRML describes 3D models in the form of 'nodes'. Nodes generally define 3D physical descriptions that may be made up of 3D primitives, such as spheres, cube, cones and cylinders, or of complex polyhedra composed of polygon facets. In addition to these form descriptions, nodes can also define materials, colours, texture maps, lighting, shape transformations and viewing criteria. An important characteristic of VRML files is the ability to compose files together through inclusion and to relate files together through hyperlinking. Another essential characteristic of VRML is that it is intended to be used in a distributed environment such as the World Wide Web.

### 3. ILLUMINANCE FIELD PROCESSING AND VISUALIZATION

An appropriate lighting plan in home and industrial environments is important to provide confort and good working conditions, besides generating economy in many ways, such as energy efficiency. Engineers and contractors are using lighting software programs to assist in the design of new construction projects and in planning the retrofit of existing facilities. In general, lighting application software programs use the point-by-point method of calculation, which is very accurate and precise and which can also be used for graphic renderings.

Point-by-point method is a design procedure for determining the illuminance at various locations (or at a mesh) in a lighting system using luminaire photometric data, for example, an IES file (IESNA, 2008). These files are in the Illuminating Engineering Society (IES) standard format, so that files of fixture products from just about any manufacturer can be put into the database. In addition to photometric data the point-by-point method need the geometrical information project (location and direction of focus of each light source), which can be obtained from the CAD model. In this context, a 3D virtual environment can provide a great 3D graphical interface for illumination planning software application. The Fig. 3 shows a example of geometric information needed in the illuminance field process.

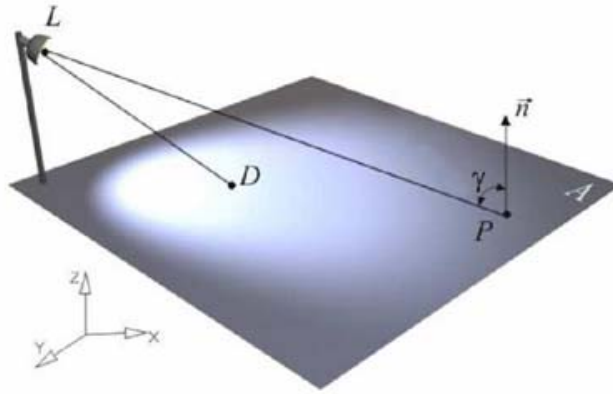


Figure 3: The geometric information needed for the illuminance process.

In Fig. 3, L is the point of light source, D is the focal point, P is the point of interest, n is a normal vector of plane A and gamma is the angle between PL and n. Whereas already built the CAD model, the lighting design can be built using the geometry of the CAD model to define the points of installation of fixtures and point of focus. Thus, the coordinate system used in the processing method of point-by-point will be the same coordinate system of CAD model.

#### 4. THE APPLICATION DEVELOPED

The illumination field numerical processing, as mentioned, needs some input information such as photometric data of light sources, the project geometry (includes coordinates of each luminaire position and focus direction) and coordinates of grid points which the illuminances will be calculated. For input this informations was used a CAD system (SolidWorks) workspace as a 3D interface. This allowed a easy and interactive choice of light source, localization and focus direction. Whith the 3D CAD model interface the user can select points in objects of the model by simple mouse pick and then insert light sources chosed from files from database. This process can be repeated as often is desired. The light point and focus coordinates are stored in a input file for the illuminances fiel processing. The SolidWorks customization (add-in developed) allowed also create graphical interface features for access and edit the database containing IES files of many light source models.

The SolidWork add-in implementation was make in four modules. The first is for register of luminaires in a SQL database. The second is for the geometry illumination project definitions such as lights localization and focus direction. The third module is for a mesh choise and illuminace fiel processing. Finally the last module is for the visualization of results and export the complete visualization model to a VRML file for publish.

For the first module was extended the SolidWorks GUI (*Graphics User Interface*) using the API (*Application Programming Interface*) available, Fig. 4. A graphical interface (page in the SolidWork environment) was created for add luminaires/lamps models and few information of light sources in database.

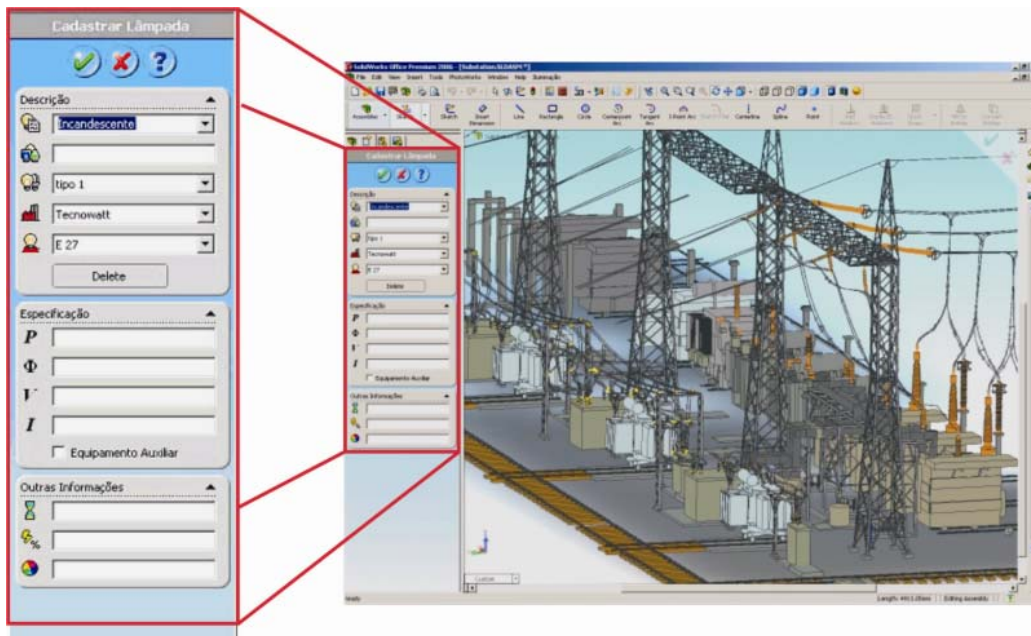


Figure 4: Interface for edit IES files database

The second module was developed using CAD features for the points coordinates capture and was create pages for the luminaires choose and insert in the digital model. Once defined a “illumination scheme” is possible save it for subsequent restore and/or edit. Many illumination designs can be created and compared for get the best result. The third module use the saved illuminations schemes for process de illuminances in a mesh defined by the user. The mesh is regular set of points evenly distributed in any plane or box (volume) desired. The point-by-point algorithm will be calculate the direct lighting at each point. Finally, the last module will be post-processing the illuminance field trough the visualization algorithm (contours, colormap, slice planes, stream lines, etc.).

The use of SolidWorks is only an alternative way to input the data in illuminance field processing algorithm. The input also can be made through an ASCII file, therefore the use of SolidWorks is not mandatory. The numerical algorithm can read the input information into an ASCII file and generate a output file in VTK *Legacy* format. This format can be easily read for a visualization algorithm written using the VTK library.

In this way, from the input information, the numerical algorithm process the iluminance field and store the results in a VTK *Legacy* file. Then, the visualization algorithm read, generates the color mapping and contours, and also, export the final model to the VRML format. Therefore using the SolidWorks interface was possible to perform several simulations for different lighting systems for different cases and compare them. The steps for the use of the application developed are: after registering the IES files in the database, for all light sources which will be used, to choose and to insert in the 3D digital model the points of light desired; select or create a face (plane) or a volume (box) where will be performed the analysis; choose the density of the mesh points to be generated and, finally, process the iluminance data and get the visualization. The mesh generated is the type structured and have cells square (pixel cells). This structure allows from the result of the color mapping to generate an image file in JPG, BMP or PNG and therefore can be inserted into the model as a texture, which usually more "economic".

It was also possible using methods of the SolidWorks API perform the simulation taking into account the existence of opaque bodies which block the light in some points of mesh. The methods used were the *RayIntersections* and *GetRayIntersectionPoints* allowing given a point and one direction, see if there is any object in that direction. With these methods were unable to examine whether or not there is any object from the point of installation of light source and the point of the loop in which the illuminance is calculated. If there is an object, the influence of this source of light will be disregarded, or will only be computed the influence of the sources of light whose light rays focus directly on the point. An example of a simulation performed and displayed in the CAD environment, considering the obstructions, is shown in Fig. 5a and texture generated is shown in Fig. 5b.

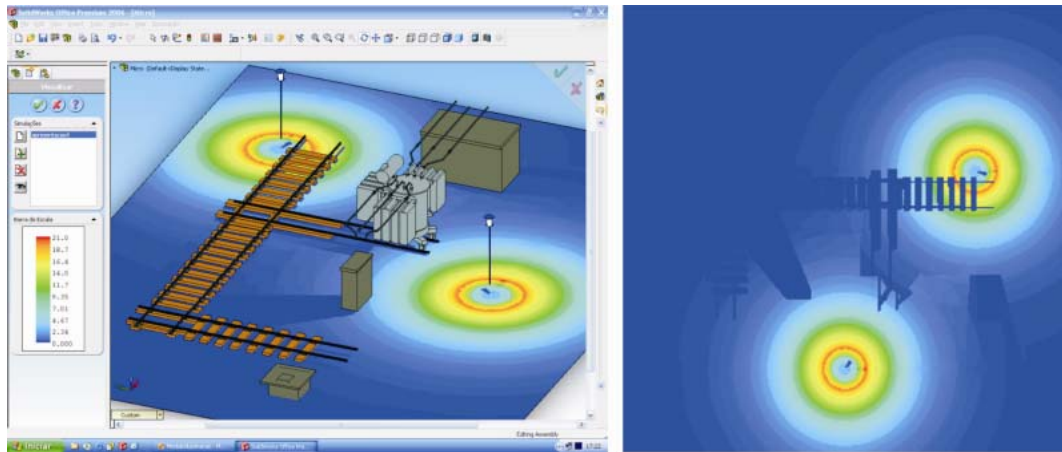


Figure 5: (a)Result of simulation performed considering the opaque bodies obstructions and (b) the image generated for visualization of illuminance field

This approach is without the influence of the light sources whose luminous intensity does not directly reach certain point. However, due to the computational cost needed for the processing, it was only possible to simulate in parts of the substation, or in smaller models. A use diagram of application developed is showed in Fig. 6.



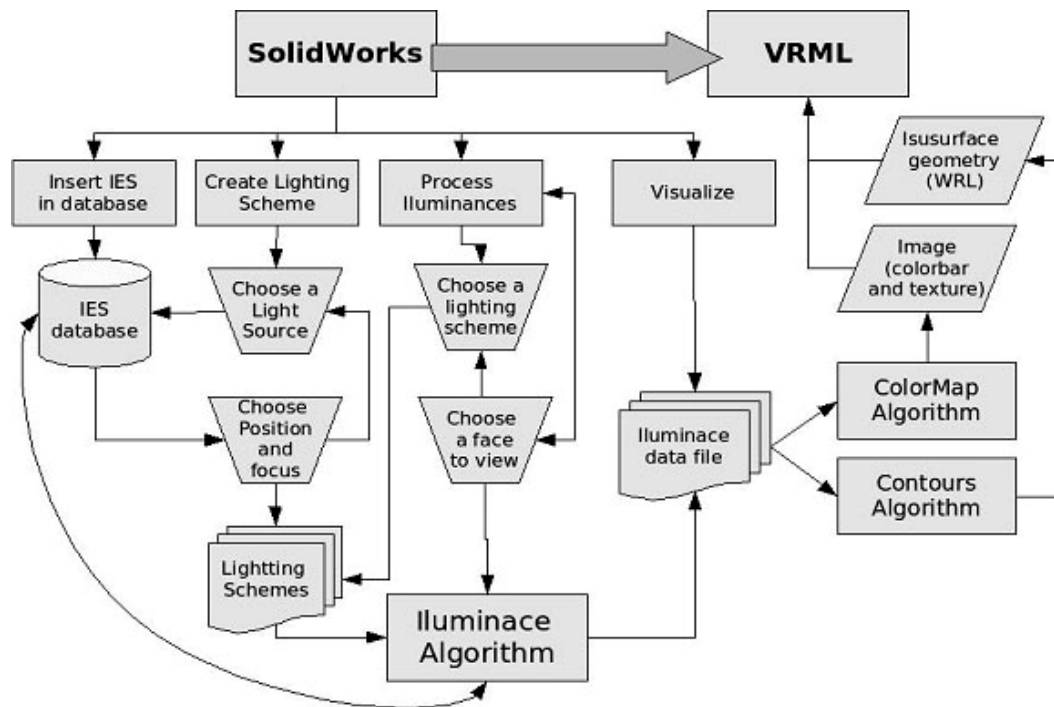


Figure 6: Dataflow of application developed

The main advantage of application developed, compared with other existing, is that its fully integrated with 3D CAD Solid Works and was designed with an open source toolkit VTK making it more flexible and more expandable, and free.

## 5. CASE-STUDY: LIGHTING MEASUREMENT FOR A POWER SUBSTATION

During the R&D project “3D Virtual Reality System Applied to Power Substation Activities” with ANEEL (Brazilian National Agency of Electric Energy) funds and support of Furnas Centrais Elétricas, it was developed a joint cooperation with LACTEC (Institute of Research for Development). In this collaboration the add-in sub-system for illuminance field was tested. The project goal was to develop a system of Virtual Reality for several plans, such as cargo transportation, using the three-dimensional model to access information that is often not available due to the impossibility (technical and safety) to do the lighting through traditional methods. The application was tested in the 3D model of the electrical power substation located in the city of Jacarepaguá, State of Rio de Janeiro, Brazil. The cited transmission substation have capacity for 600 MW.

The digital model used was obtained through laser scanning performed by a contracted company. The technology of laser scanning employed allows generation of models with geometric precision of 2 to 6 mm. The product of scanning process is a dense point cloud (given into x, y, z coordinates) captured at a speed of 1800 points per second. The point cloud is passed through a process that generates a corresponding CAD model. The CAD model is then analysed, corrected and converted in a VRML file to be viewed in available free browsers.

The data had been initially in DWG format file (native of AutoCAD software, version 2004) in five parts: area\_of\_capacitors (33MB), area\_of\_trafos (29 MB), area\_128KV\_a (47 MB), area\_128KV\_b (49 MB) and area\_345KV (121 MB). The DWG models was imported in SolidWorks in pieces where different equipment/parts was separated by layers and imported separately. Each part was then converted in a VRML file using the SolidWorks and later meeting through *Inline* VRML nodes. This process allow create a distributed virtual reality model and implement techniques for up the navigation performance such as LOD (Level Of Detail) and FOG.

As initial data, the developed add-in uses a given plan of the lighting system (number, type, location and direction of focus of the light sources). In sequence, an algorithm calculates the three-dimensional field of

horizontal illuminances, and then some visualization techniques (slice planes, isocontours and colormap) are applied. To illustrate the operation of the developed application, a simulation was performed for a system of lighting, using the 3D model of the case-study power substation. Several configurations could be tested varying the position of the light sources, different luminaire and lamp types. Fig. 7 and Fig. 8 show both illuminance field visualization and substation CAD model in a VRML virtual environment.

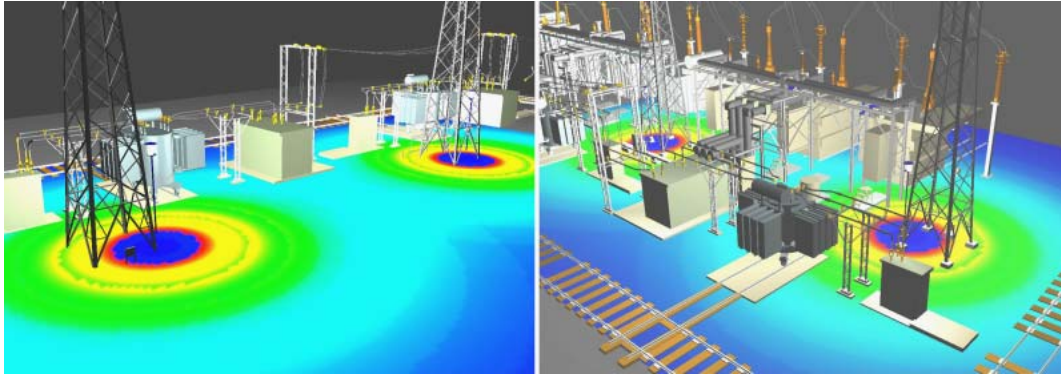


Figure 7: Illuminance field visualization and the power substation digital model

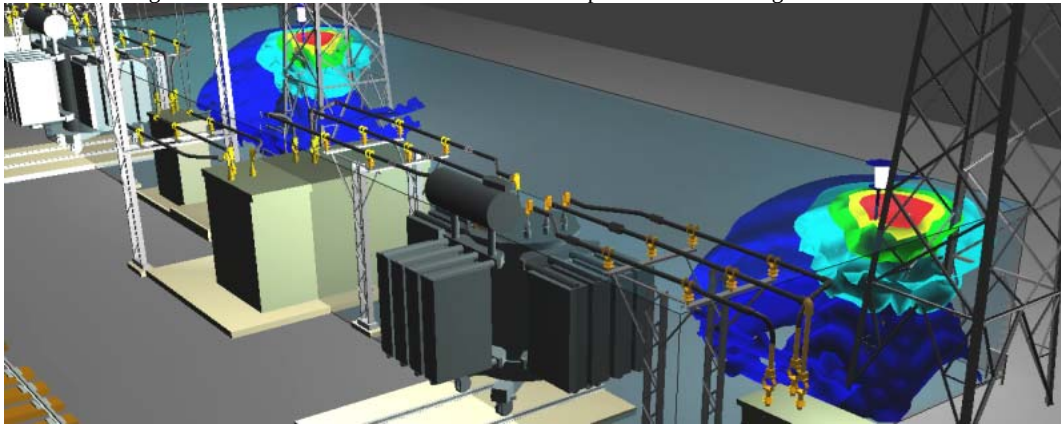


Figure 8: Isosurface illuminance field visualization

## 6. THE KICHTEN EXAMPLE

In order to study the potential of VTK for development visualization systems, a program has been developed, called PPGMNE DataViewer (Neto et al., 2006) - PPGMNE stands for the Numerical Methods Graduate Program at the Federal University of Paraná in Brazil.

The PPGMNE DataViewer or simply DataViewer (DV) is a VTK based visualization program which provides a graphical user interface for control several parameters of visualization algorithms. Using DV users can easily load a dataset (in VTK Legacy Format file) and, then, to apply visualization techniques such as slice planes, color mappers and contours. A sequence of filters and mappers can be applied for a visualization pipeline construct. The resulting model can also be exported in a VRML format file.

In order to illustrate an application of illumination field visualization, a house example was created. The geometric model was constructed in a CAD program and then exported for 3DS format. This format can be imported by the DV program. The illuminance field was processed separately and then the results loaded in DV were the resulting illuminance field was created. This procedure allowed a complete understanding of lighting data. The Fig. 9 shows some views obtained by some DV capabilities.

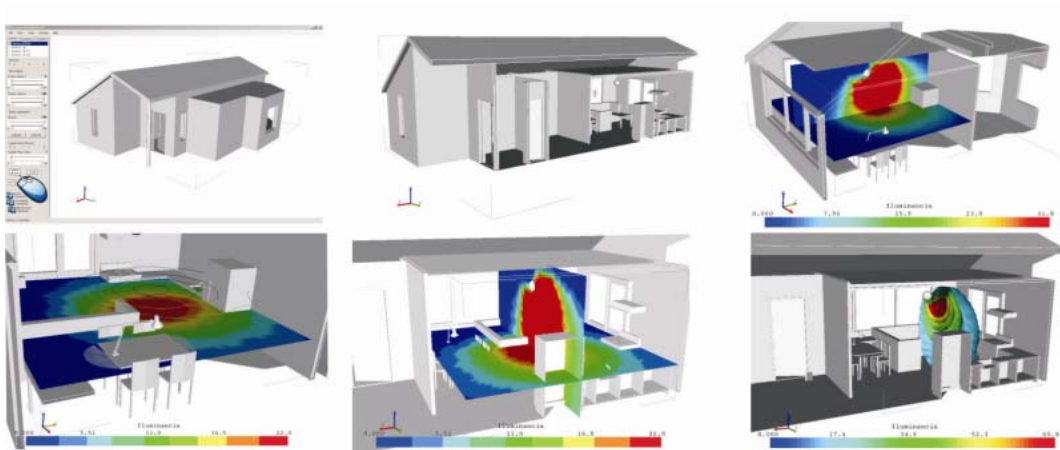


Figure 9: The visualization of illumination field in a house kitchen: (a) the CAD model; (b) a cut in CAD model; (c) two orthogonal slice planes of illuminance field and colormap (d) slice plane and isolines; (e) more two orthogonal slice planes; (f) isosurfaces

## 7. CONCLUSION

Through customization of a 3-D CAD system is possible to incorporate algorithms for pre-processing, processing and post-processing of numerical analysis in order to obtain an application that provides features of different systems into one. The conversion of the final model in a VRML format file provides several advantages from the point of view of communication and collaborative visualization/planning. The integration of features that are typical of different software into a single system (a CAD or a Virtual Reality system) is interesting to decrease the difficulties arising from the data transfer between different file formats. In particular, CAD systems are commonly used in engineering for geometric modeling and can be customized, so as to seize the geometry built to generate the mesh of points that will be used in numerical analysis. For this, tetrahedralization and triangulation algorithms can be used. In addition, CAD systems that support the use of textures, such as SolidWorks, allow numerical data to be represented as images in the 3-D model, as shown for viewing the illuminance fields through color mapping. Scientific visualization tools such as VTK, provide algorithms for mesh generation and scientific data representation which may be used in applications development and software customizations for creation of new functionalities. Finally, a conversion in a VRML file provides all the visualization and communication facilities.

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## USING VIRTUAL PROTOTYPING TECHNIQUES FOR IMPLEMENTATION OF A VIRTUAL CONSTRUCTION ENVIRONMENT (VCE)

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### ABSTRACT

The current-state-of-the-art of Virtual Prototyping (VP) for communicating project data and information is currently limited to the development of interference checking and schedule simulation (4D) tools that rely heavily on BIM models with monolithic CAD objects. While helpful, these interference checking and *macro* schedule simulation tools only scratch the surface and do not approach the possibilities of generating much needed estimates and schedules expressed in the currency of the individual work tasks that contractors and subcontractors use to bid, construct, measure and track.

Virtual Prototyping technologies provide features and capabilities that can be utilized to develop richer and more sophisticated tools to assist project participants to think, plan and conceive construction strategies at the *micro* level. At the same time, monolithic CAD objects from BIM models, produced during design phase, must be somehow transformed into a more granular and robust form amendable to representing the individual work tasks that comprise estimates and detailed schedules.

This paper discusses ongoing research work at Virginia Tech for the development of a 2<sup>nd</sup> generation Virtual Construction Environment (VCE) framework for micro project planning. The paper addresses the issue of transforming monolithic CAD objects into more granular form to correspond with work tasks. The proposed VCE framework is comprised of graphical and analytical functions for visualizing and manipulating graphical and non-graphical project information necessary to perform different work execution planning scenarios. A prototype implementation is presented to demonstrate concepts proposed.

### KEYWORDS

virtual prototyping, macro and micro planning, BIM, CAD, 4D schedule simulation

### 1. INTRODUCTION

Technology and state-of-the-art programs are constantly evolving and making the design and planning processes easier across industries. However, the state-of-the-art for construction planning still heavily relies upon traditional methods for project planning and very little to digitally rehearse assemblies and sequences through virtual prototyping (Huang et.al, 2007). Several factors affect the lack of change within the construction industry when it comes to planning and virtual prototyping (Sarshar et.al, 2004). Until programs easily deal with common problems of interoperability and data transfer presented to project planners (Gudgel, 2007; Fox and Hietanen, 2007), virtual prototyping in construction planning will not be utilized as state-of-the-art.

Currently, Virtual Prototyping (VP) applications for construction planning focus mainly on simulation applications to communicate construction project information (time, cost, etc.), and on interference checking. While very beneficial, these processes barely scratch the surface of what VP applications can potentially handle. Virtual Prototyping applications have been investigated for planning construction sequences and resources (Waly and Thabet, 2002; Huang, et.al, 2007), but barriers still exist to take full advantage of A/E developed CAD models. One barrier is the use of monolithic CAD objects representing larger construction assemblies that do not offer the granularity needed for accurately representing construction processes. In order to be granular enough to represent work tasks the models need modification or development from scratch by the construction planner, a task not easily completed without experienced personnel, adding cost and use of resources to a project (Gugel, et.al, 2007). Only

when an application allows for easily manipulation of an A/E model to accurately represent construction activities will the use of VP develop beyond common practice of schedule representation and interference checking.

The recent introduction of BIM concepts provides new opportunities to develop richer and more sophisticated VP applications. BIM allows for digitally modeling the facility so that “the model and its properties and attributes are the information of record for the project” (ENR, 2008). The Contractor’s Guide to BIM (Ernstrom et.al, 2006) defines BIM as “a data-rich, object-oriented, intelligent, and parametric digital representation of the facility, from which views and data appropriate to various users’ needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility.” Valuable information stored in BIM models can be extracted and utilized towards the VP application. The A/E/C industry is still trying to answer various important questions, including what type of information and how much of it should be included in a BIM model, and what are the types of structure/schemes to be used for classification and representation of the information.

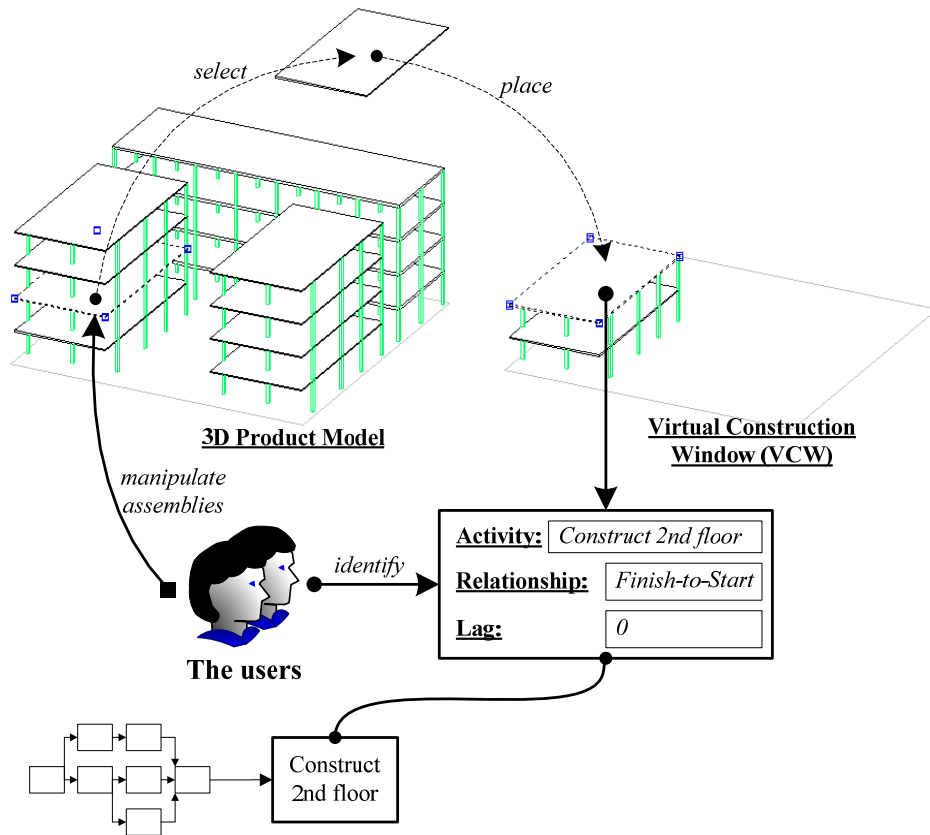
Ongoing research at Virginia Tech is examining some of the shortcomings of current state-of-the-art VP applications and the first generation Virtual Construction Environment (VCE). In response to these shortcomings a 2<sup>nd</sup> generation Virtual Construction Environment (VCE2) framework and prototype are being developed that will allow a construction planner to easily manipulate an A/E generated model for planning work task activities, quickly receive quantities, develop resource allocations and review scheduled tasks through 4-D visualization, bar charts, and activity-on-node diagrams. This paper discusses the original VCE concept, the shortcomings that were identified, and the framework development of the VCE2. A working prototype is also presented.

## **2. VCE CONCEPT**

Waly and Thabet (2002) proposed a Virtual Construction Environment (VCE) framework to assist the user in sequencing construction tasks in a virtual setting. The goal of the VCE is to enable the project team to undertake inexpensive rehearsals of major construction processes and test various execution strategies in a near reality sense. As depicted in Figure 1, the concept of this 1<sup>st</sup> generation VCE is based on manipulating CAD objects of a 3D product model. CAD objects are sequentially selected, moved and placed in the virtual construction window based on user’s perception of the actual order of construction of the project. Relationships and resources are applied in order to get an overall duration for the object and it is placed on the schedule. The VCE would also allow for major equipment placement and planning.

Generated activities corresponding to work tasks are primarily based on the monolithic segments represented by the basic CAD objects. This 1:1 correlation between monolithic BIM components and corresponding monolithic tasks scheduled is not feasible for adequate

Figure 1: VCE 1st generation concept (Waly & Thabet, 2002)



construction planning. If the process of how tasks are derived from CAD objects and the complex interrelationships between the tasks are better understood, the necessary innovative processes and tools can be devised to transform BIM objects to forms more useful for construction. This would close the missing productivity link and advance the state-of-the-art.

The problem with the 1<sup>st</sup> generation VCE is object granularity. When an architect or engineer designs a model they do not have to consider activity level construction processes. In this sense, the construction planner is presented with a series of monolithic CAD objects that can only represent larger groups of activities (i.e. one CAD object to represent a slab that would involve three separate concrete pours) (Ernstrom et.al., 2006). In order to accurately and easily plan from an A/E created model there is a need to easily modify monolithic graphical objects into objects that represent activities for assembling a project at a detailed (micro) level. The smaller graphical objects that accurately represent the activities allow for inexpensive rehearsals of complex construction sequences to identify flaws in the plan before construction begins.

In response to problems of current planning methods a second generation VCE framework is developed. The second generation VCE address issues of needing an application possible of modifying monolithic CAD objects into a form that properly represents the task level activities being planned. Allowing the user to easily calculate quantities, allocate resources, and determine durations for each activity and inexpensively rehearse construction processes at the work task level. This second generation framework is described in the following sections of this paper.

### 3. SECOND GENERATION DEVELOPEMENT

In response to the problems of the first generation of the VCE a 2<sup>nd</sup> generation prototype (VCE2) is developed. The VCE2 allows the user to plan sequences of task level activities by easily manipulating larger objects to accurately represent construction processes, manipulate graphical and non-graphical project information for scheduling, and developed a detailed schedule of activities allowing the user to rehearse and modify planned construction processes.

For development purposes a poured-in-place concrete retaining wall as part of new construction on the Virginia Tech Campus is examined while reworking the VCE2 framework. In a common CAD model one monolithic graphical object would typically represent the wall. This single object does not correlate to construction needs. In order to use this graphical object to represent the analyzed retaining wall construction it needs modification to nine different pieces to represent nine activities (i.e. wall section 1, wall section 2, etc.) with work tasks for constructing each activity (i.e. Interior Formwork, Rebar, etc.). A tool is needed to make these graphical medications. Once the construction planner can modify the object, the system can assist in creating the tasks for each activity, designate resources, calculate durations, and create a detailed schedule.

A decision diagram was created to layout the VCE2 framework for preliminary investigation (Fig. 2). The first step is for the user to input the BIM model of the entire building into the VCE, select the assembly to plan, and define some basic parameters. These parameters include an assembly type, sub-assembly type, and construction type. Currently, these parameters are organized based upon the assembly classifications in "Means Assembly Cost Data" (RSMeans, 1999). Using a BIM model, embedded information related to the assembly, sub-assembly, and construction types can be automatically extracted. The user can review and revise if needed. For the case study assembly the classifications for assembly, sub-assembly, and construction type are "foundations", "footings and foundation", and "walls – cast-in-place" respectively.



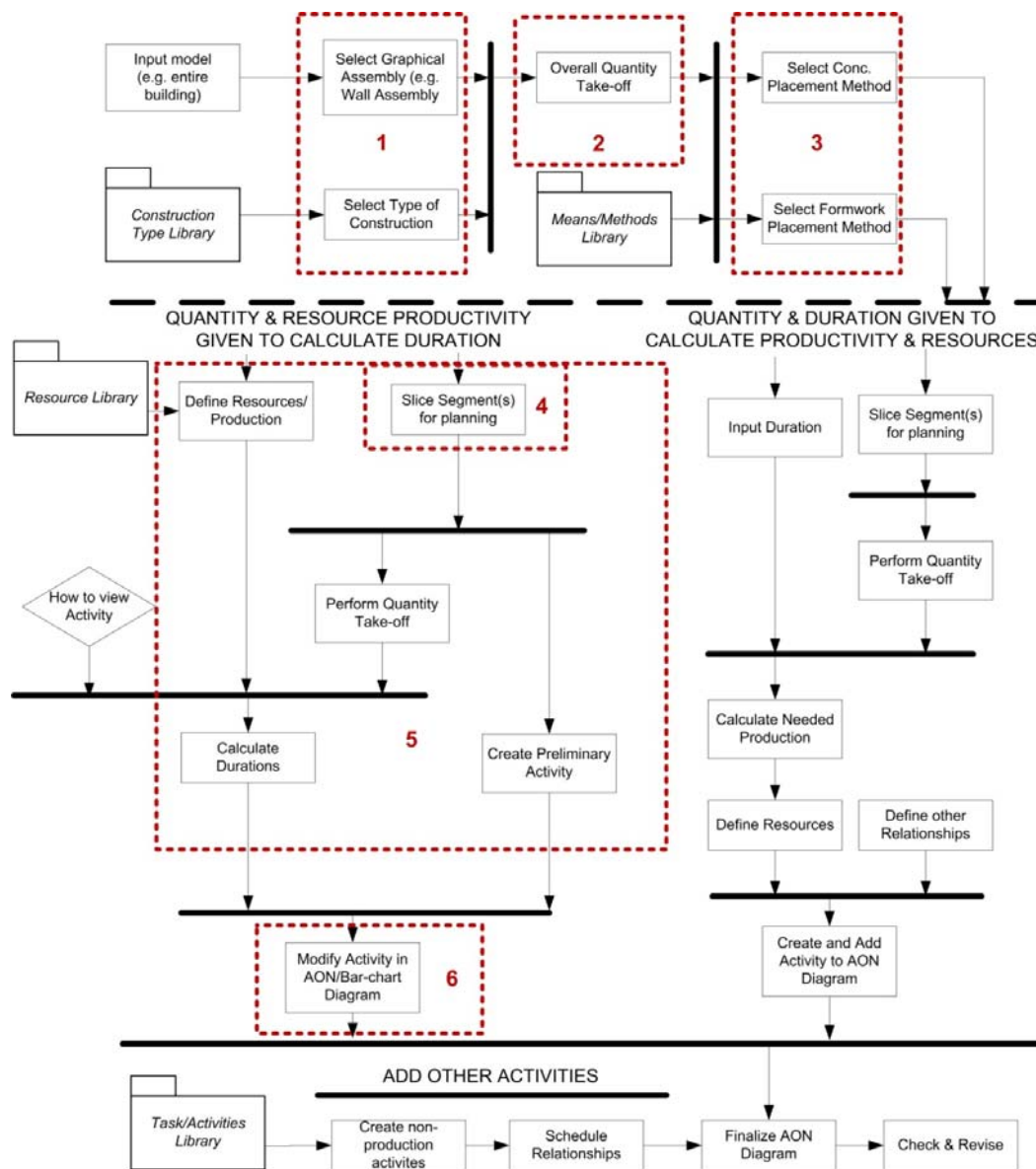


Figure 2: VCE2 Framework

Once the assembly is defined, overall quantities for concrete and formwork are calculated by the application. The quantities are reviewed while defining major means and methods.

The classifications of the assemblies determines which database the system accesses for means and methods of construction to create associated tasks (formwork, rebar, etc.) with each activity. For the “walls – cast-in-place” construction type means and methods for concrete placement and formwork placement are required. The means and methods limit the equipment listed when the resources are allocated by filtering the resource database.

To modify the monolithic assembly into more granular objects suitable for planning, a tool created to slice off a segment is devised. When an section is sliced from the monolithic assembly object, the application creates the activity-on-node (AON) diagram, dependency relationships, quantities of work, resources, production rates, and durations (Fig. 2 – area 5). The process of defining resources and calculating durations can be accomplished one of two ways. The first is to define resources and production rates and have the duration calculated. The second is to assign a duration value, useful if a deadline exists in the planning process, and determine production rates, calculated by dividing quantity

by time. Available crews to meet the calculated production rates will be listed for selection. After the activities are formed planned construction sequence is reviewable through various graphical representations (e.g. Gantt charts, AON diagrams, and 4D animations). A prototype mock-up application has been developed as proof of concept of the steps above and described in detail in the following section.

#### 4. APPLICATION PROTOTYPE

The VCE2 mock-up uses Bentley's MicroStation™ and ProjectWise Navigator™ products on a desktop platform running Window's Vista™. MicroStation, a CAD software application, offers various query, modeling, and modification tools useful in the development of the VCE2. MicroStation also allows for development of functions and tools through its compatibility with Microsoft's Visual Basic for Applications (VBA) offering methods of automating processes and references to databases.

The user interface, set within MicroStation, consists of a tool to isolate a planning assembly and an "Information Dashboard," a multipage form where assemblies are defined and quantities, resources, durations, and sequencing information is reviewed. The model is loaded into the environment where the user selects the graphical object(s) that represents the assembly to plan. In this case the graphical object representing the retaining wall is selected. With the graphical objects selected it is isolated by clicking the "isolate" icon which initiates the planning process for that assembly.

When isolated the assembly is then defined on the "Assembly Definition" tab of the "Information Dashboard." This is done through a series of drop down menus populated with categories of assemblies based on RSMeans assembly data. The "Construction Type" menu is populated based on the "Assembly Sub-type" that is selected. The "Assembly Sub-type" menu is populated based on the "Assembly Type" selection. The values that show up within these three menus are derived from information tied to the graphical object assuming the model has intelligence built into it. The user can review and change this information or define this information if the model they are using does not have the information included. Also on this tab of the form the user defines the name for the assembly.

When the assembly is defined and a name is given, the user is able to define major means and methods for concrete, interior formwork, and exterior formwork on the "Means and Methods" tab of the "Information Dashboard" form. Overall quantities are shown to aid the user in understanding the scope of work in selecting the means and methods. The means and methods listed are dependent on the "Construction Type" selected within "Assembly Definition" tab. The drop-down menus are populated based on RSMeans data. Figure 3 depicts the (a) process of isolating a graphical object, (b) defining the assembly, and (c) selecting means and methods.

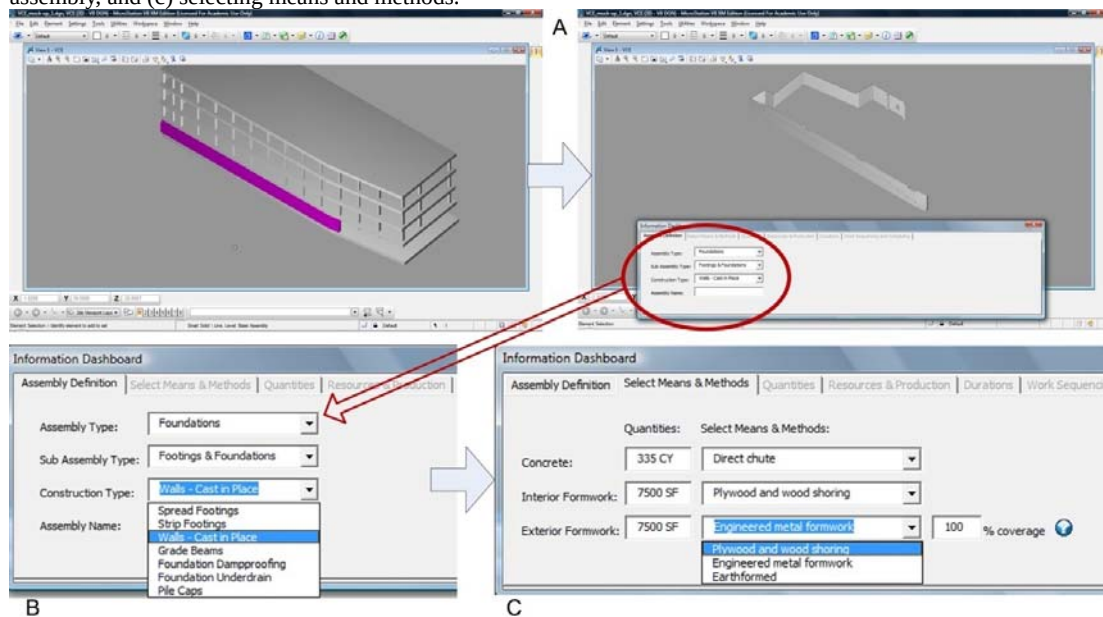


Figure 3: VCE Environment for starting planning process and defining assembly.

After the monolithic graphical object is isolated and basic parameters for planning are in place the graphical object needs modification to correspond to construction activities. This is accomplished with the introduction of a designed tool to allow for slicing a section of the retaining wall assembly from the monolithic graphical object. When the user slices each section of the wall a construction activity is created with the corresponding work tasks (i.e. Interior Formwork, Rebar, etc.). The user then reviews/modifies quantities, resources, durations, and dependency relationships for each activity through the “Planning Center,” an interactive graphic user interface (GUI) (Fig. 4).

Figure 4: Create activity and assign planning parameters

If the dominant quantity, the concrete in the case of the retaining wall, exceeds or is excessively less than the scope of a typical work package, the user can adjust the quantity value and the system will re-slice the object representing the activity based on the new quantity value. The other quantities (formwork, rebar, etc. for the retaining wall) are automatically recalculated. The “Planning Center” also allows for the review of resources and durations. When inputting resources the user has three options. The first is to select a default crew and production rate from the drop down menus. These are crews that the system has incorporated from the database that were previously defined within the program. The next option is to use a crew and modify its production rate. The last is to design an entirely new crew with its own production rate. If a production rate is changed or a new crew selected, the preview of the duration rate is updated. The user can immediately see how the change affects the duration of work. The user can also input a duration if they need a task or activity completed in a set amount of time and the system will calculate the production rate needed and offer the sets of resources that can manage the production rate. Lastly within the “Planning Center,” the user assigns dependency relationships to previously created activities. The default value is a “finish to start” relationship with the activity previously sliced.

Once the activity information is selected within the “Planning Center” and approved by the user it is recorded into the “Information Dashboard” under the tabs of “Quantity,” “Resources & Production,” “Durations,” and “Work Sequencing & Scheduling.” The user can easily review the information under each tab for each created activity. They can also revise the resources, production rates, and durations with each of the others automatically updated. The “Work Sequencing & Scheduling” tab allows for review of the created AON diagram, Gantt chart, and schedule simulations (Fig 5.).

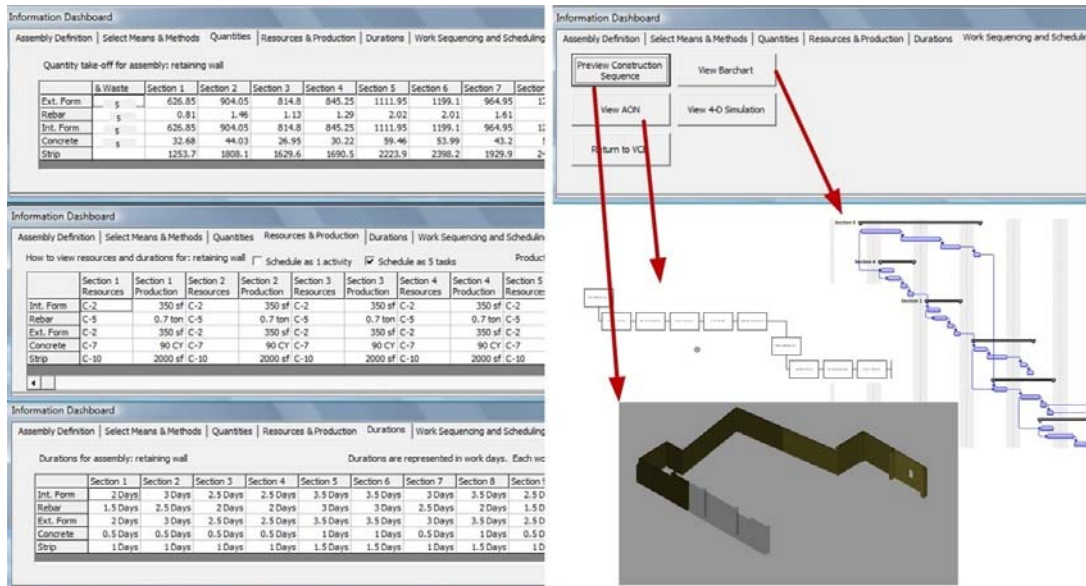


Figure 5: Planning parameters documented and reviewable

## 5. DISCUSSION

Even though technology and state-of-the-art programs are constantly evolving and making processes easier across industries, the state-of-the-art for construction planning still heavily relies upon tired and true methods. Several factors affect the lack of change within the construction industry when it comes to planning and virtual prototyping. These factors include resistance to trying new methods and refusal to learn new programs but the problems go deeper into the ability of construction programs to easily perform the needed work. Until the programs easily deal with common problems presented to project planners, virtual prototyping in construction planning will not be utilized as state-of-the-art.

The goal of the VCE2 is to examine the full potential of virtual prototyping with the development of tools that allow the user to easily manipulate graphical objects into activities that can represent the planned work tasks. The process discussed above uses the example of a concrete retaining wall for the basis of framework development for the working prototype. A completed program would include means and methods for each construction type based around the developed decision tree and allow for planning of any construction task's durations and resources. A second module of the application would also involve methods for site planning, equipment location, crane reach, work zones, and other non-production planning.

It is hoped that the basic framework of using quantity and resources, or quantity and duration, for graphically planning construction sequences on a micro-level can be expanded to accommodate various other assemblies. Minor variations to the framework would exist but the overall concepts to drive a fully implemented program that can help to eliminate tedious manual processes and take full advantage of digital models already created and in use by design professionals are similar to the developed prototype. With such implementation a fully functional program would better utilize the concepts of virtual prototyping of construction projects through planning and not limited solely to visualizations and clash detections.

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## ENHANCEMENT OF VIRTUAL DESIGN AND CONSTRUCTION METHODS

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### ABSTRACT

In this paper we report about a three-tier applied R&D approach for the Enhancement of Virtual Design and Construction methods at the Institute of 4D Technologies UAS, Northwestern Switzerland (i4Ds). In collaboration with the CAD vendor and developer cadwork informatik AG our research focuses on technology, its introduction into the market the effects and difficulties of the tool use and the induced process changes. We will describe the methodology, the expected outcomes of the enhancements, the research approach, initial findings and the further proceedings.

In the first tier cadworks introduces an intuitive integrated 4D modeler called (LexoCad or Baubit CAD) for contractors which is commercially available since one year. Analogue to playing with building blocks users create 3D building models and 4D phasing models for the construction of the building directly from 2D pdf drawings. The expected outcome are that the virtual building blocks serve as a test-bed for constructability analyzes, enhanced planning reliability, better coordination and communication, optimized procurement and wide-spread use in practice. The next two tiers of VDC enhancements are currently developed at i4Ds. For the second tier we introduce a semantic, flexible, database-backed, object-oriented data structure for hierarchically structured Product, Organization and Process models (POP models) with an enhanced intuitive 3D/4D graphical user interface for the rapid generation of design alternatives. Users can easily propagate information to related property sets of construction elements and assemblies. Behavior methods (scripts) can be assigned for a variety of tasks e.g. BOM creation, construction method modeling, creation of cost performance predictions etc. This approach technology-wise moves the model management from the modeler or viewer components to the data base domain. The flexible hierarchies not only allow users to manually restructure and rearrange the model to their needs but enable automatic AI optimizers to even alter the construction method e.g. timber element, precast concrete or masonry walls etc. The expected outcomes are a pro-active 4D planning, rapid generation, comparison and evaluation of POP- design- alternatives, derivation von case from existing designs, easy and effective integration of client information into POP models, creating performance predictions (quality, time, cost, risk, etc.) from this models, easy creation of 4D sub-models for knowledge transfer for inter-disciplinary cooperation.

In the third tier we introduce a novel process design concept which we named Process Design Patterns (PDPs). They are based on Christopher Alexander's (1977) concept of design pattern as a formal way of documenting successful solutions to problems and as templates describing how to solve problems of a particular domain. In a study, we called Process Archeology, we chose a recently finished four storey residential concrete building and reconstructed and re-modeled the over-all building processes with an inter-disciplinary team. Therefore we created the necessary 3D-, 4D- and process- and organization-models with commercial available modeling tools. We were able to derive one generic and seven specific PDPs for the whole erection of the building. We describe a strategy to apply PDPs directly on 3D building information models (BIM) to automate and optimize the planning process.

### KEYWORDS

Virtual Design and Construction, 4D Modeling, Product, Process and Organization Modeling and Simulation, Process Design Patterns

### 1. INTRODUCTION

Fischer and Kunz (2004) define "Virtual Design and Construction (VDC) as a methodology, which utilizes computer-based multi-disciplinary performance models in the building sector which include the



product (building, concept), the organization of the design, construction, operation teams, the processes and the economical outcome (quality, cost, time, etc) to support explicit and public objectives to integrate design, engineering, construction, operations and business strategies, etc. by design". These models are shortly referenced as product, organization, and process models or POP models.

Modeling of design alternatives in all three POP dimensions is a time consuming task and includes predominant manual operations. Currently available 3D and 4D software packages in the Architecture, Engineering and Construction (AEC) domain are lacking of intuitive tools which support this design process efficiently (Breit et al 2008).

Looking at the current situation in the AEC industry, we see that there is a need to evolutionary introduce new methodologies and to develop the corresponding supporting technologies. In the next three chapters we describe the introduction of the new processes for constructors and how the development of VDC technology through applied R&D prepare the software developer and vendor for the next generation of tools.

## 2. SERIOUS PLAY: VIRTUAL BUILDING BLOCKS FOR CONTRACTORS

Since one year cadworks has brought an intuitive integrated 4D modeler called (LexoCad or Baubit CAD) for contractors to market. Analogue to playing with building blocks user can create 3D building models and 4D phasing models for the erection of the building on site directly from 2D pdf drawings (Figure 1). The intuitive modeling capabilities of the software have been developed in iterative steps. User feedback from groups of professionals e.g. draftsmen, project manager, architects, engineers as well as art students and children have been integrated. So far we observed from the use of this integrated modeling package that creating the 3D model and phasing it to a 4D model is generally regarded as an intuitive work flow. It visually reveals design and planning errors as well as clashes at an early stage. Phased BOMs are appreciated as really helpful and better than the existing manual process for streamlining the procurement.

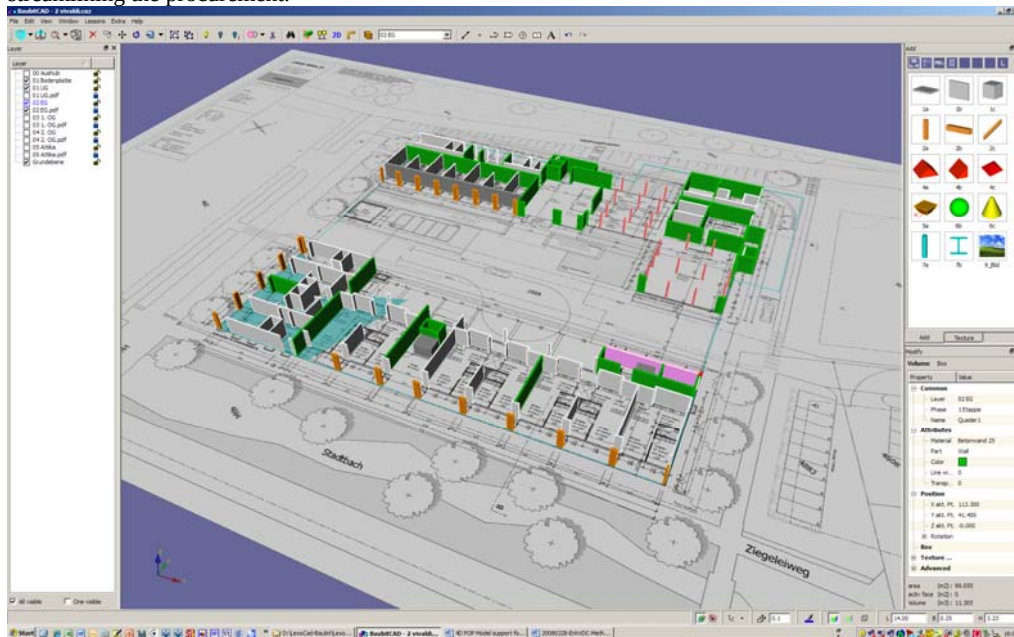


Figure 1: Intuitive 3D/4D Modeling with LexoCad/Baubit CAD based on 2D drawings

However, the creation of different variants of 4D construction models for a shopping center to demonstrate different traffic diversion scenarios in an old town was regarded as time consuming repetitive work.

Next we are going to study systematically the effects of the tool deployment in practice, the potentials that can be exploited, the difficulties, the communication and the processes changes.

### 3. RAPID CREATION OF DESIGN ALTERNATIVE IN POP MODELS

The design of buildings is a challenging interdisciplinary procedure and is only partly supported by today's ICT. The work flow is predominantly sequential in the order architects, engineers and construction managers. Most of the available 3D CAD systems do support neither the management of multiple design variants nor 3D model hierarchies that follow the planning processes in gaining more precision through the transformation from rough to detailed design. Tools for the creation of design alternatives need to handle the changing size, granularity and versions of the POP models. Project participants and stakeholders look at the same model from a different perspective. Typically, these views are organized in hierarchies. Such hierarchies are used to reduce the complexity on a specific point of interest and to maintain dependencies and relations to the remaining model. Establishing the "right" hierarchies is often essential to describe and predict design behaviors. Yet, experience shows that once a hierarchy is defined it is very hard to change - and thus the hierarchy itself becomes a main obstacle if the design objectives change or if a significant number of design alternatives have to be considered.

Hartmann and Fischer (2007) report about knowledge transfer in constructability review with the help of 4D models. To support decision making, which involve different stakeholders, a considerable number of sufficiently elaborated small sub 4D models need to be created. At the same time, these models need to be connected and integrated to the overall POP model of the project in order to keep them up to date.

In order to cope with the addressed requirements, we suggest in our second tier of development a flexible, semantic, database-backed, object-oriented data structure for hierarchically arranged POP models which will be described in the next chapter. We refer to the resulting prototype implementation Lexo4D.

We are going to describe our concept by describing use case scenarios shown in the product model of Figure 2. We are dealing with the temporary state of a product model at a certain time which, in our example, is restricted to the structure and attributes of the building elements. Different groups of stakeholders, using this model, want to compare the performance behavior of two different construction methods and the revenue behavior of possible usages e.g. as office, hotel, residential or multiple purpose spaces. The challenge is to create meaningful 4D models in a project phase where typically only limited 3D building models are available and thereby not preventing an integration of more elaborated and detailed 3D models later. To create sensible scenarios, meaningful data needs to be added to the building components. In a first step, this is to be done manually. As soon as sufficient data is available in the model, further data can be added automatically with search and propagation mechanisms.

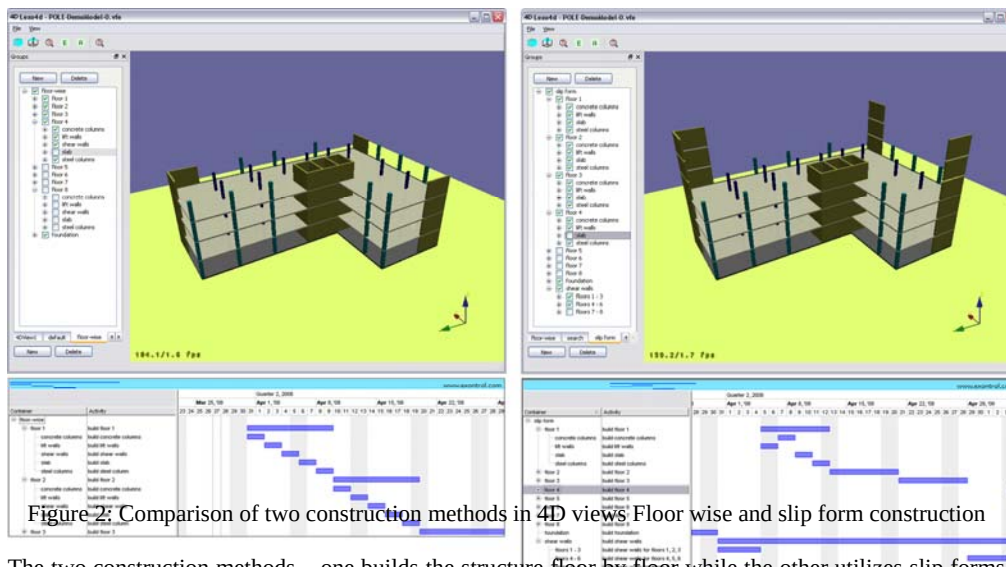


Figure 2: Comparison of two construction methods in 4D views: Floor wise and slip form construction

The two construction methods – one builds the structure floor by floor while the other utilizes slip forms for the shear and elevator walls – structure the model into two different views. The floor wise method needs to group the structure into floors as shown in Figure 2 left. This can either be done manually by selecting the elements in the 3D GUI or with a search query, e.g. by looking for all steel columns of floor one. Because search statements can be stored independently, it is possible to re-use them in other projects.



The slip form construction method needs a modified 4D structure to assign the activities. It can be derived from the floor wise view through copying and re-arranging the wall segment groups. Assigning activities and resources to the 4D structure in the views can be done manually by importing a schedule and dragging the appropriate schedule items on the 4D structure elements. With the search propagation features, the activity assignment can be automated and offers some support when the building model becomes more detailed.

At the current project stage it is not yet possible to analyze the revenue behavior of different usages e.g. as office, hotel, residential or multiple purpose spaces, because there are no relating 3D building objects available. Therefore, the available building elements will be grouped floor by floor. This presumes the grouping containers in the view to become meaningful objects such as a "hotel floor". The assignment of related property sets e.g. number and quality of hotel rooms on the floor as well as further relevant economical parameters and behavior methods (small scripts) which calculate the performance predictions, the meaningful objects are further extended. These meaningful objects are a very flexible way to create even very complex design performance predictions. Existing objects can be modified and enhanced and therefore support the rapid generation of design alternatives. To evaluate a mixed usage of the available floor space as hotel and office rooms, the user may simply create a new view by copying the "hotel floor" and "office floor" objects and change the containing number of hotel and office rooms.

### 3.1 LEXO 4D - IMPLEMENTATION

The core implementation of Lexo4D bases on two common IT concepts: a service oriented architecture (SOA) and an object oriented data model. Bianco et al. (2007) define SOA as an "architectural style where systems consist of service users and service providers". A collection of published services are jointly used by several client programs. Services must be self-contained: to extend a SOA a new service can be added without interfering with existing services. This enables us to rapidly implement new functionality. The object oriented data model is ideally suited to model 4D POP data because we can enhance the hierarchical structure of a 3D building model. 4D data such as temporal activities, materials, prices, or dimensional information is imposed on a 3D model. The 4D data model is designed to provide different views of an existing 3D model such that different aspects of a building can be compared. An architect can calculate the costs of different materials for parts of a building while a scheduler can analyze the time impacts by using different construction techniques for certain parts.

Through the usage of SOA and an object oriented data model, Lexo4D became a very flexible and extensible framework for building second generation 4D modeling tools. In particular the different views of a building allow users to gain more control over the planning process of a building.

### 3.2 ARCHITECTURE

The SOA as implemented in Lexo4D bases on a three-tier architecture. As illustrated in Figure 3 the SOA service users are part of the client layer while the SOA service providers consist of the application and data layer. The client layer contains tools to visualize, analyze, search, and modify 4D POP data. The application layer holds the definition of service methods and their implementation. The data layer is responsible for provision of the object-oriented data model and its mapping to a relational database. Additionally, it provides facilities to search data.

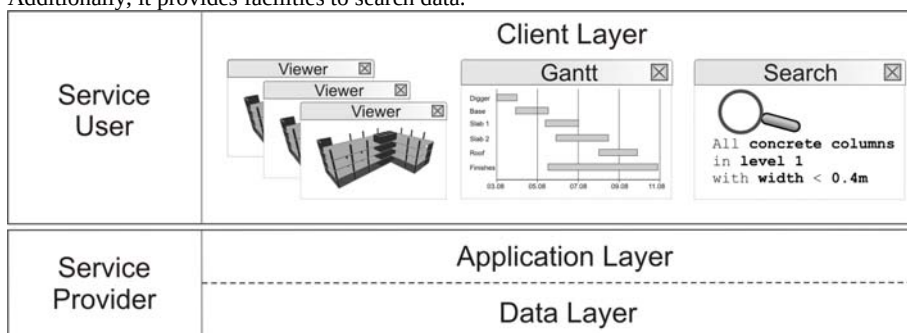


Figure 3: Service Oriented Architecture of Lexo4D  
The SOA service users consist of various client applications, the SOA service

providers consists of the application and data layer.

In Lexo4D we have implemented client prototypes for different purposes such as visualization, reporting, and data provision. The most commonly used client is the viewer, a graphical user interface (GUI) to display the 3D model and to explore the associated 4D POP data. The viewer does all 3D rendering work, and provides selection and navigation tools for 3D and 4D POP models. The Gantt chart client analyzes the 4D POP data and creates a report in form of a project plan. A typical data provision client is the search and propagate tool. A set of data entities is selected through our search tool in conjunction with manual and graphical selection. This selection is further analyzed either manually or by algorithms and the gained result is propagated back as new information to the 4D POP data structure. An alternative client for data provision would be a batch script that periodically updates some 4D POP data like a bill of quantities, etc.

Lexo4D offers various kinds of services such as for data access, searching, or system maintenance. In addition users can add their own services to perform custom tasks. Any service has full access to the underlying 4D POP model as well as to other services. This enables experienced users to easily define new functionality. As an example a custom service uses an existing search service to query for all elements that match a certain criterion and then modifies some 4D POP data on the returned elements through an existing data access service.

The Lexo4D data layer manages the object oriented data model and its mapping to a relational database. The mapping is done through NHibernate ([www.nhibernate.org](http://www.nhibernate.org)). This has the advantage that we can work with object oriented data models while keeping the data in a non-commercial relational database.

### 3.3 DATA MODEL

The object oriented data model of Lexo4D is split into two parts: the 3D building model and on top of it a 4D POP model. The 3D building model is a data structure coming from a 3D design CAD package. Typically, it is a tree-like data structure consisting of hierarchically arranged elements which are the smallest physical entities in an architectural model (e.g. walls, slabs, windows, or doors). The 4D POP model is a fully object oriented data structure which is imposed on the 3D building model. It suits two purposes: first it provides more detailed description of the 3D elements, and second it is used to hierarchically structure or group 3D elements.

To bind the 4D POP model to the 3D building model we make use of unique IDs (see Figure 4). The 3D building model provides a unique ID for each of its elements. The 4D POP model contains a corresponding entity, called 4D POP element with the very same ID assigned. This approach has two significant performance benefits. For speed reasons the rendering engine can get a local copy of the 3D building model. For memory reasons the 4D POP model can use dynamic binding to load only required data.

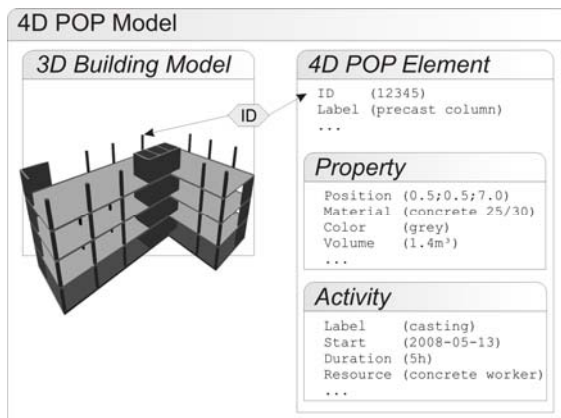


Figure 4: Bind 4D POP model to 3D model  
Matching unique IDs in both models provide the gluing entity

To group and arrange the elements of the 4D model we introduced structural data entities (see Figure 5). Structural data entities base on a hierarchy of three core classes: Projects, views, and containers. A project

holds a 3D building model. Additionally, it acts as parent entity for a collection of views. Views define a custom scenario for a 3D building model.

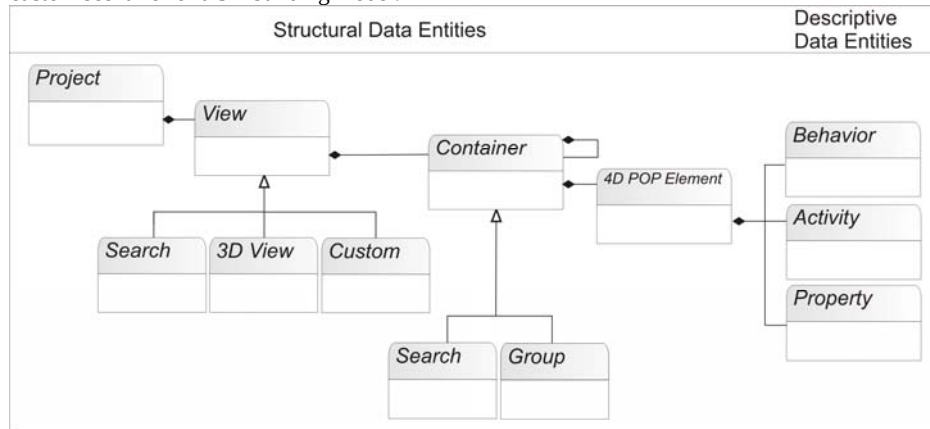


Figure 5: Structural data entities of the 4D model  
Project, view, and container provide hierarchical grouping of 4D POP Elements

A site manager could create views for different design alternatives focusing on the planning process whereas a financial manager would configure his or her views having financial issues in mind. Each view is the parent entity for a collection of containers. The purpose of a container is to group 4D elements. A container could collect all walls of a building while another holds all elements of a specific floor.

Views and containers have been defined as abstract classes such that concrete implementations can serve multiple purposes. Lexo4D comes with a standard view to group element manually by dragging and dropping the elements. A special view has been defined to manage search queries and their results and one view reflects the hierarchy of the underlying 3D building model.

To further describe the 4D elements of a 4D POP model we introduced descriptive data entities. They are used to provide semantic information about a 3D building covering arbitrary domains. This enables us to extend our 4D POP models just by adding a new object and assign it to the 4D element.

Descriptive data entities can be divided into three groups: properties, activities and behaviors. Properties describe static attributes of an element such as type, purpose, location, volume, dimension, material, color, and part-number of 4D elements. Activities are temporal processes that add project planning capabilities to Lexo4D. Behaviors describe dynamic attributes of an element. They are typically implemented as small scripts. As an example the thickness of the ground floor may change depending on the intended usage of a building, e.g. as an office, a shop, or a restaurant. A behavior script calculates the optimal floor size.

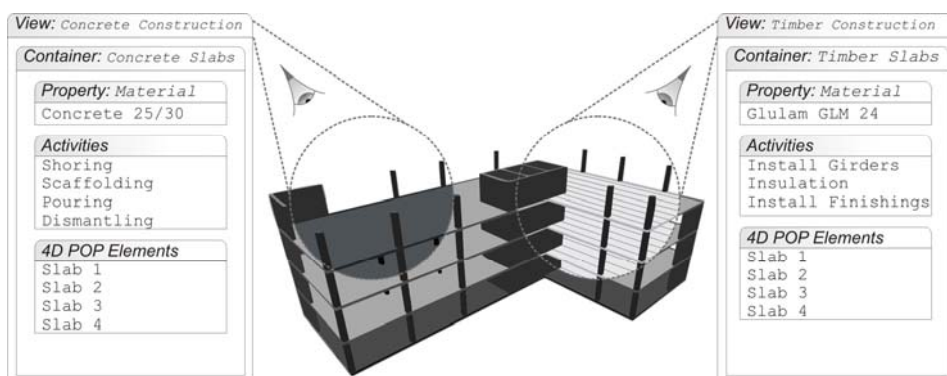


Figure 6: Comparison of two scenarios for a building

Furthermore the 4D POP model supports propagation of 4D POP data by assignment of descriptive data entities to a container. Therewith 4D POP values can be changed just for the current view rather than globally. An overriding mechanism ensures that a view always returns the value that is closest to the root of the according container tree. As illustrated in Figure 6 one view shows the building as it was made of wood, while the other shows the building made from concrete.

### **3.4 FURTHER DEVELOPMENTS, STUDIES AND OUTCOME**

The flexible hierarchies not only allow the users to manually restructure and rearrange the model to their needs but enables AI optimizer to even alter the construction method e.g. timber element, precast concrete or masonry walls etc. We use rapid prototyping methods to include the feed-back of project managers and engineers which use and test the features. We will take selected projects which have been modeled with LexoCad before and study and compare how different user groups create, analyze and evaluate new POP design alternatives. We expect that these developments support pro-active 4D planning, rapid generation, comparison and evaluation of POP design alternatives, derivation from existing designs, easy and effective integration of client information into POP models, creating performance predictions (quality, time, cost, risk, etc.) from models, easy creation of 4D sub-models for knowledge transfer for interdisciplinary cooperation.

## **4. PROCESS DESIGN PATTERNS**

In the third tier we introduce a novel process design concept which we named Process Design Patterns (PDPs). The application of PDPs on BIM are expected to create a step change in rapid creation, comparison and evaluation of POP design alternatives in VDC and a better exploitation of the solution spaces through AI methods for decision and process optimization.

### **4.1 DEFINITION OF PROCESS DESIGN PATTERNS**

The idea to use patterns as formal descriptions of generic solutions to classes of commonly occurring problems was first introduced by the architect Christopher Alexander and has been adapted for various other disciplines (Alexander et al. 1977). A pattern records the design decisions taken by many builders in many places over many years in order to resolve a particular problem. Patterns may be collected together into a pattern language that addresses a particular domain. While the pattern language idea has so far had limited impact on the building industry, it has had a profound influence on software engineering (Alexander et al. 1977).

A design pattern is not a finished design that can be transformed directly into a solution to an individual problem. It is a description or template for how to solve a problem that can be used in many different situations.

In construction and planning process- design, we use process design patterns to formally describe actions or events leading the construction or planning process from one defined stage to the next. Preliminary studies by Häubi and Righeti (2005) proved that business processes could be described by a very limited set of process- elements, all performed in more or less equivalent steps and using the same sets of resources. This was the key to use the pattern- approach for describing business processes. Typically, such patterns are implemented on homogenous tasks, performed by specific taskforces using a given set of resources e.g. machines. Thus the scope of change caused by a certain pattern varies with the level of detail in the planning process. The concept of pattern based process design is therefore not limited to a certain stage or scale in the overall planning- process.

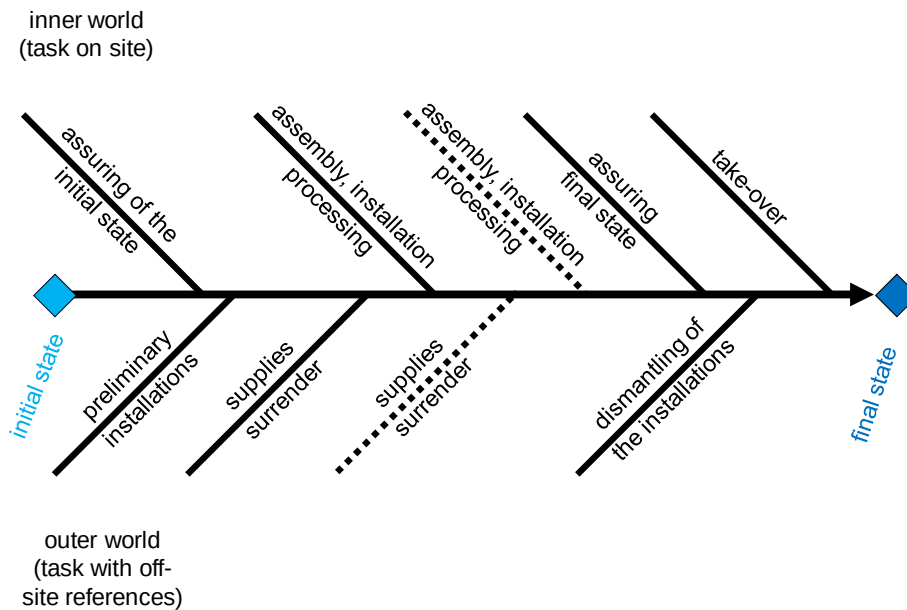


Figure 7: A possible generic process- design- pattern applicable to most construction processes.

#### 4.2 PROCESS ARCHAEOLOGY AND THE DEFINITION OF PDPS

In a study, we called Process Archeology, we chose a recently finished four storey residential concrete building and reconstructed and remodeled the over-all construction processes with an inter-disciplinary team of two architects, a structural engineer, construction foreman, three process managers and a computer scientist. The team creates the necessary 3D-, 4D- and process and organization models with commercial available modeling tools.

Derived from the single generic top level pattern, we recognized seven second level pattern: ground preparation, forming elements by pouring, forming elements by assembling small unified components, assembling site- or project- specific pre- fabricated elements, assembling adjustable standardized elements or mechanical components, surface treatment and setting into operation.

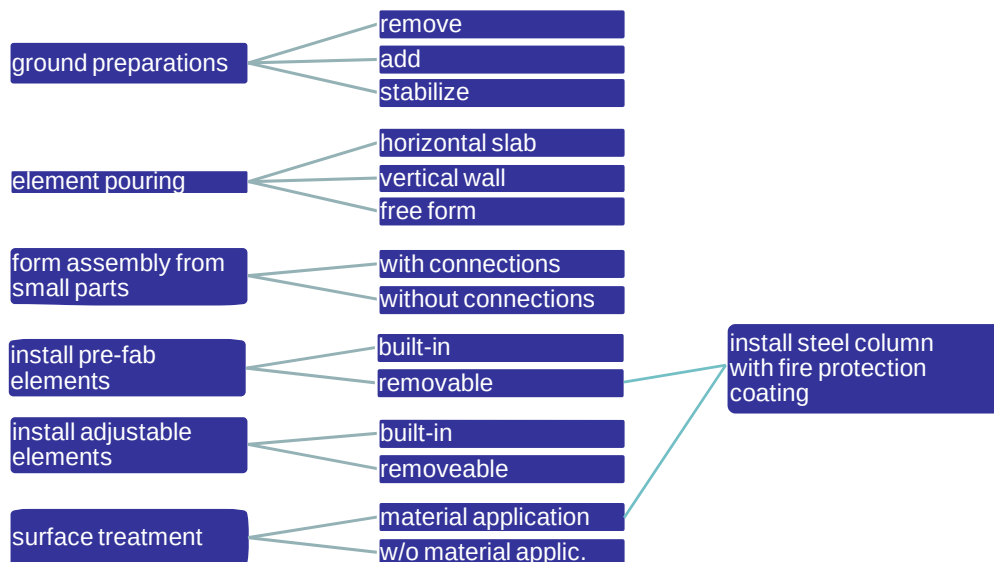


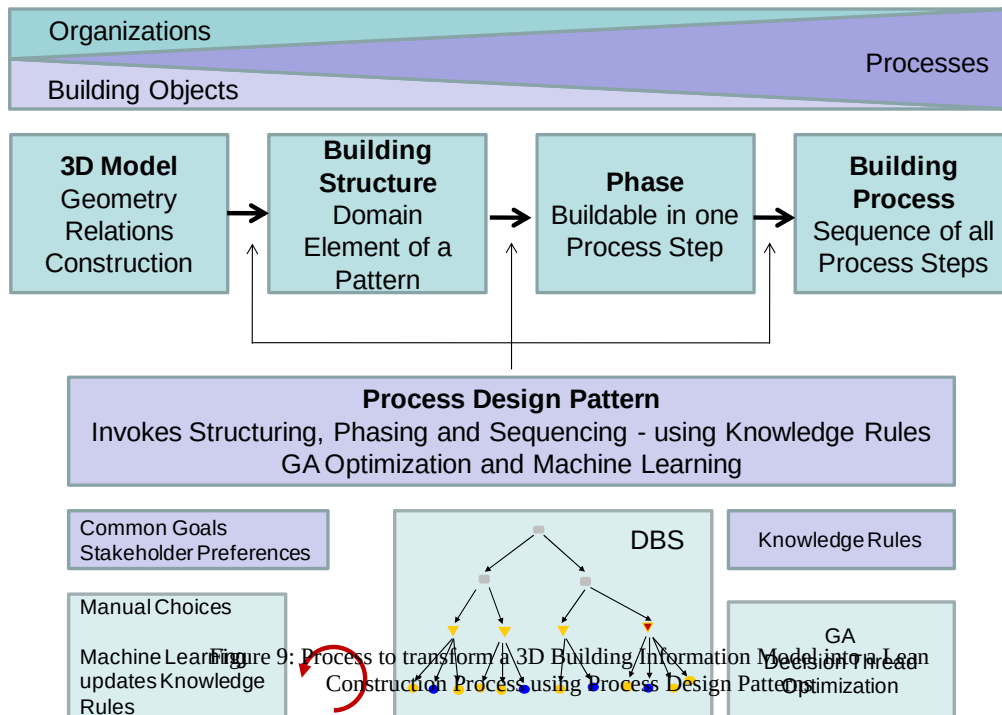
Figure 8: Types of second level Process Design Patterns, examples for the definition of third level patterns and one example of a combined fourth level pattern

The goal of our work is to create a comprehensive system for the description and definition of construction processes, where the level of detail in the description can be consistently varied up- and downwards according to the questions related to the actual planning phase.

#### 4.3 SYTHESIZING PROCESSES BY THE USE OF PATTERNS

PDPs define the rules for describing the transition process from one given building state to the next. The basic idea behind the pattern approach is to develop a system, which is able to create processes by applying pattern to the building information model (BIM). The overall process evolves in two steps from the building structure.

The first step produces a number of distinct process elements or sub-processes, generated by applying process design patterns on the building structure. The PDPs determine the type and order of actions or tasks to be performed and the BIM defines the quantities, shape and restrictions for these actions.



These process elements or sub-processes are further decomposed into phases which are work-units which can be performed in one single step.

The overall process setup finally emerges from the integration of the sub-processes. Here again, the BIM defines the overall quantities and constraints for the process design and the patterns define the rules for the possible combination of sub-processes. Both steps mentioned foremost (see Figure 9) comprise of AI methods using rule-based approaches as well as decision break down structures (DBS), optimization thread optimization with GAs (Märki et al. 2008) and machine learning for updating of the knowledge rules from project to project. As PDPs are scalable the application of generic PDPs on the BIM generates more choices for the user to specify. We develop a user interaction schema which allows direct specification input combined with a DBS where the project stakeholders define their common goals as well as their own preferences. The decision threads optimization searches the solution space and suggests fitting design alternatives which automatically specify sets of choices. We are convinced that this approach will result in a far higher number of possible design alternatives than the current manual practice which allow only a very few numbers of alternatives to be studied.

The final design of the resulting over all process is subject to project management methods like critical path analyzes or linear scheduling methods like location-based scheduling (LBS) (Kankainen and Seppänen, 2003) but also to more advanced optimization techniques like GAPO (Märki et. al. 2004). GAPO stand for Genetic Algorithm Process Optimization and is a module which optimizes project plans in terms of time, cost and resource management - forming a multiple criterion (defined by weighted combination of fitness functions) optimized building process. We will take the use cases of the second tier and study how the application of PDPs simplifies and enriches the creation of design alternatives. Further objectives are their quality in comparison to manually created alternatives and the effects of machine learning steps on the enhancement of PDPs.

## 5. CONCLUSIONS

The rapid creation of design alternatives in 4D POP models and the prediction of their related performance behaviors are the main objectives for the enhancements of Virtual Design and Construction Methods. We suggest a flexible, semantic, database-backed, object-oriented data structure for hierarchically arranged POP models which allow different stakeholders like owners, investors, users, architects, engineers and construction managers to model their specific perspective and interest on the project. The actual implementation of the Lexo4D prototype proves so far that our concepts are working. Furthermore we defined Process Design Patterns which can automatically generate candidate process chains for a wide range of construction methods. At the current state we are beginning to implement PDPs in Lexo4D. As PDPs integrate problem solution and expert knowledge, they may have the potential to intuitively support the process-oriented approach in construction.

## ACKNOWLEDGEMENTS

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## IFC BIM-BASED METHODOLOGY FOR SEMI-AUTOMATED BUILDING ENERGY PERFORMANCE SIMULATION

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### ABSTRACT

Building energy performance (BEP) simulation is still rarely used in building design, commissioning and operations. The process is too costly and too labor intensive, and it takes too long to deliver results. Its quantitative results are not reproducible due to arbitrary decisions and assumptions made in simulation model definition, and can be trusted only under special circumstances.

A methodology to semi-automate BEP simulation preparation and execution makes this process much more effective. It incorporates principles of information science and aims to eliminate inappropriate human intervention that results in subjective and arbitrary decisions. This is achieved by automating every part of the BEP modeling and simulation process that can be automated, by relying on data from original sources, and by making any necessary data transformation rule-based and automated.

This paper describes the new methodology and its relationship to IFC-based BIM and software interoperability. It identifies five steps that are critical to its implementation, and shows what part of the methodology can be applied today. The paper concludes with a discussion of application to simulation with EnergyPlus, and describes data transformation rules embedded in the new Geometry Simplification Tool (GST).

### KEYWORDS

Simulation, simulation input, IFC-based BIM, interoperable software, data transformation, rules, methodology, semi-automated process.

### 1. INTRODUCTION

Building energy performance (BEP) simulation is still used quite rarely in the building design, building commissioning and building operations. While credible statistics about the use of simulation are difficult to find, it is possible that BEP simulation is involved in the delivery of less than 1% of the “run of the mill” new U.S. building stock; similar minimal participation is likely to be true globally. Some of the main reasons are that BEP simulation is too costly and too labor intensive and it takes too long to deliver results. Its quantitative results are not reproducible due to arbitrary decisions and assumptions made in simulation model definition and can be trusted only under special circumstances. However, these are only symptoms of deeply rooted structural problems in the way BEP simulation and analysis is practiced today.

Preparation for energy performance simulation and analysis traditionally starts only after architectural and HVAC design have progressed sufficiently to provide enough information to depict the building, or the understanding of a problem and the information about it have developed far enough to make the start of the modeling possible. This means that simulation and analysis typically do not start until *after* some fundamental design decisions, potentially critical to energy performance of the future building, have already been made.

In the current widely practiced traditional process, building geometry information is taken typically from 2D CAD drawings, which depict the architects’ view of the building. Whoever is preparing the simulation and analysis takes that information and defines *his or her* “thermal” view of the building (see Figure 1). The resulting definition depends on the person’s understanding of the subject building, his or her knowledge and skill, experience, worldview, complexity of the building geometry of the subject building, complexity of the building itself, available resources, and more. Ultimately, the result is always likely to be quite arbitrary: Different people defining the thermal view of the same building will generate view definitions that differ from each other.



The definition of thermal view geometry involves additional subjective decisions.

Detail and accuracy of the defined geometry depend on the modeling person's understanding of the original geometry of the building, ability to use a given CAD tool, need to simplify because of resource and/or time limitations, preoccupation with finding and defining shortcuts, need and willingness to approximate, the understanding of implications to taken simplifications and assumptions, and more. Thermal view geometry is often defined as "planar" 3D where constructions like walls and slabs are represented as a single plane (i.e. the geometry does not represent their thickness). Some of the new CAD tools facilitate the definition of simplified 3D geometry on top of original 2D drawings, or the drawing of a "new" geometry that depicts the thermal view. However, any such geometry (that includes elements not identical to the original geometry definition of the same building elements) in reality constitutes a *simplification* of the original geometry, and is in most cases arbitrary. The resulting geometry definition of the thermal view is thus even more likely to be arbitrary than the definition of the thermal view itself: Different people documenting thermal view geometry of the same building will define geometries that differ even more from each other.

The definition of HVAC systems and plant is often no less arbitrary. Original data that describe the components, flows, linkages and dependencies, performance and deployment of the designed or planned HVAC systems and plant usually have to be transformed as well to fit what the simulation engine can accept and model. A substantial part of this data transformation is subjective and depends on the same factors as the definition of thermal view and its geometry.

The same can be true of the definition of plug loads needed for the simulation and analysis. Occupancy data, the different building use schedules, electrical design data (about electrical lighting and equipment), and all sorts of other data that may be needed, are often transformed from their original form. At times, even original values are changed. Some of these data are not available in any form at all, and are thus estimated or guessed for use in simulation and analysis – they are fabricated and used even if they have no resemblance to the real world data they are substituting for.

The preparation of input for simulation and analysis is not only arbitrary, it is also a very lengthy, laborious and resource consuming process. The work mostly consists of manual or semi-manual transcription and recoding of already existing information, which often results in numerous coding errors. Some of these errors can be very difficult to detect and, if not detected, can corrupt simulation and analysis results.

Consequently, traditional energy performance simulation and analysis is in general based on potentially arbitrary model definitions (Bazjanac 2008). Its quantitative results are not reproducible and can be trusted only under special circumstances: It typically results in over-prediction of energy savings in buildings (Mills et al. 2004). Such a process *is not sustainable from an information science point of view*. Traditional BEP simulation does not fit the integrated, Building Information Model (BIM) based processes the Architecture, Engineering, Construction, Owner and Operator (AECOO) industry is now beginning to demand, nor does it match well with the American Institute of Architects' (AIA) Integrated Project Delivery concept (AIA 2007). This process is in itself the main cause of some of the underlying problems in the current use of building energy performance simulation and analysis.

Recent "improvements" to this practice consist mostly in the emergence of new tools and graphic interfaces (such as Green Building Studio, DesignBuilder, etc.) that make this process easier and somewhat faster to accomplish. These improvements are not changing the process – they target the same old process with its fundamental shortcomings, and do not advance the state of the art. They are not resolving the underlying problems in the use of building energy performance simulation and analysis, and can ultimately contribute relatively little to the design of more energy efficient buildings.

Dependence on special expertise, the arbitrary nature of models and treatment of data, as well as results that cannot be routinely reproduced, are some of the major reasons why some in the AECOO industry are not taking simulation and analysis of this type seriously – the traditional process, regardless of the simulation tools used, cannot qualify as means of testing and experimentation with virtual buildings. Because of the length of time it typically takes to perform this type of simulation and analysis (and deliver sought answers) in the traditional way, its results always lag in time behind the timing of design decision making, often making the sought answers irrelevant by the time they are delivered. This

contributes to the many reasons why building energy performance simulation and analysis is not regularly used and why, when used, its results rarely have an impact on the eventual energy efficiency of the constructed and occupied building (Torcellini et al. 2004).

## 2. METHODOLOGY TO SEMI-AUTOMATE BEP SIMULATION

In response to the shortcomings of the traditional process of performing building energy performance simulation and analysis, LBNL developed a methodology for such simulation and analysis that is based on the principles of information science. The goals of this methodology are to bring scientific principles to the process, to make the process and its results consistently reproducible, to enable the integration of energy performance simulation and analysis tools into suites of interoperable tools that are routinely used in building design, and to make the use of such tools productive and attractive throughout the AECOO industry.

The essential objective of LBNL methodology is the elimination of all inappropriate human intervention that results in subjective and arbitrary decisions which affect BEP simulation. This is achieved by automating any and every part of the energy performance modeling and simulation process that can be automated. Given principles of information science applied to building science and industry processes, this involves:

- Necessary transformation of data which are part of the process that is based on unambiguous rules which reflect the purpose of transformation;
- Data transformation rules that are embedded in software code;
- Consistent use of original data – defined by the party responsible for their professional definition – wherever possible throughout the process;
- Use of a BIM as the authoritative repository of project data;
- Rigorous model and data testing and validation.

LBNL methodology to semi-automate the process of building energy performance simulation and analysis in support of building design is depicted in Figure 2. The process starts with the population of the BIM; this is followed by model and data checks, correction of faulty information, addition of missing data, rule-based data transformation to meet data formatting needs of the simulation engine, continuous additional model and data checks, execution of simulation, and analysis of results. The methodology contains five essential steps, some of which can be concurrent:

1. Populating IFC-based BIM with data;
2. Automated rule-based data transformation;
3. Rigorous model checking;
4. Building energy performance simulation;
5. Analysis of results from simulation.

The success of energy performance simulation and analysis in support of building design depends critically on software used in the process. All deployed software applications must be “up to the task” – they must be able to properly deal with any model and data involved in the process – and must be mature and robust. LBNL methodology was developed with the use of open source software in mind; this facilitates process modification and extension possibly needed in the future. The methodology is based on the assumption that the data model of buildings used in the process is open, “intelligent” (i.e. object oriented), itself extensible, and is an international standard. Consequently, any BIM used in the process must be IFCbased, as IFC (IAI 2007) are the only data model available today that meets these requirements.

### 2.1 POPULATING IFC-BASED BIM WITH DATA

An IFC-based BIM, as a populated instance of the IFC data model of buildings, can be populated with data only by a software tool, and that only by a software tool that is IFC compatible (i.e. its interoperability is based on the IFC data model). This means that such a tool must have an IFC interface. Arrows pointing out of the circle “IFC-based BIM” in Figure 2 represent IFC interfaces. Tools with such interfaces are called (IFC) BIM authoring tools. Interfaces that can only import data from an IFCbased BIM are represented with arrows that point away from the “IFC-based BIM” circle in Figure 2. Interfaces

to BIM authoring tools which are able, or must be able, to import as well export data to/from a BIM are represented with arrows that point both ways.

When fully implemented, LBNL methodology requires that all data needed in the simulation and analysis of energy performance are entered in the BIM from their *original source*. This is essential to maintain data integrity later in the process. Consistency in modeling is crucial to data that populate a BIM. The same building objects must be defined the same way by all BIM authoring software that can define and exchange these objects, or interoperability is interrupted. For example, curtain walls must be defined in the same way by all software that defines or uses curtain wall definitions.

A fully populated BIM can become an enormously large data base, much too large for any single software application to manipulate its entire content. The main purpose of software interoperability is *seamless* data exchange or sharing among multiple software applications engaged in an industry process (Eastman et al. 2008). Model views define “data exchange requirements” (i.e. specific data and data sets within a BIM) that must be supported by all interoperating software that participates in a specific process; model views can define exchange requirements for a given industry discipline, a specific industry process, an organization, a group task, etc. The International Alliance for Interoperability has defined a Model View Definition methodology (MVD) for the IFC data model (IAI 2006); LBNL methodology to semi automate BEP simulation assumes the existence of an “energy simulation” view of IFC, either explicit or implicit.

HVAC design tools must import the original building geometry from a BIM in order to create a thermal view of the building. Thermal views identify building zones which include one or more spaces that behave thermodynamically in the same way.

The definition of a thermal view is necessary to relate the designed HVAC systems and plant to the architecture of the building – to relate the designed HVAC systems and plant’s definitions to geometries of thermal zones they are serving.

LBNL methodology assumes that the BIM contains architectural design data, HVAC design data, electrical design and, and some other essential data about the building (such as occupancy and operating schedules) before the process of energy performance modeling and simulation can start. (The BIM does not have to be populated with structural design data.) The process defined by LBNL methodology starts with HVAC design and the semi-automatic creation of thermal zones by dragging-and-dropping selected IFC space objects in the object tree into appropriate newly created and named IFC zone objects.

The process continues with the definition of “2nd level space boundaries”. Proper geometry of a thermal view must include the definition of all *surfaces* that enclose each space – these are called *space boundaries*, and they define the inside surface of walls, slabs, windows and doors that enclose a space. Space boundaries define areas of thermal transfer between two zones. They must often be subdivided into smaller segments – *2nd level* space boundaries – to match possible smaller space boundaries on the other side of a given wall, slab, window or door (Bazjanac 2005). The definition of 2nd level space boundaries is done automatically with software utilities such as the ArchiCAD IFC Utility.

## 2.2 AUTOMATED RULE-BASED DATA TRANSFORMATION

This step is crucial to LBNL methodology: transformation of original data into format necessary for use by the simulation engine, according to data transformation rules embedded in special software: data transformation software. Transformation rule types include data set reduction and simplification, as well as data translation and interpretation (Bazjanac and Kiviniemi 2007). Data interpretation rules are the most extensive type, as they include numerous rules of deriving new from existing data.

Embedded transformation rules related to building geometry include those that reduce and simplify original “rich” geometry data sets that are “too rich” for energy performance simulation, identify and define columns embedded in walls, identify and redefine external shading surfaces, and more. HVAC data sets (which also include plug loads and schedules) are also transformed as necessary per rules embedded in data transformation software. Some transformation rules are part of the related MVD; most are embedded in transformation software that serves a given simulation tool.

A populated IFC-based BIM contains original data entered by the author(s) of those data using BIM authoring software. All data in an IFC-based BIM are in IFC format. Data transformation software

extracts data needed for BEP simulation from the BIM. All needed data and data sets will have been defined in the “energy simulation view” of the IFC data model as part of the exchange requirements for that model view. Some of the extracted numerical values are usable as extracted; other must be transformed to meet simulation input specifications. Data transformation software automatically performs the necessary transformation per rules embedded in it, and automatically generates streams of transformed information.

Transformed data are next wrapped with input syntax of the simulation engine that will be used in simulation. This is accomplished automatically with software that “recognizes” particular data sets, surrounds them with appropriate simulation input syntax, and generates part of the simulation input file. Definitions of composite construction, originally defined in IFC compatible CAD tools, are linked to a library that contains thermodynamic properties of materials and constructions, and are automatically appended with thermodynamic data.

All data transformation is performed semi-automatically – human participation is limited to directing “information traffic” and sequencing of operations. The output file generated by data transformation software is created in the format required by the given simulation engine and contains most of the necessary content of the final simulation input file. The still missing data (such as run controls, report requests, etc.) are added later manually with a text editor or a given simulation tool utility.

### **2.3 MODEL CHECKING**

Model checking is a critical task that must be repeatedly performed throughout the simulation preparation process. Model and data are checked for different purpose at different times, and can involve different model checking software. Failure to check the model and data continuously will likely result in problems and errors later; finding errors and omissions later becomes much more difficult.

A check of the original building geometry model for its completeness, consistency and validity is performed first – errors and omissions in the original data can later cause problems in the simulation. Quick initial checks can be done visually with visualization software; proper checking to also detect errors that are not visually obvious employs software like the Solibri Model Checker that can report in detail each incidence of a specific error and/or omission type. If errors and/or omissions are detected, they are (manually) corrected with an IFC compatible CAD tool; this process can take several iterations before it is complete.

A model is checked next for space boundaries to detect incorrectly defined or missing 2nd level space boundaries. This is done by a tool like the IFC Explorer that has the ability to identify space boundaries. Correcting detected space boundary errors or omissions can be difficult and may cause a significant time delay, as they are typically caused by the IFC utility that generated them originally. Simple errors and omissions can sometimes be corrected manually.

A completeness and consistency check of HVAC data that will be involved in the simulation of energy performance follows. If the check fails, authors of the original data involved in the failure have to make the necessary corrections and repopulate the BIM with correct data.

### **2.4 BEP SIMULATION**

As explained above, a small amount of additional data must be added to the simulation input file manually before the simulation can be executed. Additional data can include data that identify simulated meters, simulation output reports, etc. As these data largely reflect the objectives in executing the particular simulation(s) and thus may vary from one simulation of performance of the same building to another, it is not feasible to automate their definition. Simulation run control data are always added manually to the simulation input file.

When a simulation engine cannot properly model a particular building feature or element, specific equipment, or a system, expert simulation users may be able to define a “work-around” – a substitute definition that approximates what the simulation engine is not able to model directly – and add it to the simulation input file. In most cases work-around definitions must be added to the input file manually. This is the only instance when direct human intervention in the definition of simulation input is always legitimate.

Selection of appropriate weather data, as well as definition of building location (building site latitude and longitude, elevation above sea level, time zone, and building orientation) is done automatically using GIS information contained in the BIM. Such GIS data are often entered also as part of the architectural design data set. A path to the local directory that contains weather files may have to be (manually) included as part of the simulation run control data.

The simulation engine processes the input information, executes, and delivers the results in the form of electronic output reports. At this point data generated by energy performance simulation are ready for post-processing and analysis of results.

Some of the data generated for or by simulation have to be entered into BIM (in IFC format), so that the simulation can be recreated and its results reproduced, if necessary. These include definitions of work-arounds, summary results, time stamps, paths to external files that contain records of simulation input and output, and more.

The simulation engine itself does not have to be directly fully IFC compatible, if an associated IFC interface can read simulation input and output and transmit the appropriate information to the BIM in IFC format.

## 2.5 ANALYSIS OF RESULTS FROM SIMULATION

Output from sophisticated energy simulation engines is typically enormously large. It requires planned selective electronic post-processing of generated data before the results from simulation can be properly analyzed. Post-processing is semiautomated and human participation is again limited to directing “information traffic” and sequencing of operations. Tools used in post-processing of simulation results do not have to be IFC compatible, as the outcomes of post-processing hardly ever affect the content of BIM directly.

Results of simulation can have a significant impact on architectural design of the building and may prompt changes in building design or the design of alternatives. Such changes will inevitably result in the modification of the original architectural design data, which may prompt the repetition of the simulation process with new data. Simulation results may have a similar impact on other original data sets: HVAC systems and plant design, electrical design, and/or other data about the building. In most cases energy performance analysis will not directly affect structural design data, unless it causes changes in architectural design that affect structural design.

Analysis of simulation results and the design decision making response to it constitute the essence of using building energy performance simulation in support of building design. By definition, both require human intervention and rely on human creativity. Any attempts to automate them would be counterproductive and would result in failure. On the other hand, it is important to *automatically inform all parties* that are affected by the outcome(s) of BEP analysis about the results of analysis.

## 3. WHAT IS POSSIBLE NOW

Standard, commercially available IFC compatible software and some of the newly developed special purpose software tools make it possible to implement part of the LBNL methodology for semi-automated BEP simulation. Dark colored blocks and black lines in Figure 3 show implementable parts of the semi-automated process. Model-based CAD and other IFC compatible BIM authoring tools can populate a BIM with architectural data (i.e. building geometry and construction materials), electrical design data, and some other data needed for BEP simulation. Thermal zones and, implicitly, a thermal view of the building are defined by agglomerating space objects into zone objects. Model checking software verifies building geometry and space boundary definitions; originally used BIM authoring software repairs detected errors and/or omissions. Newly developed software performs appropriate rule-based transformation of data necessary for BEP simulation, and wraps the data with simulation input syntax. Following this semi-automatic process results in the automatic creation of a partial input file for BEP simulation, which is completed manually before the simulation is executed.

Full implementation of this methodology is still not possible because none of the currently available HVAC design tools are IFC compatible (and thus the BIM cannot be yet populated with original HVAC

data), and because the rules of necessary HVAC data transformation have not yet been developed. Faded-color blocks and gray lines in Figure 3 identify the part of the LBNL methodology that cannot yet be implemented.

In the absence of HVAC design data in the BIM, thermal zones can be defined from building geometry definitions contained in the BIM. This is done by displaying building geometry objects in IFC object tree form with a model-based CAD utility that can display the object tree, creating and uniquely naming IFC zone objects in the tree, and moving appropriate IFC space objects in the tree into zone objects.

### 3.1 IMPLEMENTATION OF METHODOLOGY: ENERGYPLUS

LBNL applied the currently implementable part of the methodology for semiautomated BEP simulation to preparation of input data for simulation with EnergyPlus. As shown in Figure 4, LBNL developed new middleware (a pair of software tools) with embedded rules of data transformation: Geometry Simplification Tool (GST) and IDF Generator. If necessary, GST transforms the original data in the IFC file into form needed by EnergyPlus; IDF embeds the data in EnergyPlus input syntax and creates the initial EnergyPlus input file (IDF file). Data transformation rules embedded in GST regulate and automate the transformation of building geometry data. IDF Generator embeds all data that arrive from the IFC file through GST in proper syntax, whether they were transformed or not.

The initial IDF file contains only building geometry and related data. HVAC data must currently be added to the input file manually. That is done with a text editor or with the IDF Editor (a utility bundled with EnergyPlus). LBNL developed an IFC HVAC interface to EnergyPlus; HVAC and schedule data entered manually can be exported directly back to the BIM via this interface. Once HVAC design tools become IFC compatible, this interface will facilitate the import of original HVAC design data directly from the BIM. This will eliminate the need to manually enter such data.

Other data needed to run the simulation (as described above) are added to the input file manually. With the input file completed, EnergyPlus simulation starts and executes in the conventional manner.

### 3.2 DATA TRANSFORMATION RULES EMBEDDED IN GST

GST source code includes a set of data transformation rules. The tool reads an IFC file, extracts building geometry and related data, and transforms extracted data as necessary to meet geometry input data requirements for EnergyPlus. Rules embedded in GST perform the following data transformation tasks:

- Direction verification of normal vectors for space boundaries that represent surfaces of walls, slabs, windows and doors;
- By-pass of space boundaries located inside the volume of a thermal zone;
- Splitting of donut-shaped slabs into combinations of rectangular slabs;
- Space boundary association with containing object's construction materials;
- Reversing of material layers sequence for interior walls, slabs, windows and doors when viewed from the other side;
- Transformation of definitions of columns embedded in walls into definitions of walls;
- Transformation of walls and slabs protruding outside of building volume into EnergyPlus building shades.

## 4. CONCLUSION

The traditional process of preparing and executing BEP simulation is ineffective and must be replaced if BEP simulation is ever going to be used *routinely* in support of building design, commissioning and operations. LBNL methodology to semiautomate BEP simulation, based on principles of information science, offers a way to prepare and perform BEP simulation much more effectively.

LBNL methodology shows immediate and tangible benefits when applied to simulation with EnergyPlus. Preparation of input files for building designs used in early testing demonstrated dramatic (70-80%) savings in time and effort compared to the traditional process of preparing the same input (Bazjanac 2008).

The methodology can be applied to any energy performance estimation and analysis process that involves IFC compatible software. The use of different simulation and analysis software may require partial modification of some of the data transformation rules embedded in GST, or the addition of new rules.

GST is still in rigorous beta testing. Given proper funding to complete the testing and support the tool's use after release, GST may become the critical element in enabling semi-automated BEP simulation for use in every building design and building procurement project.

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## **A PROPOSAL FOR REUSING SIMULATION MODELS IN THE DESIGN OF PRODUCTION SYSTEMS IN CONSTRUCTION**

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### **ABSTRACT**

One of the main difficulties of using simulation in the management of construction projects is the fact that developing simulation models is time consuming. One of the possible strategies to cope with this problem is the reuse of an existing model or part of it in other simulation study. Although many authors have pointed out that the unique nature of construction projects leads to the necessity of starting each model from the scratch, the reuse of models for simulating projects of the same market sector seems to be reasonable. This paper aims to assess the main benefits and difficulties of developing reusable simulation models for designing production systems for housing projects. A case study in which a simulation model was developed for supporting that task in a construction company involved in repetitive housing projects is presented. The development of this model took into account the possibility of reusing it in other similar projects of the company in order to reduce the time for doing the simulation study. The main findings are related to the limitations and requirements of reusable models as well as to the implementation of those models in the design of production systems for real construction projects.

### **KEYWORDS**

Simulation; Reusable models; Production system design.

### **1. INTRODUCTION**

Simulation has been widely used for modeling the behavior of production systems, and understanding the combined effects of variability, interdependence and uncertainty. It is especially useful if the system does not exist yet, i.e. for analyzing the performance of production systems in the design phase (Law and Kelton 2000).

One of the main benefits of using simulation is that it allows managers or engineers to have an idea of the overall effects of local decisions in the production system (Law and Kelton, 2000). Through simulation models it is possible to understand the implications of the complexity of a production system (Robinson 2003), and to support the decision-making process involved in the conception and design of complex production systems (Welgama and Mills, 1995). Moreover, since the operational behavior of the system under study can be reproduced, it is possible to compare alternative designs and to measure the effects of different policies on its performance (Robinson 2003).

Despite the well known benefits of using simulation to support decision-making, its use has been very modest in the construction industry. In fact, in the proceedings of the Winter Simulation Conference between 1997 and 2006, the papers on simulation applied to construction management represent only



3.5% of the papers presented. Moreover, in IGLC<sup>10</sup> Conferences 11 papers about simulation in construction have been presented in the last ten years.

Shi and AbouRizk (1998) pointed out that, despite the potential of using simulation in the construction industry, there is still a need for making simulation widely used in the sector, especially by making it an effective user-friendly tool and by reducing model development time. In general, simulation studies in construction have focused on individual construction operations or processes. Little has been written about the use of simulation for designing production systems in construction. Most of them have used simulation for testing propositions using hypothetical or existing production systems (e.g. Draper and Martinez 2002, Alves et al. 2006, respectively). None of them have explicitly used simulation models to support decision-making in the design and implementation of new production systems in construction.

The aim of this paper is to make an assessment of the benefits and difficulties of developing and implementing reusable simulation models for designing production systems for housing projects.

Firstly, it is presented a brief literature revision on the use of simulation and, more specifically, a visual simulation model as a tool to support decision-making process in the design of production systems. Also, some key concepts on reusable and generic models are presented. Then, it is described a case study in which a simulation model was built taking into account the possibility of reusing it in other similar projects from the same company in order to reduce the model development time<sup>11</sup>.

Finally, the main benefits and difficulties in using that approach, as well as some requirements to use those models in the production system design are presented and discussed.

## 2. SIMULATION IN CONSTRUCTION

One of the first simulation tools for construction management was CYCLONE, which was developed by Halpin in 1973. Based on that system, many other simulation programs were proposed aiming to develop simulation models for support decision making in construction management. More recently, STROBOSCOPE has been one of the most used simulation languages in the construction field. Many studies have been developed using that language, including several ones related to the application of lean production principles and concepts to construction management.

However, typical construction simulation models provide information that is hard to communicate to decision-makers (Kamat 2003). Very often, they are not trained in simulation, and do not have means and time to validate or verify the models based only on numerical outputs (Ioannou and Martinez 1996). Thus, construction practitioners are often skeptical about simulation models and find difficult to rely on their results (Kamat 2003). Besides, there are other causes that contribute to limit the application of simulation in construction: (a) the complexity of the construction processes and the difficulty to devise models of those processes (Oloufa et al. 1998); (b) the increase in the model's development time due to that complexity (Shi and AbouRizk 1997); and (c) frequently, a simulation model is perceived as a "black box" by the users, making it difficult to understand it and rely on it (Shi and Zhang 1999).

## 3. VISUAL INTERACTIVE SIMULATION (VIS)

In recent years, several studies have applied visual modeling and simulation techniques for analyzing construction activities, aiming to make this tool friendlier to its users (Oloufa et al. 1998, Hajjar and AbouRizk 1998, Hajjar and AbouRizk 1999, Shi 1999, Hong et al. 2002, Nasereddin et al. 2007). Kamat (2003) suggests that this has become a trend in construction simulation. For example, Ioannou and Martinez (1996) used the visual postprocessor PROOF to animate STROBOSCOPE models in 2-D, while Kamat (2003) has studied techniques of 3-D visualization of STROBOSCOPE simulation models.

Visual Interactive Simulation (VIS) is a technique that involves the use of a dynamic display in which the user can change the model's parameters during the routine execution to analyze their impacts (Au and

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<sup>10</sup> IGLC is the International Group for Lean Construction makes up a network of professionals and researchers in architecture, engineering, and construction (AEC) whose goal is to improve the AEC process as well as product, by developing new principles and methods for product development and production management, based on lean production concepts.

<sup>11</sup> This paper has focused on the process of developing and applying a model which was intended for being reused in another project of the same company. However, at the time this paper was written this study was not already finished and it will be reported in another paper.

Paul 1996). A VIS model can be formed by block diagrams, icons, charts, and texts to show the system behavior while running a simulation (Au and Paul 1996). The dynamic features and the discrete changes of a process can be seen on the computer screen (Law and McComas 1992, Law and Kelton 2000). By visualizing these changes the user can test the simulation model and validate its results (Shi and Zhang 1999), obtain insights on the real system behavior (Welgama and Mills 1995), compare various alternative scenarios and predict the future behavior of the system (Ceric 1997).

The advantages of using VIS are pointed out by many authors. However, two are especially relevant for this research. Firstly, through visual display it is possible for the user to follow the events while they occur and to identify potential mistakes, i.e. it is easier to verify and validate the model (Law and McComas 1992, Law and Kelton 2000, Robinson 2003). Secondly, a Visual Interactive Modeling and Simulation (VIM/VIS) environment is adequate to increase the understanding of the model by the user as well as to promote its participation in the development and run processes (Pidd 2002, Robinson 2003). VIM/VIS improves the communication of the model and its results for all project participants, specialists or not (Law and McComas 1992, Law and Kelton 2000, Robinson 2003), making it possible to devise solutions that are jointly discussed by different members of the simulation study (Robinson 2003).

#### 4. GENERIC AND REUSABLE MODELS

Some studies that have tested the use of alternative model development strategies to reduce the development time of simulation models. Oloufa et al. (1998) explain that in manufacturing production systems are fairly stable and the time and money invested for building models tend to result in a good cost-benefit relationship. By contrast, as production systems in construction are temporary, it is necessary to reduce the time available for developing models in order to answer questions more quickly (Oloufa et al. 1998).

Two alternative solutions can be used for reducing the model development time: (a) a generic model is one built for a particular purpose which can be used through a number of organizations; (b) a reusable model is one used in another context for which it was originally intended (Robinson 2003). Developing a reusable component of a simulation model is another similar concept. In that case, part of a model is reused in a new simulation model, in a new context or for other purposes (Robinson 2003).

Pidd (2002) presents a spectrum of different types of reuse (Figure 01). That spectrum shows four points on a scale and two different horizontal axes (frequency and complexity). According to that author, the first axe indicates that reuse is much more frequent at the right-hand end, code scavenging. The second axis runs in the opposite direction, where code scavenging is relatively easy, but successful reuse of entire simulation models can be very difficult (Pidd 2002).

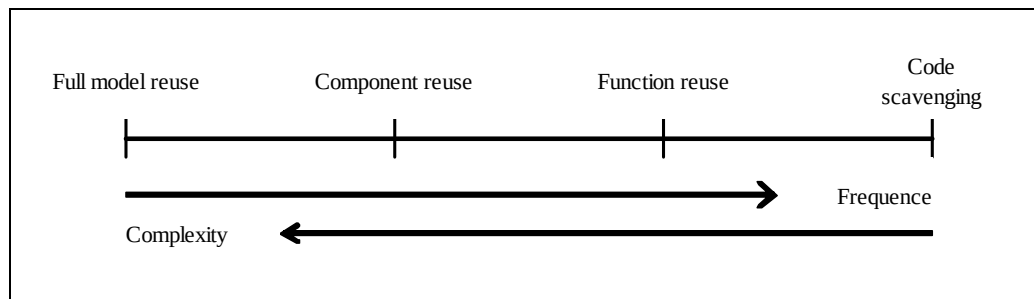


Figure 1: model reuse spectrum (based on: Pidd 2002)

According to Paul and Taylor (2002), there are many forms of reusing simulation models: (a) reusing modeling basic components; (b) reusing subsystems' models, i.e. the modeler has previously developed generic models of parts of the production system which can be adapted to a new model; and (c) reusing a previous model which has similar features to the system under study.

Reusable models are especially useful when someone is modeling systems of the same domain or sector. According to Mukkamala et al. (2003), in that case the modeling process is repetitive and the models are similar but slightly different. Thus, the modeling effort can be reduced by using domain specific modules or templates which encapsulate the specific logic of that domain and hide many of the model details (Mukkamala et al. 2003).

In the construction sector there are some examples of the generic/reusable modeling approach. Oloufa et al. (1998) developed a pre-programmed library of production resources aiming to reduce the development time of simulation models. When modeling a specific project, the user chooses the resources needed and specify the project logic, by linking them. Nasereddin et al. (2007) have proposed a reusable simulation model to be used in a modular housing factory. In that study, a generic model was employed, and the model could be configured to address specific situations, through a spreadsheet for data input.

## 5. RESEARCH METHOD

In order to guide the discussions a model for devising the production system design (PSD) of repetitive low income housing building projects (Schramm et al. 2004) was used. This model grouped the main PSD<sup>12</sup> decisions in six sequential steps. It also suggested that the PSD in those projects should be carried out before the construction phase began, since most project requirements and design details are usually defined in advance. Figure 02 presents the proposed model.

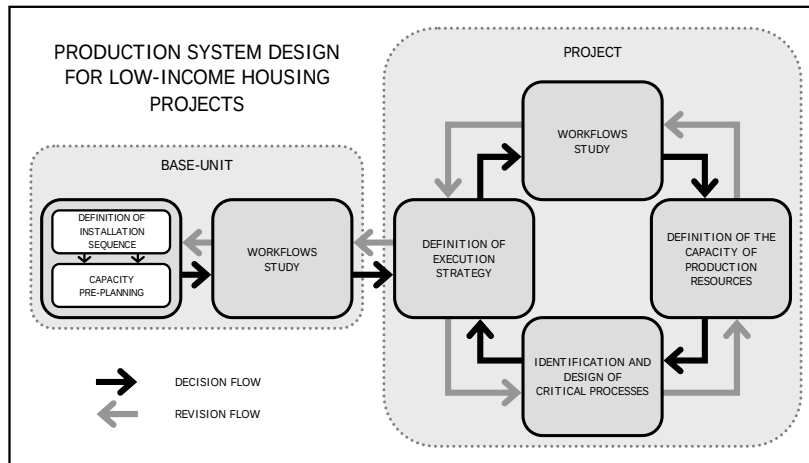


Figure 2: the production system design model (Schramm et al. 2004)

A major limitation of that model was that it employs deterministic methods to model the production systems what is one of the main reasons to the use of simulation models to model the effects of variability on the performance of production systems.

In the study it was used a general-purpose visual interactive simulation package, named Arena<sup>®</sup> (Rockwell Software Inc. 2005) to develop the simulation model.

## 6. CASE STUDY

The case study was carried out in a small construction company located in Canoas, a small town of the Porto Alegre metropolitan area, South of Brazil. That company has been involved in developing and building low-middle residential building projects.

The project investigated consisted of a low-rise terraced housing project which was made up of 112 ninety square-meter two-story houses, grouped into 21 blocks of 4, 8 or 10 dwellings. The main construction techniques used were: load-bearing concrete block walls, pre-cast concrete slabs and ceramic roof tiles.

<sup>12</sup> Production System Design is a managerial activity that should take place before a project construction phase. In that stage the production system should be structured to accomplish the project goals. According to Skinner (1985), the production system design (PSD) aims to establish a set of manufacturing politics which can be grouped into two parts. The first is related to facilities and equipments, resource capacity, and technologies to be used. The second is related to infrastructure, i.e. decisions related to vertical integration level, production planning and control, workforce management, quality control and so forth.

Several weekly meetings were held among the research team and the company's production engineer. Eventually, company's architect and key subcontractors were invited to the meetings. The first decision made was to establish a constructive sequence to build the project's base unit<sup>13</sup>. Based on previous case studies, the definition of a sound constructive sequence is a fundamental decision since it is the base for the model building<sup>14</sup>. Although the company had already built three previous projects with the same features (dwellings configuration, constructive techniques and materials, etc.), it was not possible to identify a unique constructive sequence. Thus, after a number of meetings an agreement on the most suitable construction sequence was reached. Besides the technological constraints that sequence took into account the production and transfer batch sizes<sup>15</sup>, the times to process completion (in terms of a triangular distribution) and the resources which would be used to complete each process.

Based on that discussion, a precedence diagram was built and sent to the project site to be pinned on the site office wall and discussed with all involved. That discussion brought in production engineer, foreman, project planner and key subcontractor in order to explain the document and make a commitment to follow the standard constructive sequence. Figure 04 presents part of that precedence diagram.

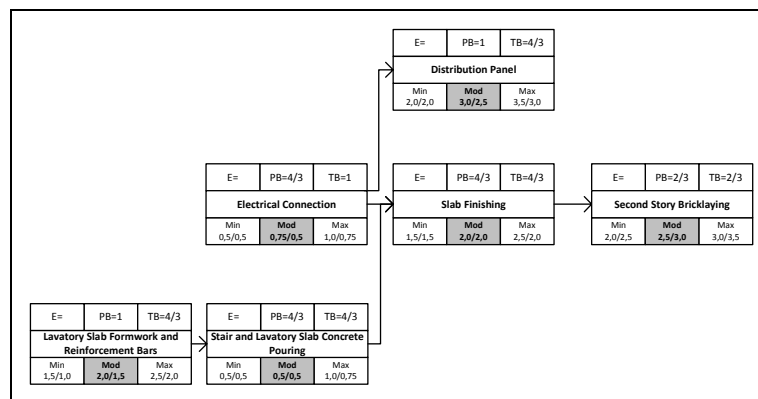


Figure 4: part of the precedence diagram built from the meetings

The second step was to build the simulation model in order to help the study of the base unit workflows, the execution strategy and the impacts of those decisions on the entire project workflows.

In order to put in practice the possibility of reusing that model in other company's projects, a generic simulation module was proposed for summarizing each production process features (production and transfer batch sizes, time to completion and the required resources). Besides simplifying and reducing the modeling time, the generic module allowed to record and write specific process data (process start and finish time, process lead time and so on) which would be used to build planning and control tools (as lines of balance, production control charts and S-curves, for instance). Figure 05 shows the conceptual model of the generic simulation module.

<sup>13</sup> A base unit is a repetitive production unit which is replicated many times during the project production phase.

<sup>14</sup> That decision plays a vital role when the model is being built aiming the reuse.

<sup>15</sup> The process batch is equivalent to the quantity of one product that is processed by a resource before starting the production of another product, and the transfer batch is the quantity of units that will be moved at the same time from one workstation to the next. According to Umble and Srikanth (1995), the transfer batch does not need and should not be the same as the process batch and the transfer batch should be ideally as small as possible.

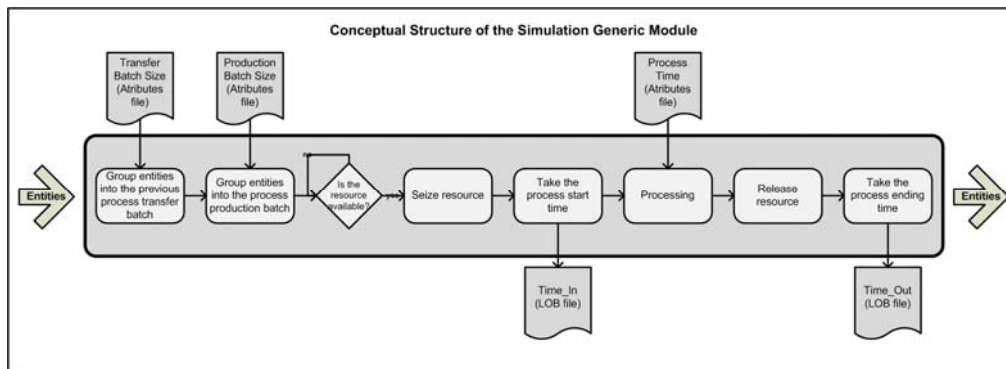


Figure 5: conceptual model of the generic simulation module

It is worthwhile mentioning that by using the generic simulation module only 10 mouse clicks were necessary to configure a production process. Instead, if the modeler used all required commands to configure each process features it would be necessary 85 mouse clicks to accomplish that objective.

A simulation model was built using the generic module considering the need for model flexibility, i.e. the possibility of simulating scenarios considering different execution strategies, use of resources, for instance, and the possibility of reusing the model in other company's projects with similar features (mainly the same kind of base unit and production sequence). Other objective was allow to the production engineer to be able to test different scenarios through a user-friendly interface, in which he could change some parameters, run the model and check the more relevant results without having to know how to use the simulation software.

Using the generic module, not only input data of the model but also the simulation outcomes could be entered and accessed through a MS-Excel® spreadsheet. Thus, besides each process time to completion and the production and transfer batch sizes, the number of house blocks in which the project was grouped into, the number of dwellings in each block and the sequence in which they would be built could be easily configured by the modeler/user. Figure 06 presents part of the input spreadsheet.

| Batch's Name | Batch Size | Batch | Foundations |             |            |                              |                            | First Story Bricklaying |             |            |                              |                            |
|--------------|------------|-------|-------------|-------------|------------|------------------------------|----------------------------|-------------------------|-------------|------------|------------------------------|----------------------------|
|              |            |       | Min (days)  | Mode (days) | Max (days) | Production Batch (dwellings) | Transfer Batch (dwellings) | Min (days)              | Mode (days) | Max (days) | Production Batch (dwellings) | Transfer Batch (dwellings) |
| A            | 4          | A     | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| B            | 4          |       | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| C            | 4          |       | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| D            | 4          |       | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| E            | 10         | B     | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| F            | 4          |       | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| G            | 4          |       | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| H            | 4          |       | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| I            | 4          | C     | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| J            | 10         |       | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| L            | 4          |       | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| M            | 4          |       | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| N            | 4          | D     | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| O            | 4          |       | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| Q            | 4          |       | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| R            | 4          |       | 5           | 7           | 10         | 4                            | 4                          | 5                       | 5           | 6          | 4                            | 4                          |
| S            | 4          | E     | 15          | 20          | 25         | 10                           | 10                         | 4                       | 4           | 5          | 3                            | 3                          |
| T            | 4          |       | 15          | 20          | 25         | 10                           | 10                         | 4                       | 4           | 5          | 3                            | 3                          |
| U            | 8          |       | 15          | 20          | 25         | 10                           | 10                         | 4                       | 4           | 5          | 3                            | 3                          |
| V            | 10         |       | 15          | 20          | 25         | 10                           | 10                         | 4                       | 4           | 5          | 3                            | 3                          |
| P            | 10         |       | 15          | 20          | 25         | 10                           | 10                         | 4                       | 4           | 5          | 3                            | 3                          |
|              |            |       | 15          | 20          | 25         | 10                           | 10                         | 4                       | 4           | 5          | 4                            | 4                          |
|              |            |       | 15          | 20          | 25         | 10                           | 10                         | 4                       | 4           | 5          | 4                            | 4                          |
|              |            |       | 15          | 20          | 25         | 10                           | 10                         | 4                       | 4           | 5          | 4                            | 4                          |

Figure 6: input spreadsheet

At the other end, the simulation outcomes were designed to improve and facilitate the engineer understanding on the impacts of changes in the production system configuration. In order to facilitate the study of project's workflows study a Line of Balance could be automatically from the simulation outputs. That tool provided a direct and easy mean to visually assess any production system change. Moreover, that tool could be used to control the production system performance during the production phase as well. Figure 07 shows part of a Line of Balance devised from the simulation model.

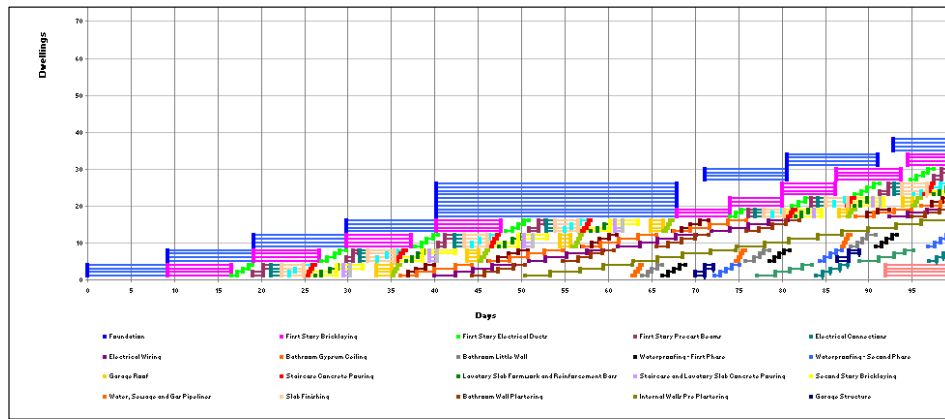


Figure 7: Line of Balance devised from the simulation model

Other tool devised from the model was a production control chart. That tool allowed the engineer to control each critical process's outcomes. Figure 08 shows that tool.

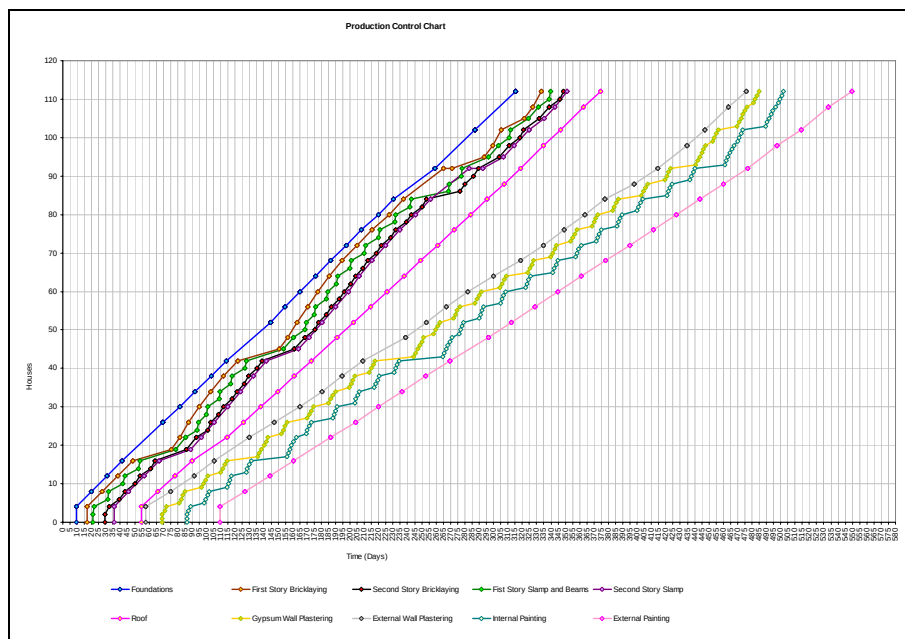


Figure 8: production control chart

Also, an S-curve can be devised from the model, allowing the production engineer assess the impacts of the production system design on the cumulative costs and expected receipt plotted against time.

## 7. DISCUSSION

Based on the case study, it is possible to point out some difficulties and requirements about the adoption of reusable simulation models in the design of production systems of construction projects.

Firstly, one of the main difficulties in using that kind of simulation models is related to the necessity of a minimum level of process standardization. In special, the case study showed the importance of establishing a sound constructive sequence in order to build a model that effectively represented the project production system. This problem is not related only to reusable models but to any model of

construction processes or operations. Thus, a first requirement to use simulation as a decision taking tool is to reach a minimum level of process standardization.

Secondly, in order to build the generic simulation module, it was necessary to include a group of parameters that could represent any construction process. Thus, besides the basic features as time to completion, required resources and their capacity, for instance, it was included the concepts of production and transfer batch size. Thus, that module could be used in any simulation model, allowing its reuse as well. Besides contributing to reduce the model building time by simplifying the use interface, the module provided a simple form to collect the more relevant data from each process which was used in a number of useful tools (line of balance, production control chart, etc).

Thirdly, although in practice the reuse of the model has not already been tested (that will be done soon), some tests that have been made and the results pointed out that this is feasible. In those tests, the researchers change some project's features, like the production start time of each house block, the number of dwellings in the project, the number and the size of blocks, and some process's time to completion.

Finally, while the generic simulation module can be reapplied in other simulation models in different contexts, the proposed reusable model has some limitations. It can only be reused if the production sequence keeps the same for the next projects. Also the model is only adequate to projects of that company or, projects with the same features.

## 8. CONCLUSIONS

A generic simulation model and a reusable model were proposed in order to improve the process of designing production systems of construction projects. A case study in which those artifacts were tested was described and the main findings and difficulties for applying that strategy discussed. The main findings pointed out to the reduction of the model development time and the flexibility in the testing of different system scenarios.

The tools devised from the simulation outcomes was designed to help the production engineer to control some key points of the project, specially workflows and project's physical advance. In that specific case, other series of tools were also devised to improve a process of mass customization the company was adopted but that was not presented in this paper.

The main difficulties to apply as simulation as reusable models are related to the need of establishing a standardized production sequence. Although that relative "flexibility" could be positive to cope with uncertainty, the lack of a standard procedure inserts also its share of uncertainty to the system, making it harder to control.

Thus, based on the case study findings, one of the main requirements to the use of both simulation and reusable models in construction is to standardize the construction sequence of the project, by discussing it during the production system design phase.

Other important requirement is the necessity of creating construction processes data gathering protocol to be used during the model building process. After a number of case studies, the research team has faced with the complete lack of historical data on the production processes. Also, in order to reach more reliable models is fundamental to enter data that could effectively feature the process. In practice, in the absence of historical data, the research team has used process's time to completion based on subjective probability from the engineer or foreman experience.

## ACKNOWLEDGEMENTS

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## ENTERPRISE SIMULATION OF THE PRECAST CONCRETE MANUFACTURING INDUSTRY

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### ABSTRACT

The lack of applied innovative tools, for improving the performance of the precast concrete products manufacturing industry, has led the researchers in this paper to develop an Enterprise Simulation Precast Concrete (ESPC) model, to improve the performance of the precast industry. As an initial stage, a detailed layout for the precast concrete production processes is developed in order to understand the relationships amongst the manufacturing processes in such industry. In addition, simulation methodology is developed to analyse the precast manufacturing system and identify the resource bottlenecks. Heuristic searching rule is developed in order to simulate the accommodation process of the produced items in a temporary stockyard area.

The results indicated low utilisation of the used resources due to using only one curing area for storage and retrieval processes.

### KEYWORDS

Precast concrete products, enterprise simulation model, discrete event simulation modelling, manhole manufacturing system, heuristic searching rule.

### 1. INTRODUCTION

The precast concrete industry in the UK is very traditional and highly influenced by the fluctuated construction market. The industry has been utilising outdated tools and methods to plan and manage production processes. This has limited the growth and development in such industry.

Production managers are calling for more advanced systems that enable them to identify and model production processes and hence identify bottlenecks and production hotspots. This should lead to a better production, higher machine utilisation, and better workflow.

In order to achieve this, a holistic Enterprise Simulation of Precast Concrete (ESPC) is proposed in this paper. The ESPC is being developed as a part of a major research initiative with the objective of improving the performance of the industry by modelling and simulating the enterprise process.

### 2. STATE OF THE ART LITERATURE REVIEW

Several research projects, using simulation technology to improve the performance of the precast concrete product manufacturing systems, have been conducted. Dawood, N., (1995) developed a scheduling model using the simulation modelling approach in order to help production managers to make better planning decisions, and explore alternative options.

Liu, L.Y., (1995), used a discrete-event simulation methodology in modelling the construction of precast-concrete parking structures. Marasini, R., et al (2001), presented an innovative stockyard layout planning system for a precise building products industry.

Vern, K., (1998) developed a simulation model to capture many of the random elements, and facilitate the analyses of complicated “what-if” scenarios, within the precast concrete building elements. Sacks, R., et al (2004) emphasised on the importance of studying the precasting processes in order to find the ways in which companies can manage businesses to achieve best performance of their production systems. Bravo, E.B., (1998) used the simulation for the production of precast pieces in a workshop to obtain several working alternatives. The main objective was to improve productivity and therefore reduce the production

costs. Shi, J.J., et al., (1998) adopted the simulation technique for modelling and simulating public housing construction in order to speed up the public housing construction process with the intention to conclude the appropriate floor cycle construction time and necessary resource combinations. Benjaoran, V., et al. (2005) proposed an integrated, comprehensive planning system called Artificial Intelligence Planner (AIP) to improve the efficiency of the process by targeting production planning as it has a significant impact to the success of business.

The limitations in the above literature are that the modelling has been focused on one part of the system and the lack of applied innovative intelligent enterprise tools where a holistic approach would be more effective.

The rest of the paper is organized as follows: section 3 describes the research methodology; section 4 presents development of ESPC model, section 5 shows the experimental work, section 6 presents results analysis and interpretations, and section 7 outlines the conclusions and future developments.

The next section will define the research methodology and other related objectives.

### **3. RESEARCH METHODOLOGY**

The aim of this ongoing research is substantially to improve the current practices of production planning by applying simulation tools and methods that will integrate the whole precast concrete enterprise.

The main objectives of the research are:

- (1) To study current processes, and develop a detailed process map of the precast concrete products manufacturing plant, in order to understand the production flow processes that exist.
- (2) Develop a system framework and a simulation prototype to analyse the precast manufacturing system and to identify the resource bottlenecks.

To satisfy the above objectives, the following methodology has been developed:

1. Data collection from the precast manhole manufacturing industry has been conducted through data collection at different precast concrete products manufacturing companies.
2. Integration Definition for Function Modelling (IDEF0) has been used to model the decisions, actions, and activities of the production processes in the precast concrete industry.
3. Discrete Event Simulation methodology is used to develop an enterprise simulation model which will enable the planners to identify the bottlenecks and to improve the productivity to achieve the best course of action.

### **4. DEVELOPMENT OF THE ENTERPRISE SIMULATION PRECAST MODEL (CASE STUDY FOR THE MANHOLE PRECAST MANUFACTURING INDUSTRY)**

#### **4.1 DEVELOPMENT OF THE ENTERPRISE SIMULATION FRAMEWORK**

The research framework is proposed in terms of how to improve the performance of the precast concrete products manufacturing system. This demonstration is useful to define the components of the proposed intelligent system and to understand how these components can be efficiently integrated with each other.

The enterprise simulation framework is illustrated as shown in Figure (1).

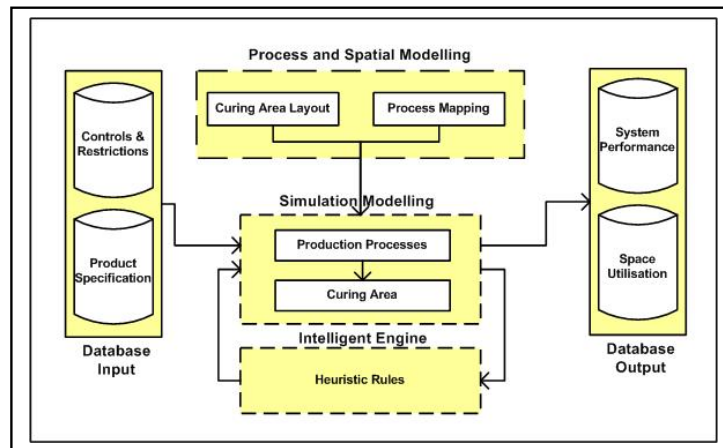


Figure 1: shows framework of the enterprise simulation model

The main core of the ESPC framework consists of:

- (1) Modelling of the processes for the whole enterprise.
- (2) Detailed modelling of the temporary stockyard area as an integral part of the production system.
- (3) Modelling of a heuristic rule as a decision rule to guide the process of accommodating products inside the temporary stockyard area.

To model the processes of the whole enterprise, a visual modelling language (IDEF0) has been developed to provide the simulation programmer with a full understanding about the relationships amongst the manufacturing processes.

By Depending on the product type, different layouts of the temporary stockyard area were drawn and sketched using AutoCAD.

A heuristic rule is developed to guide the process of accommodating products, ARENA simulation in conjunction with VBA were used to enable the modelling of this type of rule.

ESPC model is developed to improve the performance of the precast industry. Efficient management of the temporary stockyard area is required to achieve the best utilisation of the temporary storage area.

## 4.2 ENTERPRISE SIMULATION PRECAST CONCRETE DEVELOPMENT TOOLS

### 4.2.1 DEMONSTRATION OF THE ENTERPRISE SIMULATION THROUGH A CASE STUDY

The purpose of the developed case study layout is to provide a framework for applying logic that can simulate each of the manhole manufacturing sub-systems individually. See figure (2)

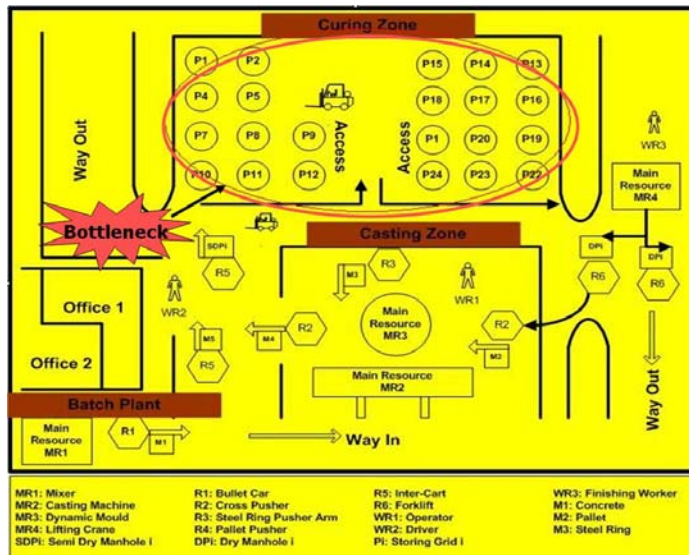


Figure 2: The layout of the case study.

In the layout showed in figure (2), the manufacturing system is consisting of three main zones: batch plant, casting, and curing zones.

In this first zone, the mixer works with the bullet car (mix transfer car) in order to provide concrete to the casting zone. A set of transporters are working together in the second zone to form the final shape of the produced manhole in terms of mould and other details. The third zone is temporary stockyard which used to accommodate products temporarily. (For more details, see the process flowchart in the next section)

#### 4.2.2 PROCESS FLOWCHART

Manufacturing of precast product elements is essentially performed in a job-shop environment. That is, the produced manhole has several variants depending on the order type. The production stages and details about the manufacturing processes are described in figure (3).

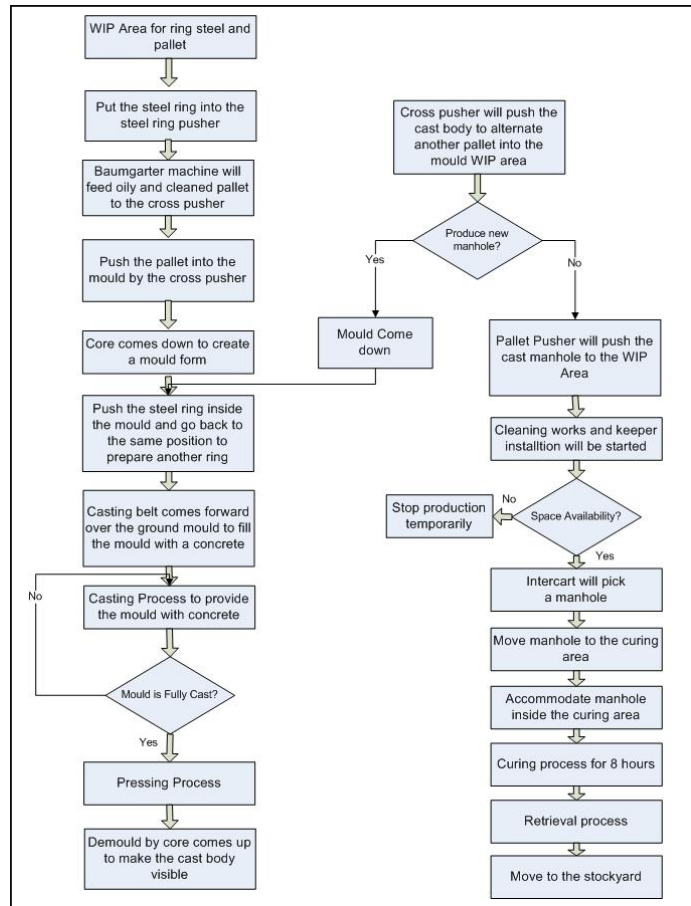


Figure 3: Flowchart represents the details of the production processes

The production process starts when the concrete material is moved from the mixer (main resource) using a special vehicle called a bullet car in order to provide the casting zone with the concrete required for casting.

At the casting zone, several mechanical operations are carried out to form the final shape of the manhole. Cross pusher performs the first activity to position the pallet assigned for each manhole. The dynamic mould is the second movement which takes place after the pallet is positioned to form the circular shape of the manhole ready to receive concrete. Before the casting process, a steel ring is placed inside the mould using a steel ring pusher arm by a positioning device.

The casting process is started when the concrete from zone one is received via a bullet transporter car. After the mould has been filled with concrete, a pressing shaft applies pressure to press the concrete inside the mould under vibration to form the manhole into the final shape. The manhole after pressing is pushed by the pallet pusher to enable finishing works to be conducted by two operatives.

A lifting transporter called an InterCart is used to grab the cast manhole, and transport / position it into the storage grid inside the curing area.

There is an access bottleneck in the storage and retrieval processes due to the limited space capacity in the curing area. The objective of the research is to optimise the curing area space utilisation in order to achieve the maximum output possible within the space constraints.

### 4.3 MODEL ASSUMPTIONS

In order to simplify the modelling process, assumptions were made while constructing this model, some examples of them are:

- Each order is processed by the same processing machines.
- All manufacturing machines can process one manhole at a time.
- Machine failure is not considered in this study and idealistic machines were assumed.
- The process setup time of the machines is considered in this model.
- All work process take place over a 24 hour period.
- Raw materials are already available at Work In Progress (WIP) Area.

### 4.4 DATA COLLECTION FOR ESPC SIMULATION MODEL

The fundamental conceptual approach used was to obtain reliable information about the duration of each production cycle and the resource that employs. The tools used were: *Time study* to measure the machine cycle, *Work Sampling* to measure the human work, *IT tools* (AutoCAD 2007) to estimate the distances from the casting zone to each of its storage places.

All information required in the ESPC model was gathered by conducting an on-site data collection. On-site measurements using measure tape were carried out to determine the scale of the job-shop. A scaled map of the manufacturing system was drawn using AutoCAD to estimate the distances between the casting machine and each storage place (in the form of a grid). Crane X,Y, and Z axis distances were estimated using AutoCAD. The intercart transfer vehicle paths and routes were determined after structured interviews with the intercart driver and curing area workers. See figure (4).

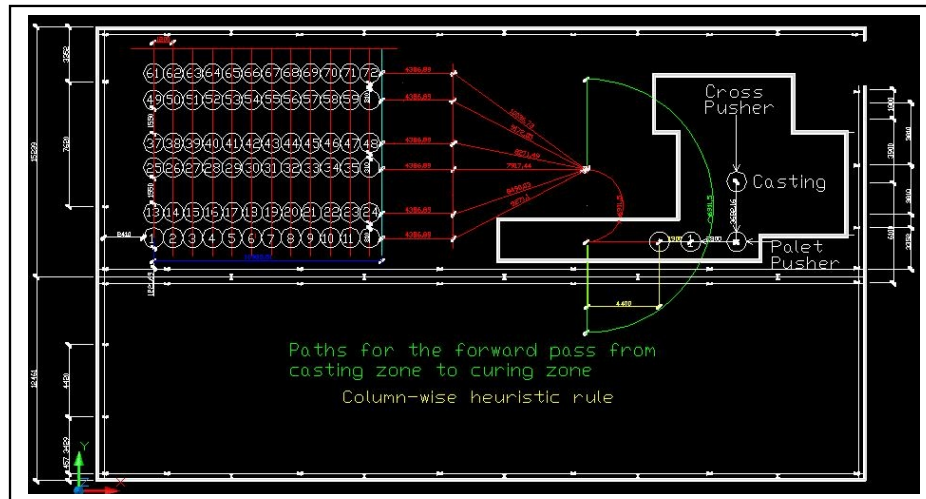


Figure (5) shows the application of ARENA simulation software.

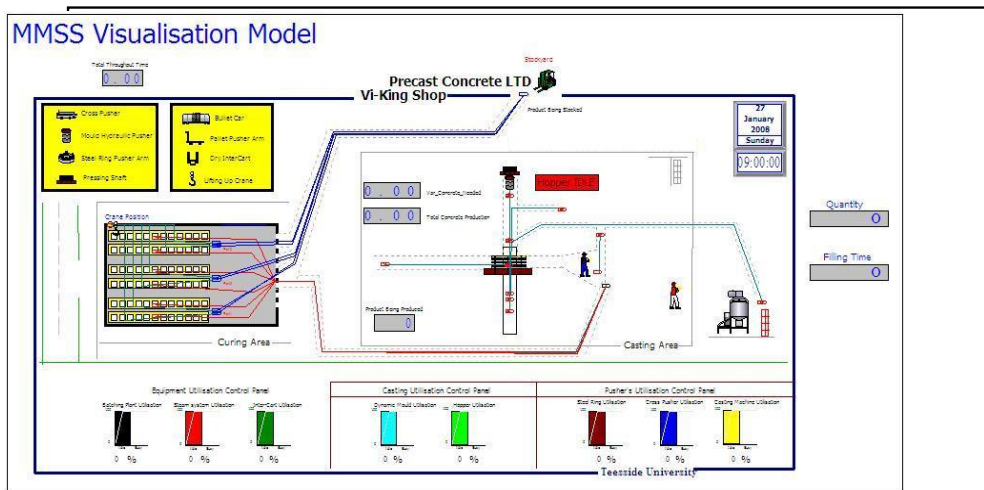


Figure 5: Snapshot of the ESPC model

#### 4.6 SIMULATION OF THE CURING AREA

As an integral part of the production system, the curing area is considered to be simulated in conjunction with the production system. This type of integration will enable the production planner to maximise the efficient use of the curing area in terms of space utilisation to increase the production productivity further. In the temporary stockyard area, each storage area is modelled as a resource. A set of twelve resources will form a storage zone. Six zones are considered as the whole storage capacity for the curing zone. See figure (6)

The temporary stockyard resources are: a grid of storage (12×6) places, intercart, forklift and overhead crane. Constraints on the storage and retrieval processes, are:

1. The intercart has its own paths in order to reach the curing storage places.
2. Some of the paths are identical and others are not depending on the curing area occupancy.
3. Retrieval process start after the whole curing area has been filled.

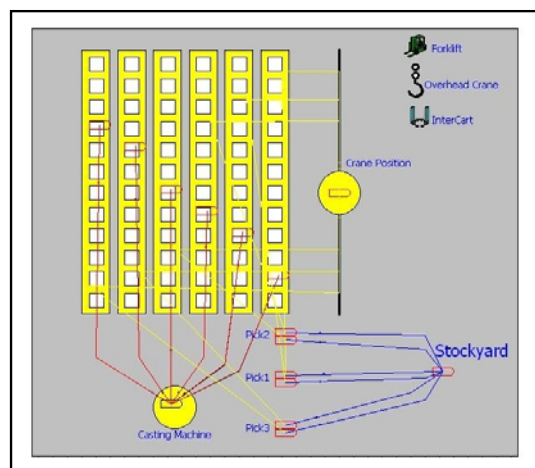


Figure 6: Snapshot of developed temporary stockyard simulation model (Part of ESPC model)

In figure (6), the applied storage rule was a column-wise heuristic storage rule. The retrieval heuristic rule used a First-In First-Out (FIFO) strategy.

The dry manhole is placed in-front of its zone (one over one) to be picked up by the forklift. (Two manholes in one go)

The difficulties faced in developing this type of simulation were:

1. How to accommodate manholes in each of those zones sequentially.
2. When to start retrieving manholes from the curing area.

The challenges in developing ESPC model were:

1. How to changeover between production process and the storage process.
2. How to synchronise the production rate with the capacity of storage area.
3. How to sustain the working of a production system as long as possible.
4. How to avoid clashes between curing area resources and the production process resources.

The simulation model was developed for each zone individually (*batch*, *casting* and *temporary stockyard* zones) as sub-models depending on the complexity of each sub-system. The sub-models then were simulated and combined together to generate the Enterprise Simulation Precast Concrete model.

#### 4.7 MODEL VERIFICATION AND VALIDATION

Initial verification was carried out by tracking the animation of the entities using a trace function to track entities through the system, this technique is used to ensure that all entities are travelling to the proper location in accordance with the entity flow diagram. Additionally, to ensure the model accurately reflected the data supplied and that it generated the outputs required by the conceptual model. Two separate structured interviews were conducted: one with the production manager and other with a wider group of operators, to access the impact of the simulation on the users was performed during the validation procedure.

The validation was performed by comparing the actual time value of a cycle for a manhole with an estimated value obtained from simulation. From this outcome, was proven that the model reflects actual cycle time of the selected processes sufficiently and accurately.

#### 5. RUNNING THE EXPERIMENTAL WORK

The following scenarios are considered after detecting the bottlenecks that were yielded due to the restrictions of the curing area in terms of space and other restrictions.

1. *Scenario 1*: Using one InterCart transporter to move out each produced manhole from the casting zone to the curing zone.
2. *Scenario 2*: Use of two Intercart transporters working together in moving the produced manholes.
3. *Scenario 3*: Use of the fastest InterCart transporters to speed up the process of moving the manholes to their storage grids.
4. *Scenario 4*: Use an additive material\* to speed up the curing process.

By running the simulation model for each scenario, their effects can be determined in terms of “throughout time” and “utilization of resources”. Figure (7) shows the reduction in total throughput time by running scenarios 1,2,3, and 4.



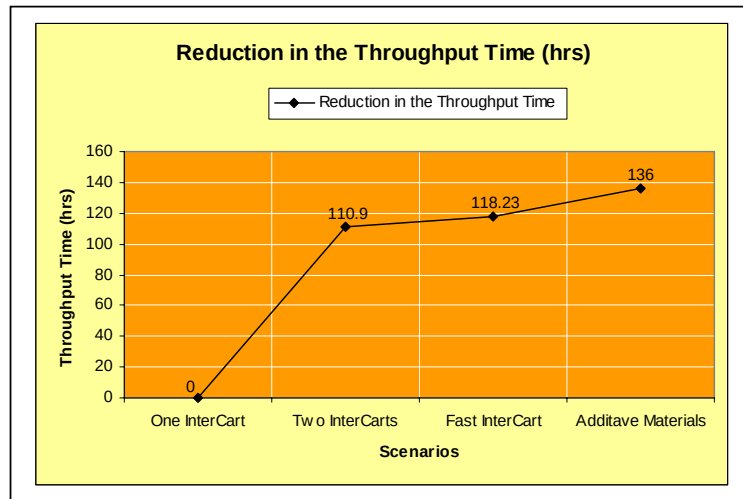


Figure 7:

Represents the effects of adopting various curing area resources

Figure (7) reveals that scenario 4 has the maximum reduction (136hrs) out of 795.51 hrs. It means that by adding some additive to the concrete, the process of curing manholes will be faster which reflect the influence of running scenarios on the production flow.

The continuation of resources working in any production system has a great effect on the utilization of the resources used especially those in the production zone. See figure (8)

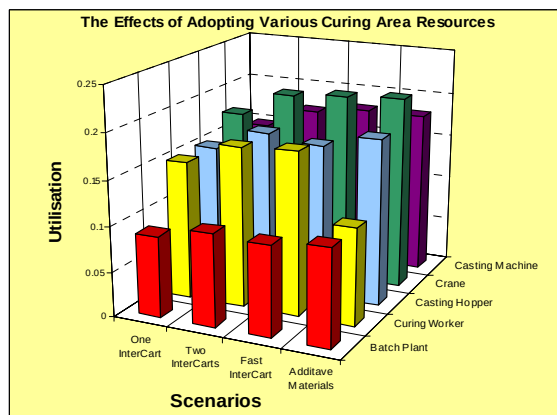


Figure 8: Represents the effects of adopting various curing area resources

\* Additive materials were used here to speed up the curing time while maintaining the quality of the product within the industry quality standard.

The best scenario in terms of maximizing the resource utilization was scenario 4. The resources utilization shows the effect of adding additive materials in speeding up the curing process by minimizing the curing time. Casting machine, batch plant and other production resources were improved in terms of utilization. Crane resource utilization is improved as well by providing a minimum curing time which diminishes the idle time of the crane.

## 6. ANALYSIS AND INTERPRETATION

The results above indicated low utilization of the used resources, and maximum throughput time. This bottleneck in the production system is caused due to using only one curing area for storage and retrieval processes. The problem is that, the production system is stopped each time the curing area is filled and that issue increases the idle time of the production resources. The production will not be started until all products have been removed from the curing area for health and safety purposes. The retrieving process

in the curing area is not allowed until the whole curing area is filled by manholes. The limited capacity of the curing area in terms of space, resources and other restrictions has caused the reduction in resource utilization and subsequently maximizes the total throughput time.

## 7. CONCLUSIONS AND FUTURE DEVELOPMENTS

### 7.1 CONCLUSION

The purpose of the study was to develop an Enterprise Simulation Precast Concrete model for a manhole production system as a case study. The production system was modeled using ARENA to identify bottlenecks and evaluate curing area performance.

In spite of the slight improvement in the performance of the manufacturing system, the curing area is still a crucial factor which needs to be deeply investigated in terms of the way of storing and retrieval products is undertaken, which will be the main functionality of the intelligent searching rule.

More intelligence is needed to investigate and run more scenarios in terms of investigating more alternatives.

### 7.2 FUTURE DEVELOPMENTS

Another curing area will be considered and simulated to be worked together with the first one. Both of them will be working alternatively, one for storage when retrieving the other and vice versa. This solution will ensure the production system in terms of resources will be worked in a more continuous manner. Less idle time will be associated with waiting for the products to be cured and retrieved.

Different layout regarding the way of storage will be investigated as a later stage in this project. Column wise storage layout is adopted in this research, row, column block set, row block set, and clock-wise layout will be adopted to determine the best storage method and the fastest retrieval operation.

The optimization engine will be developed to optimize the performance of the manufacturing system by manipulating of the number and capacities of the used resources, a different layout for storage pattern, and various loading rules for both orders and the retrieval process. Therefore, a sequencing algorithm will have to take into account the effect of a lot of combinations. To solve this problem, an approach that combines simulation and an optimization engine in terms of heuristic rules to generate sequences of storage strategy, that leads to optimal or close-to-optimal performance, will be adopted.

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## **CITAX: A COLLABORATIVE ICT STANDARDS MODEL FOR THE IRISH CONSTRUCTION INDUSTRY**

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### **ABSTRACT**

The Irish construction industry is facing a series of fundamental challenges that is affecting every player in the AEC lifecycle, from architects to engineers to quantity surveyors to owners to tenants. Despite technological advances in recent years, the Irish construction industry lags behind other industries in respect to ICT investments. Although there is a pressing need for innovation, existing procurement and tendering procedures in Ireland largely discourage new ideas and put further pressure on thin margins that characterise the competitiveness of the construction sector. The low level of inter-company ICT connectivity reflects the general fragmented and adversarial nature of the Irish construction industry, where the absence of dominant players has precluded the imposition of de facto inter-company ICT standards, as has been the case in the retail supermarket sector. This paper will present the results of a two-year research project which sought to demonstrate that, by the adoption of readily available ICT tools, particular business processes in construction could be dramatically improved. The paper goes on to describe the opportunities and challenges that have arisen as the project draws to a close. It will, in particular, focus on the introduction of ICT standards within the Irish construction industry. The ultimate goal is not only to have ICT standards in place, but also to provide the impetus to ensure that as many stakeholders as possible use them. How this might be achieved is also part of the project and its success will be judged by the extent of the adoption of the standard by the industry.

### **KEYWORDS**

Construction, ICT standards, re-engineering.

### **1. INTRODUCTION**

The Irish economy has come to rely heavily on the construction sector with the result that construction accounts for a sizeable proportion of economic activity. The direct contribution of the construction sector to the Irish economy was almost €35bn, or 24% of GNP, in 2007 (DKM, 2008). The buoyant construction industry in Ireland has resulted in many of the larger industry players operating internationally with the majority of work being done by local or national Small to Medium Enterprises (SMEs).

It has been extensively reported by many authorities that the exchange of data between project teams in the construction industry is not efficient (for example, Latham, 1994; Gunnigan et al., 2004; NIST, 2004, Hore and West 2005a and Hore and West 2005b). There are many millions of documents (such as drawings, specifications, bills of quantities, correspondence, schedules, programmes) currently exchanged in paper form between Irish practitioners. It is commonplace that each of these documents are subsequently re-keyed, photocopied, scanned and filed, as they pass between different locations and computer applications (Hore and West, 2005c).

There is an array of collaborative initiatives globally seeking to introduce interoperable data exchange standards within the AEC/FM sector, through organisations such as the Construction Industry Institute (USA); VTT (Finland); Construct IT (UK), Construction Excellence in the Built Environment (UK). The International Alliance for Interoperability (IAI) is a global coalition of industry practitioners, software vendors and researchers who collectively promote the need for information to flow from one computer to the next throughout the life cycle of a construction project. The IAI have developed Industry Foundation Classes (IFCs) for both product and non-product data exchange standards to enable them to be adopted in the industry (Froese, 2003).

This paper will outline the progress of a particular project managed by the Construction IT Alliance (CITA) in Ireland, a group that is endeavouring to promote ICT standards in the Irish construction industry. The project, known as the CITAX (CITA eXchange) project, is a two-year collaborative project involving twenty five CITA member organisations who are seeking to demonstrate that significant measurable economic improvements can be achieved by using readily available ICT tools to radically improve business processes in the Irish construction industry. This paper will specifically focus on the progress being made by CITA in delivering these ICT standards. It will be seen that although good progress has been made, a formal implementation of ICT standards has not yet been achieved. The barriers to its introduction will also be examined.

## **2. DEVELOPING ICT ADOPTION IN THE IRISH CONSTRUCTION INDUSTRY**

At present the extent of use of ICT in the Irish construction industry is relatively unsophisticated, mainly dependent on telephone, facsimile machines and networked personal computers (Thomas, 1999). At the simplest level, the electronic transmission of business documents offers savings in paper and postage (Hore and West 2005a). By going a step further, businesses can make strides in communicating with their partners, at relatively low cost, through direct links (internet or intranet) between their computers (Hore and West, 2005b).

The opportunity to enhance efficiency in a fragmented industry by working together has been recognised by the government and industry leaders. Consequently, CITA was formed to focus on the promotion of ICT in the Irish construction sector. Having its origins in the Dublin Institute of Technology, CITA is now an independent company whose membership currently comprises in excess of 140 corporations drawn from a broad cross-section of the Irish construction industry, including architects, engineers, contractors, suppliers, clients, ICT companies, government departments, state agencies and third level institutions. The main source of funding originates from membership subscriptions with other income sourced from training courses and sponsorship of events. The main activities involve organising bi-annual member meetings, training courses, information dissemination through the organisations website and online newsletters and promoting the work of its Special Interest Group (SIG) network. The Alliance aims to encourage participants in the Irish construction industry to take full advantage of current and emerging ICT (Thomas and Hore, 2003).

## **3. ICT INTEGRATION AND THE NEED FOR COMMUNICATION STANDARDS IN CONSTRUCTION**

Competition from international firms, as a result of increased globalisation, has prompted a renewed focus on improving general performances within the construction industry, both in Ireland and in the United Kingdom. For over 10 years the question that is often asked is why, when other industries have successfully made use of ICT, construction has been so slow to do the same (see, for example, Latham 1994, Egan 1998 and Building Centre Trust, 1999)

There is broad agreement that the nature of the construction industry is different to other industries, such as the manufacturing or retail sector, where processes and the working environment are well defined and controlled (Gann, 1996). The temporary nature and uniqueness of construction projects is reflected in one-off locations, designs solutions and project teams, which leads to a very fragmented communication platform (see Figure 1). This has led to poor communication and inefficient information practices that have contributed to the emergence of dysfunctional supply chains (Love et al., 1999).

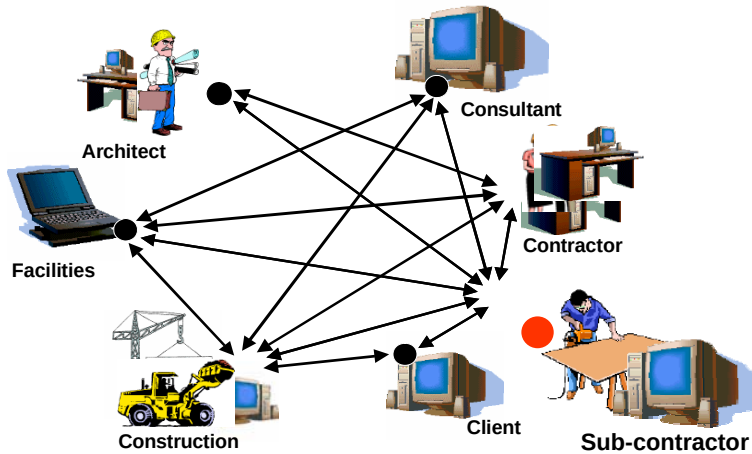


Figure 1: Fragmented nature of the construction industry (Sarshar et al., 2000)

A study by the US National Institute for Standards and Technology (NIST, 2004) has estimated that the cost of not having interoperability in the US Capital Facilities industry is about \$15.8 billion per year. This has stimulated many major construction clients in the US to develop a national Building Information Modelling (BIM) standard. In both Finland and Denmark, for example, there has been a major commitment by the public sector and large construction process stakeholders to the adoption of Industry Foundation Classes (IFC) (Howard and Bjork, 2008). This, in turn, has created challenges for the application of ICT in the Irish construction industry.

It is now becoming accepted that the preferred communication model for managing information on a construction project should be based on a central project model, through which all the information is disseminated (Figure 2).

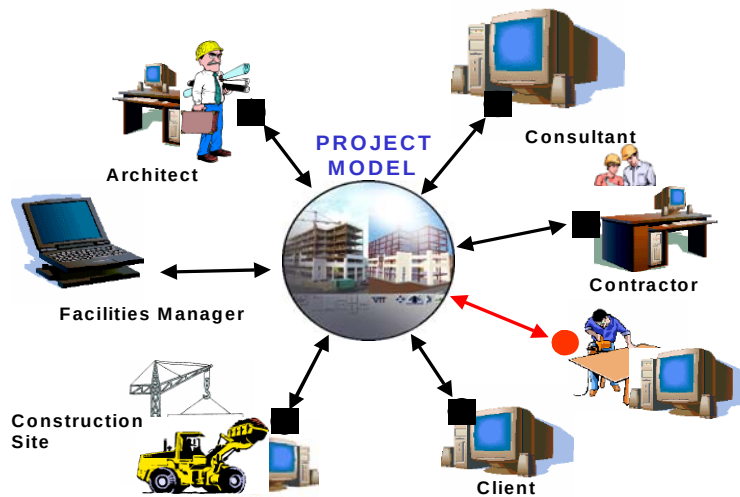


Figure 2: Preferred communication model for construction (Sarshar et al., 2000)

Construction sectors in many countries around the world are increasingly recognising the importance of ICT. ICT is improving the capability and efficiency of specific aspects within the construction process. It also has the potential to vastly improve communication throughout the construction process through electronic dissemination of information (West and Hore, 2007). ICT should support the entire construction process from inception through to the operational maintenance of the building asset. Figure 3 illustrates the integrated nature of the project model across the construction project life-cycle.

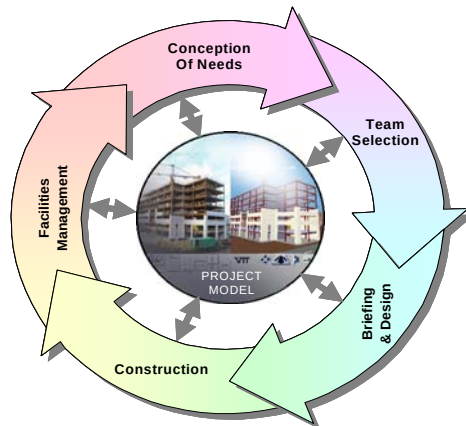


Figure 3: Project model for construction (Sarshar et al., 2000)

Representation of all the information needed to describe buildings throughout the design, construction and facilities management of a construction project has long been an objective of those applying ICT in building (Eastman, 1999). With the establishment of project information standards, the information becomes more compatible with the receiving party's systems. Consequently, the amount of information contained within the documents that can be re-used becomes greater (Building Centre Trust, 2001).

The core driver to IT integration is the establishment of common standards for the exchange of information. It is the lack of information exchange standards that prevent systems from communicating with each other and from information being exchanged effectively within the industry. Developing standards in a fragmented industry such as construction is extremely difficult and is hampered by commercial interests, which often naturally oppose standardisation for very sound reasons, such as the need to recoup investments in software developments.

The goal of the single building information model has existed for over thirty years and various standards have been published leading up to a ten-year development of the IAI and the IFCs (Howard and Bjork, 2007). The IAI and IFCs have been the most ambitious programmes for standardising object models in buildings, but neither the standard nor product modelling is widely used in industry. There is also highly differing views among researchers as to the optimal structure of BIM-models (Amor and Faraj, 2000). The IFC standard has been adopted by the majority of the large CAD vendors and in several countries there are strong government-level policies in place to ensure the adoption of the standard (Amor et al., 2007).

#### 4. THE SEARCH FOR ICT STANDARDS IN THE IRISH CONSTRUCTION INDUSTRY

From the early years of CITA, the organisation has promoted the need for universal protocols and standards. One of the earliest achievements of the Alliance was the development and promotion of its own CAD Layering Convention. Based on a standard used by a Dublin-based architectural firm, CITA expanded the convention to include layers that are also relevant to structural/civil and building service engineers. The standard quickly became adopted by a number of key architectural practices and local authorities in Ireland. It was also adopted by The Royal Institute of Architects in Ireland in their best practice guidelines in 2003.

Beheshti et al. (2003) defined the word "standard" as "either widely recognised or employed as a model of authority or excellence". However, the development of ICT standards in construction has been slow

and lacks general agreement. This is mainly due to the lack of dominant players resulting from the fragmentation of the industry.

In 2006 CITA carried out a survey among architectural and engineering practices as to the extent of use of the CITA CAD layering convention (Kenny, 2006). In excess of 40 responses were received from a total sample of 86 practices. At the time of the survey the uptake of the convention was relatively low with only 20% confirming their adoption of the standard. When asked about the barriers which undermined the adoption of the standard in the respondent's organisation, the following reasons were given.

- Lack of time to implement such a standard (30%).
- Uncertainty about how to measure the costs and benefits of such investments in time (18%).
- A general lack of awareness of the benefits that a CAD layering convention can bring to the Irish AEC industry (18%).
- Lack of promotion of the layering standard by professional bodies, clients, the government and state bodies (18%).
- Conventions are currently not yet reliable in design (15%).
- Employees are likely to resist the introduction of a CAD layering convention (12%).

Despite the clear presence of such barriers, 76% of construction professionals responding to this survey testified to being aware of the CITA CAD Layering standard. In order to further build upon this awareness, respondents were asked to rate a selection of strategies that CITA might adopt in order to gain a more widespread adoption of a CAD layering convention. The following strategies were identified, in order of preference:

- Work with professional bodies in promoting the convention.
- Promote the adoption of the convention by government and state bodies.
- Carry out a pilot study on a live project in order to review its performance and measure the business benefits of its application.
- A panel of experts should be appointed to review the CITA convention and report on its strengths and weaknesses.
- Instigate a CITA public relations programme to promote the convention.

This example of implementation of communication standards by CITA within the Irish construction industry is a useful lesson to further plans to implement other standards in the sector, such as e-procurement, e-tendering and Building Information Modelling (BIM).

## 5. CITAX PROJECT

An additional example involving the CITA eXchange (CITAX) project sought to verify that significant measurable economic benefits can be achieved by collaborating trading network members by the use of existing ICT standards in their business processes (DETE, 2006, West and Hore, 2007 and EC, 2007). The CITAX project focused on five module areas:

- Module 1 - Production and exchange of CAD drawings.
- Module 2 - Production and exchange of trading documentation, such as purchase orders, goods received notes and invoices.
- Module 3 - The pricing of tender documentation electronically and recommendation of a preferred tender for selection.
- Module 4 - The storage, retrieval and general dissemination of project information on construction projects.
- Module 5 - The use of CAD software in the production of bills of quantities.

Each module involved a Project Leader drawn from industry together with a cross section of companies from different disciplines, including the support of an academic institution. Figure 4 illustrates, at a high level, the methodology adopted in the project. CITAX has a clearly structured plan, describing tasks, schedules and responsibilities for each of the module teams.

Con formato: Numeración y viñetas

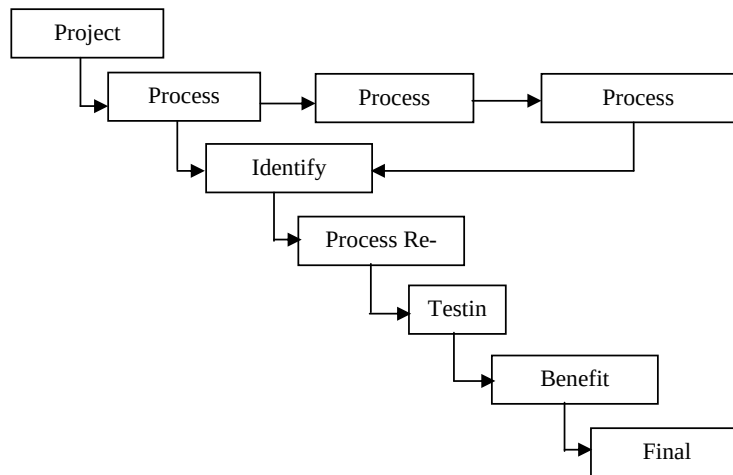


Figure 4: CITAX Methodology

An example of work on ICT standard implementation was carried out by the module 2 team investigating implementation of e-procurement, which focused on the following objectives:

1. Develop a universally acceptable XML standard for electronic exchange of purchase orders, delivery notes and supplier invoices.
2. Demonstrate, by participation in a live pilot project, that purchasing data transactions can be more efficiently exchanged between trading network members by the adoption of the XML standard.

One of the most significant challenges for the CITAX module 2 team was how to tailor-make a suitable XML standard that would be acceptable to the vast majority of players in the Irish construction sector, especially as many traders are small enterprises. For the adoption of a common XML standard to be widespread, it was important that the companies participating in the project would define and agree sets of message sets for each of the stages of the trading process.

The module team identified a number of messaging formats that needed to be agreed among the participating companies, with the intention of developing a CITAX XML Trading standard (see Table 1).

| Message Type       | Message Content                                                                                                                                                                                                                                                                                                                                   |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Order              | Order messages are created by the contractor and sent to the supplier.                                                                                                                                                                                                                                                                            |
| Order Confirmation | On receipt of an order from a contractor, it is created/saved on the supplier's system. Confirmation of the details recorded/received is transmitted back to the supplier. This can include out of stock notifications. This message can also be used to create an order on the contractor's system if it has not been recorded there previously. |
| Order Cancellation | Used to cancel an order that had previously been sent through from the contractor.                                                                                                                                                                                                                                                                |
| Shipping Notice    | An Electronic Shipping Notice (eSN) is an advice from the supplier to the contractor listing the items that are to be delivered. It is effectively the supplier's dispatch note and is transmitted in advance of the delivery as soon as the dispatch details have been verified by the supplier.                                                 |
| POD                | A POD (Proof of Delivery) is a document that lists items delivered together with the contractor's signature, captured electronically. It is the basis on which contractors can be invoiced for items delivered.                                                                                                                                   |



|             |                                                                                                                                                  |
|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| GRN         | A GRN (Goods Received Note) is the contractor's equivalent of the POD, i.e. it shows from a contractor's perspective what was delivered to site. |
| Invoice     | Document that charges the contractor for items delivered.                                                                                        |
| Credit Note | Document that credits the contractor account for items such as pricing corrections; credit for items not received; or credit for damaged items.  |

Table 1. CITAX Module 2 XML Message Formats

XML standards have been developed in several industries, such as business, retail and also the building and construction industry. For example, the Building and Construction XML (bcXML) (Tolman et al., 2001), Electronic Business XML (ebXML) (Lima et al., 2003) and Industry Foundation Classes XML (ifcXML) (Froese, 2003). These standards are essentially shared vocabularies and rules for defining the structure, content and meaning of similar XML documents. XML is extensible because each element of data is separately identified, all of the elements do not have to be present in the message, only the elements that are required by the message definition, the XML schema.

Having reviewed the standards available, the team chose to use as a base the BASDA eBuild XML standard. A variety of other standards were reviewed such as EDI and GS1 XML, but the eBuild XML standard is currently used widely in the UK construction industry, although there are a number of new messages that will have to be developed by CITA, particularly for PODs and GRNs. It has also become apparent that the proliferation of standards means that each organisation that trades electronically has to have a flexible system that caters for all of the other standards in the marketplace. The possibility of universal buy-in to one common XML schema, though difficult to achieve, has obvious advantages and is vital to successful industry-wide implementation.

To achieve this buy-in there needs to be a business impact of adopting XML technologies. For any company that shares information with its customers as a critical part of the value chain it delivers, the creation of a single source of information from which you can deliver to all current and future messages. The benefits can both increase revenue and decrease costs.

CITA have through a new eCommerce group which has facilitated dialogue between the Irish construction supply chain, which otherwise would not have been possible. The methodology currently adopted by the CITA eCommerce group to ensure buy-in includes:

1. Secure contractor and supplier commitment within the Irish construction supply chain.
2. Establish a steering group to manage the direction of eCommerce implementation.
3. Agree infrastructure for messaging formats and exchange mechanisms.
4. Initiate implementation programme with steering group members.
5. Prove business case in eCommerce among a wider supply chain.
6. Elicit support from industry bodies and lead construction businesses.
7. Rollout implementation across the industry.

The module team are currently organising the pilot or testing phase, engaging with software users and vendors. Presently there are two pilot projects underway that will adopted the eBuild XML standard. The unwillingness of some software vendors to interoperate with other software companies is a very significant hurdle that has to be overcome by the industry. Current clients of the software company see that they cannot achieve a comprehensive rollout of e-procurement with their suppliers because of this issue.

Preliminary findings from the project demonstrate that there are significant opportunities for increased efficiency and effectiveness in the industry. A strong business case has been made for ICT adoption, through:

1. Accelerating the industry adoption of CAD standards, electronic commerce, electronic tendering, electronic collaboration and computer aided measurement within the Irish construction industry.
2. Accelerating the industry adoption of product data standards sets that will support electronic commerce activity within the Irish construction industry.
3. Accelerating the adoption of interoperable building information model-based software through testing and demonstration.

4. Establishing methods that facilitate the harmonisation of existing building information modelling and bring consistency to the construction industry's efforts to integrate the supply chain with common information models.
5. Assisting the Irish construction industries in developing and implementing interoperability standards and work process improvements that reduce the life cycle time, costs and risks.

All modules have completed phases 1-5 and most are completing their benefit evaluation and are in the process of preparing their final report. There is one module team that is currently waiting for software availability to undertake its pilot, but it will complete its work in June. The project teams went beyond their original project scope to incorporate cost and time estimates for both existing processes and for the revised processes that have been developed as part of the work of the project teams. These cost estimates strengthen the business case for adopting the output from the project teams, because they clearly demonstrate the savings and operational benefits that accrue from the revised processes. The teams are now working on their final reports that will document the work that they have undertaken which will include:

1. An introduction to each project.
2. Analysis of existing industry practice.
3. Estimated cost of current practice.
4. A revised process that eliminates the inefficiencies identified in current practice.
5. Estimated cost for the revised process and identification of the savings that are possible.
6. Details of the pilots that were undertaken to prove that the revised process works.
7. Recommendations from the teams.

## **6. STRATEGY FOR IMPLEMENTATION OF ICT COMMUNICATION STANDARDS IN IRELAND**

Having demonstrated the business case for both contractors and suppliers to adopt ICT in their conversion to e-commerce practices, the key to success in implementing any ICT standards involves reaching cross-community agreement on a willingness to participate through:

1. A strong commitment from leading construction industry companies to collectively rather than individually take a lead and actively participate in the implementation.
2. Demonstration of the potential impact of ICT standards in
  - a. Creating a step-change in communication efficiency for all parties to the supply chain
  - b. Developing new or adoption of existing international standards
3. A willingness of suppliers to adopt the new XML standards for document exchange in their purchasing software and to invest in developing a supplier-specific product code database for ordering.
4. An openness of all major software vendors associated with participating contractors and suppliers to alter their software to accommodate the new XML standard. The work undertaken by the software vendors must be financed by the demonstrable efficiency gains of the contractors and suppliers on implementation of the new e-purchasing practices.

An example includes creating generic codes for products to which both suppliers and buyers would map their product codes. This would mean that buyers and suppliers would only have to map their codes once. Through CITA a wide platform has been created which has facilitated dialogue between these three parties, which otherwise would not have been possible. Therefore, the challenges facing the Irish construction include:

- develop tools, protocols and standards which are non-proprietary and which facilitate interaction between participants in the industry.
- define and promote standards in data communications.
- through piloting, measurement and demonstration, promote building information modelling across the industry.
- identify and design services and products which will enable the participants in the industry to work collaboratively through the supply chain in Ireland and internationally.

Despite these challenges, it is likely that the industry will begin adopting ICT standards in the short term, although it is recognised that it will take time to filter through the entire industry. The adoption of e-procurement by a sufficient threshold of parties is likely to catalyse others in the market because the use of e-procurement will be seen as a providing competitive edge, much as quality assurance schemes did in the 1990s.

## 7. CONCLUSION

There are some serious challenges facing the construction industry that are motivating new approaches to how one designs, builds, operates, and maintains buildings and infrastructure. While new ICT solutions are designed to address challenges in the construction industry, there is not an integrated approach to its implementation.

The aim of the CITAX project is to prove that the benefits of widespread ICT deployment within the construction sector will benefit all companies participating in electronic exchange and cooperation. The strength lies in involving both ICT providers and companies from both sides of the construction sector. The active involvement of companies from throughout the sector facilitate the dissemination of project results not only to those firms, but also among their suppliers, customers and partners, generating impact beyond the direct participants.

The advancement of data and information standards facilitates the knowledge development process which requires a group effort. The fragmented nature of the construction industry is a major impediment in this process. However, developing universal standards is essential for the construction industry. Any ICT standards must ensure collaboration and continuing commitment among the participants. The involvement of numerous stakeholders causes organisational problems, and imposes the need for consistent highlighting of the “win-win” outcome for the participants over and above any individual and conflicting interests. Effective management and administration of the ICT standard roll-out is also necessary for marketing and for spreading information, so that the standards becomes widely known and accepted in the industry.

The experience of working on the CITAX project identified a number of ingredients that must be present for successful diffusion of ICT standards in the construction industry. Developing an e-business policy initiative requires sectoral understanding and commitment that only industry can provide. A sectoral focus helps to create a critical mass as single firms are very limited in their ability to innovate without the cooperation and alignment of the wider construction community. The longer term objective of CITA is to develop a platform for the design, development and implementation of open standards that would be fully utilised within the Irish construction supply chain. This project has demonstrated what actions might be required to achieve this prize.

## ACKNOWLEDGEMENTS

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## POSSIBLE BENEFITS OF WEB 2.0 TO CONSTRUCTION INDUSTRY

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### ABSTRACT

Despite the fact that it has taken a long time for construction industry to enter the information era, information technologies (IT) significantly changed and still changes the way professionals in building and construction (BC) industry work. Consequently, construction industry is in relatively early phase of adopting web-based technology, even though the web has already moved deep into its second phase.

During the recent years, a phenomenon of Web 2.0 attracted a lot of attention not only in the Internet, but also in business community. It is considered as a next step and a major evolution of the traditional web from both a technological and social perspective. New on-line applications not only make tasks as individual and group on-line learning, communication, collaboration and creation easier, they also have the capability of upgrading the experience by using the vast amount of information from the Internet, previous sessions and so called collective intelligence of its users.

The possible benefits of adapting Web 2.0 technologies, principles and strategies into construction industry are numerous. Using new approaches can affect marketing strategies, data and information exchange, customer contacts, life cycle management, knowledge management and can result in substantial savings in time and money, customers' satisfaction, improved internal and external communication and collaboration, etc. What is more, shift towards modern web can also have a positive impact on the name and brand of the company.

This paper presents the concepts which can affect the way how construction industry currently works and the key reasons why the AEC community should seriously consider the shift towards the next generation of the web.

### KEYWORDS

Web 2.0, Enterprise 2.0

### 1. INTRODUCTION

Information and communication technologies (ICT) nowadays have a great impact on building and construction (BC) industry and the way it works despite the fact that it has taken a long time for them to enter the information era. ICT Technologies in BC industry are now mainly used to support traditional tasks, to ease communication barriers, find relevant information and to speed up processes. Majority of work supported by ICT is done inside relatively closed networks and Intranet. In-house developed software solutions installed either on servers or working machines are used in spite of all the benefits current web-based tools are offering. Consequently, construction industry is in relatively early phase of adopting modern web-based technology, even though the web itself has already moved deep into its second phase.

While AEC sector was struggling to adopt and take advantage of the use of IT and ICT tools supporting everyday tasks in the industry, powerful new ways of using the Web and the internet for various reasons

(including solving problems and supporting every day business processes) have emerged. This new wave of web applications and services is known as the Web 2.0.

The possible benefits of adapting Web 2.0 technologies, principles and strategies into construction industry are numerous. Using new approaches can affect marketing strategies, data and information exchange, customer contacts, life cycle management, knowledge management and can result in substantial savings in time and money, customers' satisfaction, improved internal and external communication and collaboration, etc. What is more, shift towards modern web can also have a positive impact on the name and the brand of the company.

After a brief review of the development of the web and the introduction of the key reasons why to move towards the next generation of the web, the authors of this paper will present the concepts which can affect the way how construction industry currently works.

## 2. FROM WEB TO ENTERPRISE 2.0

The web today is not only the source of information, but also the way people do business. World Wide Web has revolutionized the economy and impacted the majority of the world's population within in the last decade or two. In the meantime, the use of the Internet evolved from static web pages to interactive, user-driven Web experiences. (Kabir 2006).

### 2.1 WEB 1.0 VS. WEB 2.0

During the recent years, a phenomenon of the Web 2.0 attracted a lot of attention not only on the Internet, but also in business community. New on-line applications not only make tasks as individual and group on-line learning, communication, collaboration and creation easier, they also have the capability of upgrading the experience by using the vast amount of information from the Internet, previous sessions and the so called collective intelligence of its users. It is considered as a next step and a major evolution of the traditional web from both a technological and social perspectives.

Although it is the single most used buzzword in the internet community in the past several years there is still no official definition of what the Web 2.0 actually is. The term has numerous definitions and more or less all of the authors agree that it is a trend, a perception of the direction the Web is heading, and not an object that can be created (Jewell 2007). It is an attitude towards radically open communities and communication (Nivi 2005).

It is not possible to define classic and next generation web by describing the technology. Instead, the focus has to be on the changes in human behaviour that the technology enables, and those changes are hard to describe or define (Nivi 2005). Therefore it is not surprising that it is hard to define Web 2.0 since there is no good definition of Web 1.0 either. Both principles are more or less always presented as a comparison between them (see Table 1).

Table 1: Web 1.0 vs. Web 2.0 (Drumgoole 2006, Barefoot 2006)

| WEB 1.0                              | WEB 2.0                   |
|--------------------------------------|---------------------------|
| was about companies                  | is about communities      |
| was about client-server              | is about peer to peer     |
| was about HTML                       | is about XML              |
| was about portals                    | is about RSS              |
| was about taxonomy                   | is about tags             |
| was about owning                     | is about sharing          |
| was about web forms                  | is about web applications |
| was about screen scraping            | is about APIs             |
| was about dial-up                    | is about broadband        |
| was about hardware costs             | is about bandwidth costs  |
| was about lectures                   | is about conversation     |
| was about services sold over the web | is about web services     |

Tim O'Reilly (2005) stated that the concept of "Web 2.0" began with a conference brainstorming session between O'Reilly and MediaLive International. O'Reilly stated that Web 2.0 doesn't have a hard boundary, but a gravitational core, and later enumerated the characteristics of successful Web 2.0 companies:

1. The Web is used as a platform.
2. Harnessing collective intelligence.
3. Data is the next Intel Inside
4. End of software release cycle
5. Lightweight programming models
6. Software above the level of a single device
7. Rich user experiences

Almost a year later Tim O'Reilly formed a Web 2.0 compact definition as follows: *"Web 2.0 is the business revolution in the computer industry caused by the move to the internet as platform, and an attempt to understand the rules for success on that new platform. Chief among those rules is this: Build applications that harness network effects to get better the more people use them."* (O'Reilly 2006)

Authors' personal choice is the clarification of the distinction between both approaches, published by Kabir (2006): *"An analogy from the world of building construction perhaps clarifies the distinction. Web 1.0 was like building houses from cement, sand, crushed bricks and aluminium. You had to mix cement, bricks and sand together to make concrete, then use concrete to make the house. With newer Web 2.0 technologies you effectively have concrete, prefabricated walls, corrugated iron sheets, etc. to build houses. So you can make more interesting and elaborate houses than before."*

## 2.2 SEMANTIC WEB

Despite the common misunderstanding the semantic web is not a separate web, but *"... an extension of the current one, in which information is given well-defined meaning, better enabling computers and people to work in cooperation"* (Berners-Lee et al. 2001). It is not different from the World Wide Web (WWW), nevertheless has an enhancements that makes the Web even more useful (Feigenbaum et al. 2007).

The vision of the Semantic Web is to extend principles of the Web from documents to data, which would reveal more of the Web's potential. It allows data to be surfaced in the form of real data (so that a program doesn't have to strip the formatting and pictures and ads off a Web page and guess where the data on it is) and allows people to write (or generate) files which explain to a machine the relationship between different sets of data (W3C 2008).

Semantic Web technologies can be used in a variety of application areas such as data integration (integrating data in various locations and various formats in one, seamless application), resource discovery and classification (in order to provide better, domain specific search engine capabilities), cataloguing (for describing the content and content relationships available at a particular Web site, page, or digital library), by intelligent software agents to facilitate knowledge sharing and exchange, in content rating, intellectual property rights of Web pages etc. (W3C 2008).

Alex Iskold (2007a, 2007b) noted that the original vision of the semantic web as a layer on top of the current web, annotated in a way that computers can "understand", has been a kind of academic exercise rather than a practical technology for at least a decade. The main problem Iskold (2007b) found is the bottom-up nature of the classic semantic web approach (each web site needs to annotate information in RDF, OWL, etc. in order for computers to be able to "understand" it), therefore he proposed the top-down approach, which is focused on leveraging information in existing web pages, as-is, to derive meaning automatically (Iskold 2008).

Semantic Web is sometimes mentioned together with another buzzword Web 3.0, the term used to describe the future of the WWW, although the views on the next stage of the WWW's evolution vary greatly. Some authors believe that the semantic web will transform the way the Web is used; other visionaries on the opposite side suggest that increases in Internet connection speeds, modular web applications, or advances in computer graphics will play the key role in the evolution of the World Wide Web.

## 2.3 ENTERPRISE 2.0

With the popularity rise of digital platforms for generating, sharing and refining information on the internet, McAfee (2006c) used the term Enterprise 2.0 to focus on Web 2.0 technologies and platforms that can be used (or sometimes even bought) in order to make practices and outputs of knowledge workers visible. McAfee identified six most important components of Enterprise 2.0 technologies:

- Search. It is important that users can find what they are looking for.
- Links. Many technologies work best if there is a structure of links that reflect the opinion of majority of people.
- Authoring. In order to obtain valuable income from the users, there has to be a simple way for publishing.
- Tags. Users prefer to tag instead of gather into predefined categories.
- Extensions. Smart add-ons are automating some of the work and creating added value.
- Signals. With all the tools and the simplicity of them there is too much content created every day. That is why signals in the form of email alerts, pings, trackbacks and also RSS feeds are almost mandatory.

McAfee (2006a) described Enterprise 2.0 as *“the use of freeform social software within companies”*, where freeform software is optional and free of up-front workflow, indifferent to formal organizational identities and is accepting many types of data. McAfee (2006b) later changed the definition since the first one was not clear enough: *“Enterprise 2.0 is the use of emergent social software platforms within companies, or between companies and their partners or customers.”*

Since then, many authors used the term for the technologies and business practices that make the workforce free from the constraints of traditional communication and productivity tools. Enterprise 2.0 provides business managers with access to the right information at the right time (through a web of interconnected applications, services and devices) a huge competitive advantage over competition, stuck in Enterprise 1.0 (see the difference in Table 2) in the form of increased innovation, productivity and agility.

Table 2: Difference between Enterprise 1.0 and Enterprise 2.0 (Stevens (2007), Enterprise 2.0 conference web site)

| Enterprise 1.0                                  | Enterprise 2.0                   |
|-------------------------------------------------|----------------------------------|
| Hierarchy                                       | Flat organization                |
| Friction                                        | Ease of organizational flow      |
| Bureaucracy                                     | Agility                          |
| Inflexibility                                   | Flexibility                      |
| IT-driven technology / Lack of user control     | User-driven technology           |
| Top down                                        | Bottom up                        |
| Centralized                                     | Distributed                      |
| Teams are in one building / one time zone       | Teams are global                 |
| Silos and boundaries                            | Fuzzy boundaries, open borders   |
| Information systems are structured and dictated | Information systems are emergent |
| Taxonomies                                      | Folksonomies                     |
| Overly complex                                  | Simple                           |
| Closed/proprietary standards                    | Open                             |
| Scheduled                                       | On demand                        |
| Users search and browse                         | Users publish and subscribe      |
| Messages pushed to consumer                     | Messages pulled by consumer      |
| Institutional control                           | Individual enabled               |

However, there are also sceptics who think that vision like that cannot be achieved through new technology alone and that the absence of participative technologies in the past was not the only reason



that organizations and expertise are hierarchical. Davenport (2007) believes that organizational hierarchy and politics will not go away on account of Enterprise 2.0 software and the Internet, because the barriers that prevent knowledge from flowing freely in organizations cannot be addressed or substantially changed by technology alone, although this can change when generation changes.

### **3. CONSTRUCTION INDUSTRY 2.0**

One of the key challenges of AEC is to provide an efficient, effective and flexible access to information and to provide all possible channels of communication. Web 2.0 may have some solutions to such problems, since the collaboration over the internet has never been easier. Working with a group of people on the same spreadsheet, sharing calendars, reading emails with attachments on mobile phones, publishing video tutorials on internal or external company pages, sending pictures from distant construction site locations directly to the concerned co-workers using only mobile phone and web based services, etc. - all those tasks became more or less trivial with the expansion of modern web services.

Stewart (2008) just recently stressed that *“the continuous process improvement via the strategic implementation of innovative information and communication technologies is essential for the long-term survival of construction firms”*. Despite that observation, common practice in the AEC industry is still the same as it was in the 1990s - the IT department provides a new user all the equipment (laptop computer and/or stationary workstation, mobile phone device) needed when the user joins the company. In addition, all the necessary tools and software programs are also provided, including office program suites, email, access to email, secure access to internal network of some sort, anti-virus and anti-spyware tools etc. All the above mentioned equipment is usually maintained by the IT department with the security as a core requirement in mind.

#### **3.1 SATISFYING EMPLOYEES = ADAPTING TO NICHE REQUIREMENTS**

In contrast to the IT department's efforts, employees today are no longer satisfied with the predefined set of tools that have to be used since those solutions were tailored primarily for a time that already passed. This is especially true for the dynamic and mobile environments such as AEC industry, where time constraints often play important role and present the difference between success and failure. Employees today are used to live the life of “always on-line”, “present 24/7”, “access anywhere”, social networking, collaboration and feel more comfortable using tools that they are using in their personal life. Some research results (Forrester's NACTAS Q4 2006 Devices & Access Online Survey and Forrester's NACTAS Q4 2006 Youth Media & Marketing And Finance Online Survey, performed by Forrester Research) have shown that 80% of the workers born after 1980 (also called Gen Xers) are using social networking, collaboration and web tools daily (Perez 2008). The result is that the technology is also brought into workplaces and the use of traditional, conventional and awkward productivity tools are stepping aside in favour of text and instant messaging, mobile devices, web based emails, wikis, on-line document sharing etc. This new trend, emerged in the last years, is called technology populism.

Technology populism is a trend of adopting the new technologies, led by a technology-native workforce that self provisions collaborative tools, information sources and human networks with a minimal or even without support of an IT department (Forrester Research via Perez (2008)). The reason for this is that borders between personal and professional life today are more or less blurred and people are using the same tools and services at their workplaces as they are using at home. What is more, every person has its own preferences regarding what to use and it is safe to claim that using those tools and services results in more efficient and satisfying work. While some communities have already adapted to it, the AEC industry was left behind (see Fig.1). Gartner (2008) has predicted that by 2010, end-user preferences will decide as much as half of all software, hardware and services acquisitions made by IT departments.

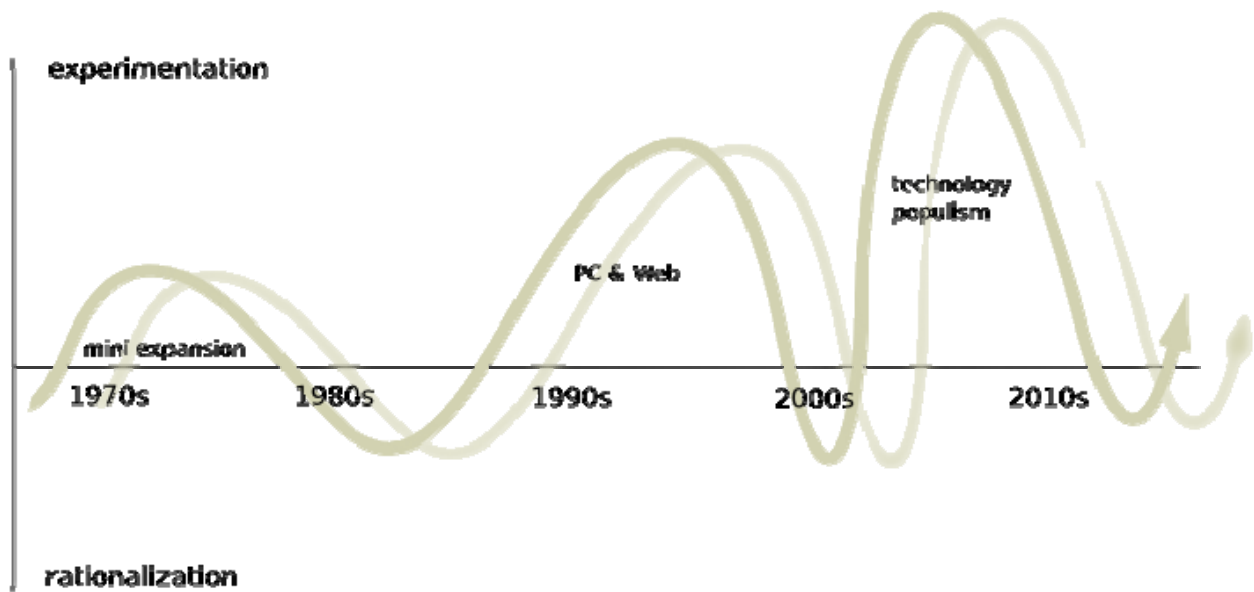


Figure 1: Technology populism as the latest adoption trend (the shadow presents the estimated lag of the adoption by the AEC industry) (based on Forrester Research via Perez (2008)).

### 3.2 MOVING ONLINE

Some of the authors speculate that in the few years' time the majority of business applications will reside on the web and that most of the business will be done on the devices smaller than laptop. Gartner (2008) is predicting that by 2012 more than 50% of the mobile workers will leave their laptops at home in favour of other devices and that by the same year more than one-third of business application software spending will present service subscriptions instead of product licenses. Ignoring those trends and predictions now can put companies into serious competitive disadvantage.

Advantages of moving online are numerous and can be found on many sides. One of them is that with the central server solutions there is only one place that has to be maintained, and everything else is left to individuals' choice. Choices can start at preferred operating system (Windows XP, Windows Vista, GNU/Linux distributions such as Ubuntu and Suse, MacOS, ..., to name just few of them), and stop at browser level (Internet Explorer 6, Internet Explorer 7, Mozilla Firefox, Opera, Safari, ...). Web based software is usually platform (software and hardware) independent and can be used in combination with variety of devices (including desktops machines, laptops, phones, smart phones and other hand-held devices). This also coincides with the Web 2.0's freedom to choose what suites one's best.

Another benefit is accessibility. If mobile workers are to move to smaller devices than laptops, the infrastructure has to be adapted. Since it is still not clear what kind of devices (and platforms) will come to the market in the two or five years time, it is safe to predict that they will be connected to the internet and will have browser of some sort.

Last but not least, there is also an issue of fast growing price of the electricity that is necessary to run and cool servers. The rise is so rapid that a lot of big companies decided to outsource their services or at least backups that are now hosted by the clouds of computers (such as Amazon S3). Computer clouds offer scalability (really important these days), high availability and low latency at commodity cost.

What is in favour of the AEC industry is the trend of developing smaller devices which are very suitable for mobile work force and off-site work places. Additionally, the trend of web based software used as a

service can lower licence cost, overcome limitations, improve productivity and help in critical situations (it is not hard to imagine how full online CAD tool (such as eCAD – see Fig. 2) can improve on-site work of the engineers).

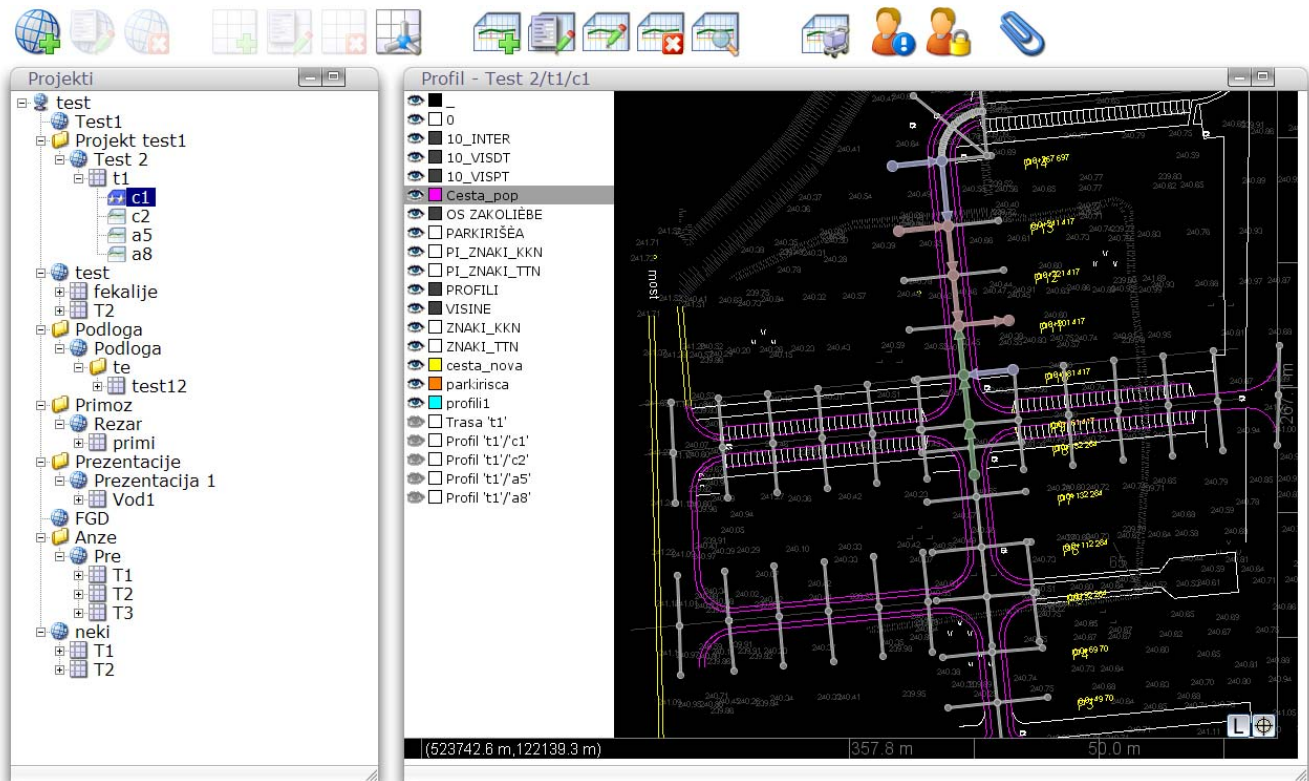


Figure 2: eCAD - CAD tool (similar to AutoCAD) as a Web 2.0 service, working through standard web browser (<http://www.ecad.si>)

### 3.3 EMPOWER SEMANTICS

Talking about semantics does not necessarily mean talking about ontologies, RDF, OWL, etc. and taking it from bottom-up, it is also possible to extract some meaning from the current set of data without too much effort (top-down approach). Web 2.0 provides some possibilities that would be interesting even to AEC industry.

Just recently some Web 2.0 start-up companies emerged that were promising to deliver semantics to the Internet. For example, Slovenian based start-up company Zemanta (<http://www.zemanta.com>) offered solution for bloggers all around the world that is giving them the opportunity to find links, pictures and text similar to theirs automatically using plug-in for either their blogging platform or their browser. They can do that by using sophisticated techniques such as natural language processing and machine learning. Their business model also predicts custom tailored solutions that would only work on custom set of data and would otherwise not be publically available, offering the chance to the industry to take advantage of it.

Another form of semantics is the usage of tags that are very popular among the Web 2.0 community. The most notable advantage of using tags is that the users are building a set of metadata about the documents, posts, texts and images without the awareness that they are doing that. It is not necessary to tag (people are not forced, for example), but they tag anyway.

Primitive forms of semantic applications are also vertical search engines. It is almost impossible to find specific information on the Internet these days, especially if the set of keywords used for search is quite common (we could try searching for “vibrating plate”, for example). That is why vertical search engines are proving to be very useful, searching only the pages and areas that we predict. Also, it is almost a trivial task building such a search engines with only few necessary information (such as which pages to include). For example, Google is offering APIs for building such engines.

#### 4. CONCLUSION

During the recent years, the phenomenon of Web 2.0 attracted a lot of attention not only in the Internet, but also in business communities. Many traditional businesses stand to benefit from the new business processes, communities and business models enabled by the Web 2.0 movement, although it cannot be viewed purely as a technological phenomenon, it is also a sociological shift of the society as a whole.

The possible benefits of adapting Web 2.0 technologies, principles and strategies into construction industry are numerous: core enterprise applications are becoming more effective through the incorporation of Web 2.0 technologies, next-generation Web platforms are highly efficient, semantic tagging is closing the gap between working groups, for the first time community knowledge can really be used etc.

That is why it is necessary for enterprises in the AEC industry to closely monitor the advances in the information technology in order to be competitive in a few years time. This paper presented newly emerging trends (technologies, services, tools, solutions, etc.) that are already changing business processes as we know and even though one might think they will not play an important role in the future all the projections show that a lot can be expected from them in the following years.

There are also some concerns regarding the newly emerging web technologies in a work place. One of major issues is centralisation of the service and is closely related to the nature of web applications. The question is what happens when the server (or servers) goes down or when internet connection fails. Another concern is the disperse location of the information and documents, which can cause many practical issues (like searching for the information on different locations, security questions, etc.). Some of them can be solved using vertical search engines and search engine APIs, others remain unsolved for the time being. Last but not least, there is also an issue of IT departments which cannot master and support each and every Web 2.0 Ajax application that emerges.

Nevertheless, it is safe to say that most of the technical issues can be solved or at least controlled. However, the resistance to IT change which is so common in the AEC industry is a completely different story.

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## **ELECTRONIC TENDERING: DELIVERING BUSINESS EFFICIENCIES FOR THE IRISH CONSTRUCTION INDUSTRY**

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### **ABSTRACT**

The tendering process predominantly adopted in the Irish construction industry is highly paper-dependent. However, the increase in the availability of Information Communications Technology (ICT) has meant that construction consultants can disseminate information more cost effectively in an electronic format. The aim of this paper is to present the results of an industry-led network project undertaken by the Construction Information Technology Alliance (CITA) in Ireland. This project aimed to demonstrate how greater effectiveness and efficiency can be brought to bear on the tendering process by the application of ICT already used widely in other industries. The paper outlines the inefficiencies of the current tendering procedures, the results of an observation study, industry survey and progress on a simulation project. The project will specifically focus on the exchange of data between network members by quantifying the inefficiencies in current processes and by demonstrating the potential benefits to be won through a live eTendering project.

### **KEYWORDS**

Construction, electronic tendering, information exchange

### **1. INTRODUCTION**

The extent of use of ICT in the Irish construction industry is relatively unsophisticated, being mainly dependent on the traditional telephone, facsimile machines and networked personal computers (Thomas, 1999). At the simplest level, the electronic transmission of business documents offers savings in time, paper and postage (Hore and West, 2005a; Hore and West, 2005b). By going a step further, businesses can make strides in communicating with their partners, at relatively low cost, through direct links between their computers (Hore, 2007).

The Canadian Construction Association (2005) found that tendering costs can account for up to 5.9% of the total value of a project cost to a client on a typical construction project (CCDC, 2005). These costs emerged from an examination of the many hundreds of tender documents produced by consultants. These included standard documents such as tender drawings, project specifications and Bills of Quantities (BOQ). Each of these documents are reproduced in multiple copies and dispatched to tenderers on a regular basis, which results in an expense that is passed on to the client.

ICT tools are used today to support Architecture, Engineering, Construction and Facilities Management (AEC/FM) business processes. The information entering into these ICT tools, however, is almost invariably passed from one ICT system to another by producing paper-based electronic documents, which in turn are re-entered into various other ICT systems along the AEC/FM life cycle (Froese, 2003).

These inefficiencies cannot, of course, be attributed to one specific process or party within the industry, which has also been acknowledged by the Irish government (DETE, 2006). It has been extensively reported by many authorities that collaborative exchange of data between construction project participants is not efficient but that sensible use of ICT enhances productivity (Thomas, 1999 and Gunnigan et al., 2004).

This paper outlines the inefficiencies of the current tendering procedures, the results of an observation study, an industry survey and the research work carried out by an industry group. The project will specifically focus on the exchange of data between network members involved in the tendering process by quantifying the inefficiencies in current processes and by demonstrating the benefits to be won through a live eTendering project.

## 2. INDUSTRY SURVEY

The Irish-based Construction IT Alliance (CITA) is a limited company comprising over 140 members drawn from the consulting, contracting, suppliers and software vendors sectors. The consulting members include architectural, structural and quantity surveying practices, while the suppliers include a wide variety of firms providing products to the construction industry.

In 2006, CITA carried out a survey examining the perceptions of eTendering in the Irish construction industry (Kenny, 2006). The survey was carried out online and an email, containing a web link to the survey, was sent to 42 CITA members actively involved in the Irish tendering process, requesting them to partake in the survey. This email also included factual background information on the survey. Following further contact, fifteen individuals responded to the request to complete the survey, thereby giving a response rate of 36%.

The survey focused on the industry's level of awareness of eTendering, its knowledge of the potential opportunities it presents to the Irish construction industry, the current levels of adoption of electronic tendering processes and the perceived barriers to its adoption. Some of the more significant results of the survey included:

- Over 70% of individuals had already received tender information in electronic format as part of their daily work.
- 27% had returned the information to the source electronically.
- 93% of respondents would consider using the eTendering solutions in the near future.

The survey found that companies believed that electronic tendering would save manpower in the processing of information, lead to a reduction in errors and would produce better records of the process. Conversely, this was tempered by significant concerns about the use of electronic processes, including their security, legality, the commitment by other firms and the technological capabilities within the Irish construction industry. Respondents perceived that the Irish government was not doing enough to encourage implementation and use of technology in practice.

Bandwidth was not an issue for those surveyed. Undoubtedly the acknowledged shortfalls in bandwidth availability in Ireland may well become a barrier to eTendering when it is more universally accepted for public and private contracts.

## 3. CITAX PROJECT

In 2005, CITA obtained funding for the CITAX project under an Industry Led Network Scheme (West and Hore, 2007 and EC, 2007). The overall aim of the project was to facilitate more efficient business transactions between companies in the Irish construction sector by the deployment of readily available ICT tools, in particular construction business processes tools and to radically improve the productivity of these business processes. The longer term objective of the network is to develop a platform for the design and development of open standards that would be promoted and implemented within the construction supply chain. The CITAX project focused on five module areas:

- Module 1 - Production and exchange of CAD drawings.
- Module 2 - Production and exchange of trading documentation, such as purchase orders, proof of delivery and invoices.
- Module 3 - The pricing of tender documentation electronically and the recommending of a preferred tender for selection.
- Module 4 - The storage, retrieval and general dissemination of project information on construction projects.
- Module 5 - The use of CAD software in the production of bills of quantities.

The Module 3 team (concerned with eTendering) sought to verify that significant measurable economic benefits can be achieved by collaborating network members through the adoption of a solely electronic tendering process on a live construction project. The project deliverables included:

- Mapping the existing process (see flow chart in Figure 1).
- Re-designing the tender process by removing, where possible, all the identified inefficiencies (see Figure 2).



- Quantifying the potential savings to the various parties in adopting the revised process.
- Simulating the revised process to measure and verify the anticipated efficiencies benefits.

The process shown in Figure 1 starts from the point where the Private Practice Quantity Surveyor (PQS) finalises the BOQ and creates multiple copies of same for distribution to tenderers on a selected tender list. Additional tender documentation is also collated, such as design drawings and schedules which are dispatched with the BOQ. Upon receipt of the tender documents, the contractor will need to examine such and prepare any queries to raise with the design team. On clarification of any of the queries from the design team or PQS, the contractor will prepare trade packages (which are currently heavily paper-based) and dispatch such to sub-contractors for pricing. The sub-contractor will, in turn, prepare their bids and submit same to the contractor. The contractor then collates all price data, often by hand, including any bids from sub-contractors and includes indicative prices into their BOQ and adjudicates their tender sum internally. Following the submission of the documents from the contractor to the PQS, the PQS, normally in the presence of the architect and a client representative, follow the code of practice for opening and checking tenders.

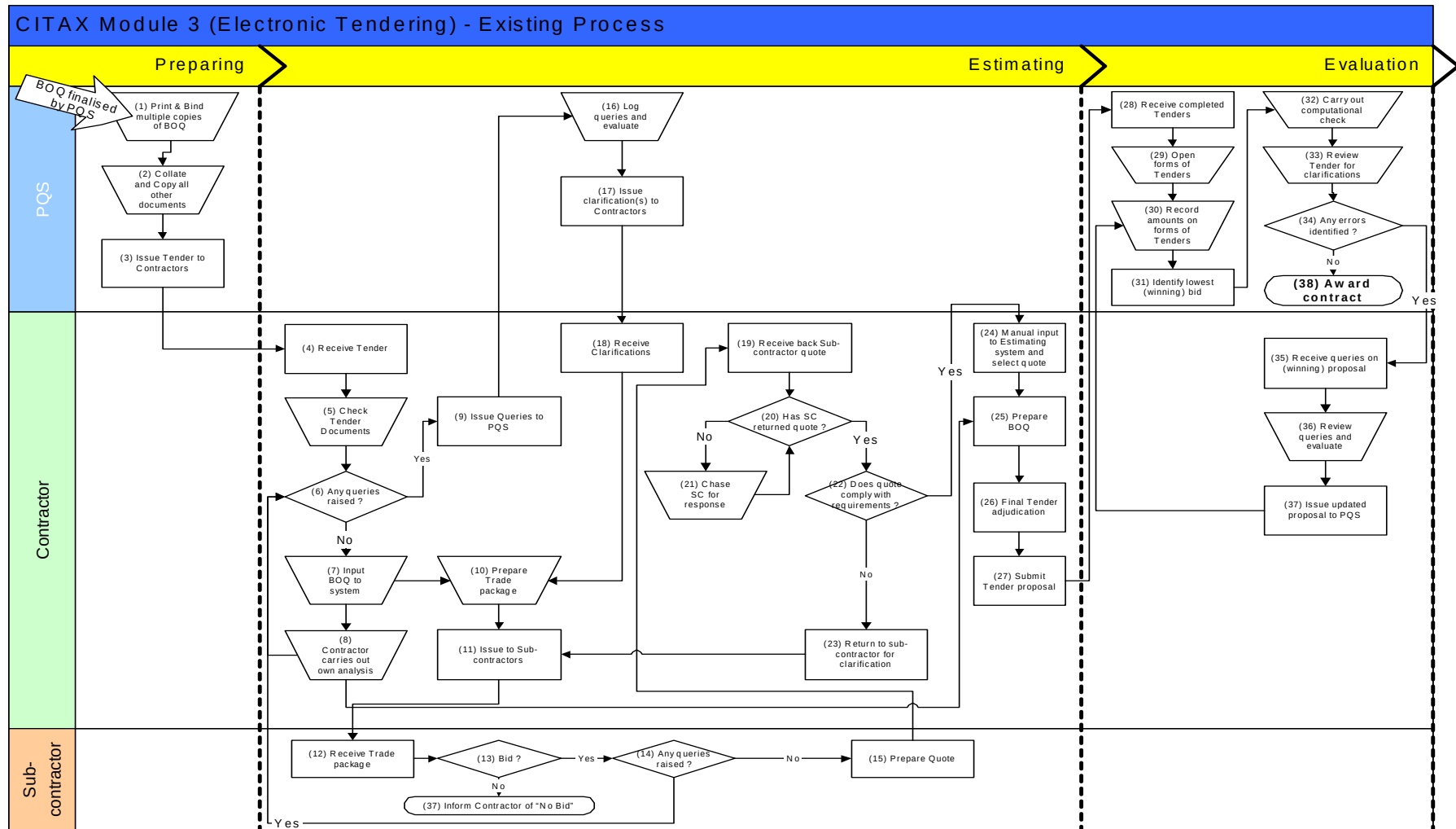


Figure 1: Existing tendering process (O'Connell et al, 2007)

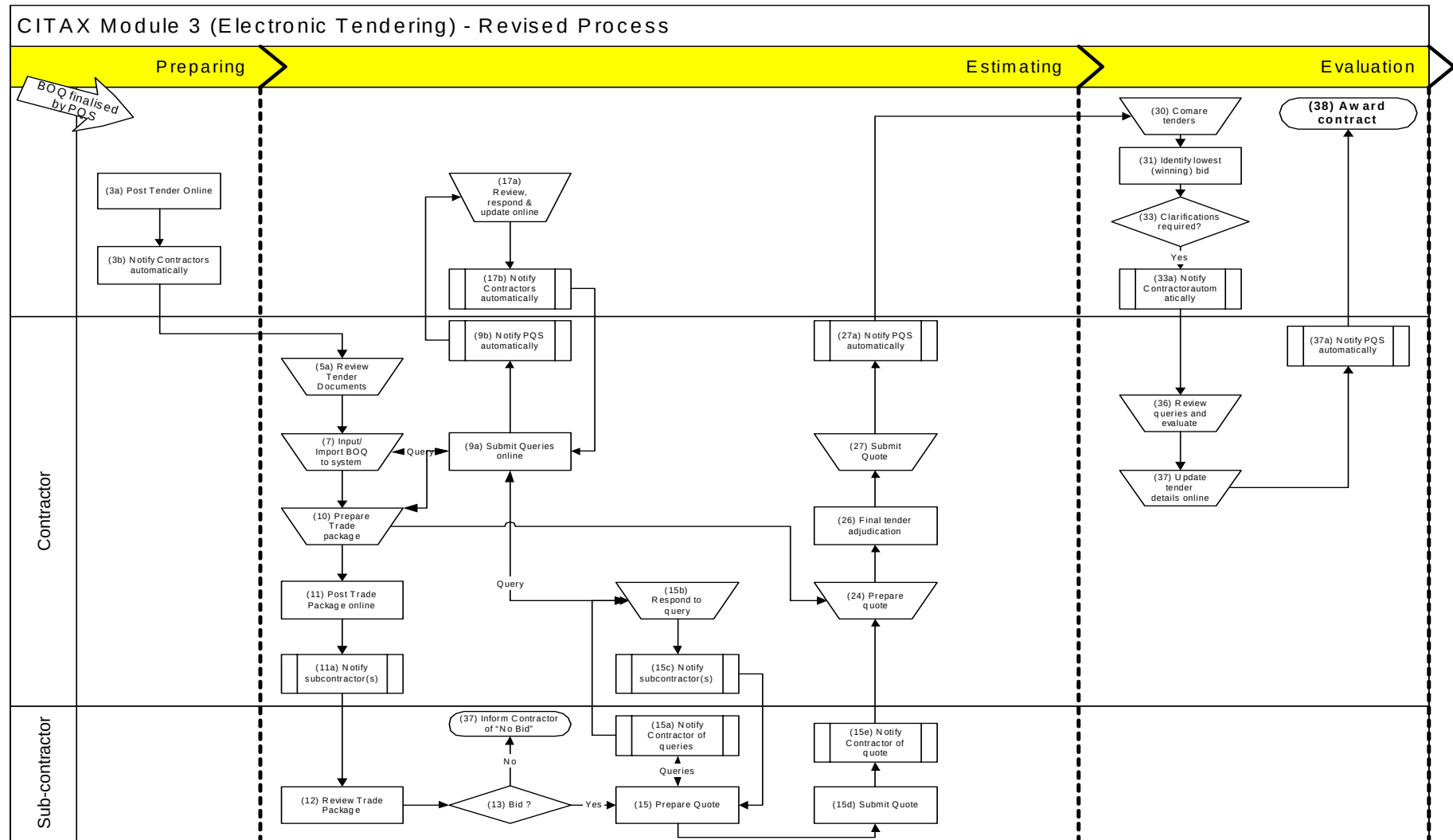


Figure 2: Revised tendering process

Using these procedural guidelines, a contractor is selected and the process of awarding the contract commences.

Of the 37 steps identified in Figure 1, 19 were subsequently removed in the revised process map. The subsequent efficiencies introduced by the module team are summarised in Table 1.

| <b>Preparation</b>                                                                                                                                      | <b>Estimation</b>                                                                                                                                                                            | <b>Evaluation</b>                                                        |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Paper eliminated as documents no longer have to be printed.                                                                                             | If the tender data can be provided in an electronic format it avoids the need to re-key in data.                                                                                             | No necessity to record tender sums on forms of tenders.                  |
| The labour effort involved in preparing the paper copies of tender documents is eliminated.                                                             | Savings in terms of paper and the time required to prepare packs for subcontractors.                                                                                                         | No necessity to carry out computational checks.                          |
| The distribution costs associated with delivering the tenders to bidders is eliminated.                                                                 | The tender system should provide validation to ensure that all information is supplied. This ensures the completeness of tenders and minimises the number of queries that have to be raised. | Receive and review tender queries in an online environment.              |
| Errors in version numbers, missing paperwork etc. are reduced because a single version of the tender is posted online to which all bidders have access. | The validation of tenders should also provide basic checks on calculations to minimise the risk of errors.                                                                                   | Tenders easily updated with notification to clients and cost consultant. |

Table 1 Efficiencies introduced into tendering process

When comparing figures 1 and 2, a number of sub-processes have been removed in the revised map which do not simply relate to the change from postal to electronic file distribution. Examples of these include raising queries; importing BOQ information into the contractors' back office systems; and final tender adjudication. With this in mind the module team costed all the stages of the tender process. While it is recognised that this practice can be highly subjective, the module team had a number of members with a significant level of experience in the current tendering process. Additionally, the team laid down some criteria to help focus what costs should and could be applicable.

These included but were not limited to:

- 350 page tender document including all Bill, Specification, Preliminaries etc.
- small allowance for queries and adjustments to the BOQ.
- Sub-contractor's allowance set at one day per tender, as there was no member of the module from a sub-contract background. Some contractors may take longer as they are involved in more detailed work while others may only price one standard small item, thus resulting in a small amount of time required in pricing.

The module team then identified software packages capable of reducing / eliminating the inefficient processes in tendering. Many of the vendors of these software were predominantly UK-based and were not in a position to consult with the module participants. However, one Irish-based estimating software developer was consistently interested in partaking and advising the module team. This vendor concurred that the communications process could be significantly boosted simply through the use of File Transfer Protocol (FTP) sites. This was not a method considered in the RICS Practice Notes (2006). Providing a company has a website, it should have the ability to use this technology.

The process map was then consulted to identify how much the process would change. After a short review period, all parties agreed that the process map itself would not change. However, what would change would be the communication of the information within each step over the entire process. This then led the group to estimate a revised cost for the tendering process (see Table 2), leading to a modest saving of about 10% in tendering costs.

| <b>Costs of Tendering Process</b> |                                   |                |                         |                       |              |
|-----------------------------------|-----------------------------------|----------------|-------------------------|-----------------------|--------------|
| Process ID                        | Process Name                      | Responsibility | Estimated Existing Cost | Estimated Future Cost | Saving       |
| 1-3                               | All Documents to contractors      | PQS            | € 804                   | € 158                 | € 646        |
| 4 - 11                            | Preparation of tender (1)         | Contractor     | € 3,131                 | € 2,431               | € 700        |
| 12 - 15                           | Sub tender                        | Sub-Contractor | € 225                   | € 200                 | € 25         |
| 16 - 17                           | Queries                           | PQS            | € 1,091                 | € 1,060               | € 31         |
| 18 - 27                           | Preparation of tender (2)         | Contractor     | € 4,944                 | € 4,681               | € 263        |
| 28 – 34                           | Receive and assess                | PQS            | € 4,837.50              | € 4,778               | € 60         |
| 35 - 37                           | Clarifications; post tender works | Contractor     | € 1,500                 | €1,500                | € 0          |
| Total                             |                                   |                | € 16,533                | € 14,808              | € 1,725      |
|                                   | <b>Predicted % saving (A-B)/A</b> |                | A                       | B                     | <b>10.4%</b> |

Table 2 – Costings associated with the tendering process

*Note: - Each of the figures presented above has a detailed breakdown of the resources expended in carrying out the various activities in the tendering process.*

The use of eTendering solutions may result in the reallocation of costs among the process stakeholders. It will inevitably reduce the printing cost of the owner and transfer these costs to the bidders. However, the bidders can pass on a proportion of these costs to specialist sub-contractors, whose prices will be ultimately integrated into the final bid.

Whilst the use of FTP servers, hosting, security and administration costs will add to the overall cost of tendering, all of the simulation participants already have their own FTP sites in place and so issues of an FTP manager and additional hardware did not arise.

To validate the revised process and the assumptions made, the project team has undertaken to partake in a simulation project. As the purpose of the test is to validate that documentation can be distributed more efficiently electronically than by paper, the team decided not to use any specialised eTendering software, but to create a basic test using available technology. A Quantity Surveying practice and two main contractors agreed to participate. It was agreed that the tender documentation would be placed on a shared FTP (File Transfer Protocol) site by the QS firm to which both of the contractors would have access. Each of the contractors was able to download the documentation from that site along with any subsequent updates to the information. The QS firm used email to notify the contractors whenever new information is added to the FTP site. Each main contractor was allocated its own directory on the FTP site for submitting tenders. The QS firm checks each of the FTP directories for the tenders submitted by the main contractors, at the appropriate time.

To minimise overheads on the simulation and to make it more manageable, each of the main contractors agreed to simulate the role of subcontractor to the other main contractor. Therefore, the FTP process implemented by the QS firm for distributing the tender will be replicated by each of the main contractors to simulate their interaction with their subcontractors.

It should be noted that the simulation has not addressed some issues, such as:

- Validating the calculations in each of the tenders submitted.
- Ensuring that all communications between the parties are recorded.

These items will only be addressed through the use of a software package specifically designed for eTendering. The results are expected to show that the estimated savings can be achieved, however, there may be some unforeseen difficulties, which may reduce the saving percentage that has been predicted. The final report on the simulation is due to be completed in the summer of 2008.

## 5. CONCLUSIONS

The Authors investigated the traditional construction tendering process, as it operates today in Ireland, including the identification of the inefficiencies involved. This was completed, firstly by means of a survey, which was then followed up by completing an observation study. It was surmised that there was significant scope for ICT improvements to the existing processes. Furthermore, it has been established that the Irish construction industry understands that they need to adopt eTendering processes, but this is tempered by significant concerns about these processes, including security, legality, commitment by other firms and the technological capabilities within the Irish construction supply chain.

CITA has acknowledged that there is a general awareness in the Irish construction industry of the business benefit of deploying readily available ICTs in improving tendering processes in construction (Kenny, 2006; O'Connell et al, 2007; Hore et al, 2007).

The construction industry approaches any change in business processes, whether it involves technology or not, with some trepidation (Rankin et al., 2006). The CITAX project has attempted to outline a set of ICT standards for a range of construction processes including tendering, to reduce the level of barriers within the industry. This could help to initiate the investment needed to achieve the wider uptake in ICT usage and, therefore, to realize the savings that have been predicted in a wide range of published articles. In an ideal system, each piece of data would be entered only once and would be available to any ICT system in the tendering supply chain that needs it (West and Hore, 2007). The simulation has worked towards achieving this end but the team went further and reviewed an example of an eTendering software package. This type of package is likely to be used in the future to provide additional levels of functionality and control such as computation analysis of analysis received that were not available in the simple FTP solution.

One of the weaknesses of the FTP solution is the necessity for the QS firm to check the tender figures submitted by the lowest bidder. Notwithstanding use of the FTP solution, the owner who uses it will have a liability if errors in the contractors' bids results from errors in discrete elemental data entry. This will be dealt with in exactly the same way that errors are handled in the existing paper-based tendering system. However with a software package (database solution), these figures could be checked automatically thus reducing the potential for errors and the client's liability.

This paper has set out the methodology within the CITAX project in which the Irish construction industry can move towards the full adoption of eTendering. Its success will inevitably be judged by the extent of its adoption, a problem exacerbated by the diverse nature of the industry's players.

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## **IMPACT OF E-GOVERNMENT ON FEDERAL FACILITY DELIVERY**

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### **ABSTRACT**

This paper provides a justification for the use of e-Government applications for public facility delivery projects. The costs and benefits from one such system used in public practice in the United States are described. The emerging impacts of e-Government systems on the facility acquisition community are also identified.

### **KEYWORDS**

e-Government, government-to-business, facility acquisition, facility delivery, business process

### **1. INTRODUCTION**

Electronic Government (e-Government) refers to the use of Internet-based technologies such as websites, email, and file servers to improve the efficiency and transparency of government activities. e-Government applications often serve a variety of different purposes, including democratic participation and oversight, access to resources and services, and access to grants and contracts. Well designed e-Government tools allow its citizens to repackage related government services, provide standard services across multiple agencies, and combine these activities into a single virtual service organization (Clark 2003). An additional justification for e-Government activities is often based upon the assumption that such efforts enhance a nation's private sector to better compete in the information technology marketplace (Budge 2004).

Until the rise of coordinated e-Government applications within the United States, listings of opportunities, systems for documenting contractor qualification, and bidding systems were operated and maintained by each federal agency. The Federal Business Opportunity system is now the centralized government service for the capture of contractor qualifications and solicitations (General 2008). This "FedBizOps" system is widely seen as having reduced the cost of bidding on government work. It has, however, increased the costs of and provided high barriers to entry for many small businesses (Innovation 2004). Of critical concern to many working in e-Government is that the target constituencies for many of these services are precisely those sectors of the public, such as the poor, elderly, or disabled, who are least likely to have internet access (Duke 2003).

While the focus of e-Government is typically on new websites, portals, and highly complex government-to-business applications, the most basic requirement is for effective electronic information transfer services such as email and electronic funds transfer. For many citizens email and electronic funds transfer services are fundamental (Innovation 2004). The real value of email, especially the "contact us" email hyperlink on web pages, is that it makes the structure of the government agency transparent to the citizen. Decreases in cost and time associated with receipt of electronic funds transfers are self-evident. While websites with the latest technology flavor will continue to be of momentary interest, is unlikely that anyone could conceive of working at the current pace of business without email and electronic funds transfers.

### **2. FEDERAL FACILITY DELIVERY**

Within the United States, negotiated contracts for Architect/Engineer services and best-value open bidding for federal facility projects are standard practice. These contracting methods are designed with a minimum barrier to entry in order to allow the widest possible set of prospective bidders on federal project. Under such a contracting regime, there are different sets of designers, consultants, prime contractors, subcontractors, suppliers, and manufacturers employed on each project. While individual designers and contractors specialize



in government projects and could have multiple awards over time, the full project team will typically be different on every project.

The only constant on federal projects is the set of specifications under which government contracts are awarded. Government contracts include general provisions derived from the requirements of the Federal Acquisition Regulations (Office 2008). The technical provisions of the contracts are expressed in criteria, guide specifications, and/or code supplements. Many agencies use the Unified Facilities Guide Specifications and Unified Facilities Criteria found on the Construction Criteria Base (Whole 2008).

While the general and technical provisions may be the same, differences between government project managers are anecdotally cited as the major factor in determining the successful completion of a project. Because managers or quality assurance staff have different levels of expertise, less-experienced government project personnel may have different interpretations of procedures. It is widely understood that in addition to technical knowledge, understanding how to successfully resolve problems is the key to success for a design project manager or construction quality assurance representative.

### **3. E-GOVERNMENT FOR FACILITY DELIVERY**

In the contracts of many federal facility projects are specifications that include the use of the ProjNet<sup>SM</sup> system. ProjNet<sup>SM</sup> is a suite of government-to-business applications provided through *a la carte* subscription from the National Institute of Building Sciences, which is a congressionally created not-for-profit organization (National 2008). The ultimate objective of ProjNet<sup>SM</sup> is to help experienced project managers to implement successful business processes in the review of designs, resolution of bidder inquiries, requests for information during construction, and review of construction submittals. ProjNet<sup>SM</sup> business processes and definitions are defined through a NIBS inter-agency committee comprised of agency administrators and system users the author is the chair of this committee and responsible to translate these requirements into the ProjNet<sup>SM</sup> suite of tools.

One of the key insights of effective project managers is that all parties to a decision must concurrently participate in the resolution of the issue. Face-to-face meetings are often the most effective way to ensure that all team members are present for the resolution of issues that pertain to them. Prior to ProjNet<sup>SM</sup>, electronic means of communication were considered to be ineffective because the programs used for these purposes required a higher level of effort than a face-to-face meeting. Client-server systems imposed on contractors by contract specifications changed from one agency and department to another. Contract partners who performed work only occasionally for the federal government often strongly resisted such electronic systems due to their *de facto* bureaucratic bias against the infrequent user.

ProjNet<sup>SM</sup> is focused on the *process* of information exchange used by effective project managers. The actual *production* of the information to be exchanged, such as design deliverables or shop drawings, remains the purview of private software manufacturers and does not directly affect the process of information exchange. While federal contracts mandate specific exchange requirements for government and lead designers or prime contractors, much of the information created on projects is created by subcontractors, suppliers, and manufacturers. As a result, ProjNet<sup>SM</sup> success is highly dependent upon the provision and adoption of tools that support efficient information exchange among private industry team members, not simply the exchanges between government and lead designer or prime contractor.

While the government partners interact using a process with which they are familiar, government personnel do not see (or need to see) the processes that allow their business partners to effectively use these information exchange tools. Design executives can, for example, route design review comments based on the specific consultancy arrangements in place for the specific contract. Prime contractors may collect submittals and interact with suppliers and subcontractors in the system before submitting a package to the government. There is a growing understanding within the federal design and engineering communities that efficiency requires them to support the entire “food chain” of the process, not just the aspect of the process that results in handover of data from the prime contractor.

Allowing project managers to implement their own best practices implies that they are able to reach appropriate team members through the website, and that these stakeholders may fully participate in the identification, resolution, and verification of issues as simply as possible. From the client-software point of view, this means that a “typical” web browser using a standard broadband connection is the maximum requirement that should be imposed by e-Government systems that are intended to be usable by the entire team. Because users may not have administrative control of their computers or networks, the e-Government system cannot impose additional software downloads. Java Applets and ActiveX controls should not be used since there will be a not-insignificant percentage of users who are not able to install these “active code” applications. While a team may require the use of specific software and place demands on the team for markup and other tools, these requirements are not shared across multiple agencies, offices, or project managers and, therefore, should not be built into e-Government systems that are intended for wide distribution.

#### 4. COST

A significant barrier to entry for most software is cost. Unless small consultants, subcontractors, and others are able to participate, their input will be lost and the business process will be broken. Because some team members may only sporadically work on government projects, even a low barrier to use, such as the per-user costs, can be enough to prevent these stakeholders from participating. To be successful, e-Government systems must be free of charge to all project-specific stakeholders. The requirement for a web browser is a very low barrier to entry for business partners. Given that web browsers are available free of charge, there need be no end-user fees for e-Government systems.

In the United States, the cost for end-users to connect to centrally served e-Government solutions should be the cost of a broadband internet connection available through Wi-Fi, cable television provider, Digital Subscriber Lines, or fiber optic lines. Given that email services are understood to be a baseline requirement at all levels of business, access to the internet through broadband networks can be generally assumed as the norm for the smallest businesses to which United States government awards facility delivery contracts. Given that internet connections are already in place, there should not be an end-user cost for connecting to e-Government applications.

Medium-sized businesses, of 10 – 30 employees, appear to have the most risk in their ability to connect to e-Government systems. Small businesses are able to manage their own networks based on home-networking solutions. Larger businesses have the overhead needed to hire full-time network staff. Medium-sized businesses purchasing turnkey services from telecommunications providers appear to have, at least in the United States, the most difficult time. It is recommended that medium-sized businesses working with e-Government applications for facility acquisition should purchase extended support services to help administer the inevitable technology tweaks needed to keep a medium-sized network operational. The e-Government helpdesk must be funded to support communication between stakeholder end users and their network service providers. While the e-Government provider may only be held contractually responsible for the application server stack they are, from the user’s perspective, responsible for the entire internet route.

While there must be no cost to end-users for e-Government services, there is a significant cost for the creation and operation of the applications. e-Government data centers require a variety of hardware such as firewalls, application servers, database servers, file servers, and additional support servers. That said, the costs associated with creating e-Government applications can be surprisingly reasonable. The average annual cost of each ProjNet<sup>SM</sup> hosted design review comment (including an entire thread of issue identification, resolution, and verification) is approximately one dollar (U.S.).

Backup procedures and contingency planning also are critical issues when fully considering the implications of providing business-process-based e-Government applications. Two types of contingency operations must be addressed: those that disable some aspect of the application or communications line, and those that destroy the entire server infrastructure. Depending on the risk-aversion of specific clients, it is possible to cost-effectively deliver different levels of service to limit downtime to less than a few hours. Real-time load balancing across multiple data centers is, in the author’s experience, not needed for e-Government applications supporting facility delivery processes.

## 5. BENEFITS

e-Government systems offer numerous benefits, the most obvious being the elimination of delays due to postal mailing time. This alone is the first-tier of savings available to all teams, regardless of how effectively they use the software. The second most obvious benefit, which applies to issue-resolution topics, is that issues are captured and presented in a common format. Often this format includes categories, such as design discipline, that allow the issues to be automatically collated and organized based on completion status, author, office, etc. The automation of collation has been reported to save approximately 40 man-hours per project (East 2006). Collation cost may be virtually eliminated through the use of a well designed e-Government content and process ontology.

Effective e-Government systems clearly explain the process through which work is accomplished and communicates those processes through multiple channels. These channels include screen-based confirmation messages that are consistently provided by the user interface, summary pages that show where specific items are in the overall process, and various types of email notifications. e-Government systems should not attempt to duplicate email and other messaging services, but they may be able to leverage data contained in project records to allow key team members to contact other team members using email sent through the e-Government system.

After processes are clearly identified and described within the system, the next order of benefits to project teams results from knowing the specific team members assigned to complete tasks within each process. Reports and automatic email notifications can streamline the process of seeking out those who have not completed their required actions. The important use of this information is not to “point fingers” at an individual’s failure to perform, but to identify stakeholder offices whose participation is necessary but, for whatever reason, has not been accomplished yet.

The benefits identified above are those related to the process of completing the work, not the benefits associated with “improved design quality” or “project collaboration.” Generalized claims of improved design quality and decreased construction costs through the use of web-based collaboration systems are notoriously difficult to verify. The benefits related to business process improvements, however, can be directly quantified. The quantification of benefits provided by ProjNet<sup>SM</sup> has begun through study of the Bidder Inquiry process (East 2008, in preparation). The results of a pre- and post- implementation study and a related discrete-event simulation, to be published in an upcoming paper, demonstrates a 90% decrease in the number of contracts awarded with open bidder inquiry issues. The average time to evaluate inquiries has been reduced to 14 days from 30 days on a typical paper/email process. Also, one study has identified a minimum savings of \$30K (US 2004 dollars) simply through reduction in the frequency and duration of face-to-face meetings (East 2006).

## 6. IMPACTS

The unforeseen impacts of new technology may take some time to become evident. A classic historic example occurred with the construction of railroad networks throughout the United States. Before the publication of train schedules, each town maintained its own local time, based on the sun’s midday zenith. Operating railroads on a reliable schedule made it necessary to synchronize clocks across longitude, by region. The establishing of time zones was a necessary but unexpected side effect of implementing railroad technology. Similarly, the impacts of e-Government sites for supporting facility delivery processes are only just becoming evident. The short-term impacts of these systems might have been predicted, but the longer-term impacts are just beginning to be felt, and they may not be fully known for several decades.

Current design and construction practice uses a hodge-podge of technology for information exchange, including email attachments, multiple anonymous File Transfer Protocol (FTP) sites, and ad-hoc use of various commercially provided web collaboration portals. The inability to limit inappropriate use of these technologies virtually guarantees that an owner’s building data will be completely accessible for any who are interested enough to look for it. Facility owners have a duty to safeguard property and building occupants by

restricting general public access to detailed design data and construction details pertaining to emergency backup systems, fire alarms, and other critical building systems. e-Government applications are able to set effective policies for the release of data that should be public. Team members can provide oversight to ensure procedures are in place that restricts the public distribution of sensitive project data. One of the short-term impacts of e-Government systems will be to decrease access to sensitive aspects of public building design and construction by those who are not project stakeholders. These same technologies, if correctly designed, ease the burden on each project team to develop their own, project-specific information technology infrastructure. Communications among project stakeholders must include those exchanges that take place outside traditional contracting requirements. e-Government systems are beginning to impact the way that government personnel think about deploying information technology to the entire project team.

It is interesting to note that all users of e-Government systems quickly become acclimated to the accessibility and ease of use of these systems. As users become habituated, the e-Government service will appear as ubiquitous as water, power, and telephone service. As a result, any outage will be seen as a critical problem by those waiting for the service to return to operation. Most often, outages will result from changes to local system or network configurations at their offices. e-Government operators must be prepared to provide technical support services to help users to interact with their internal information technology departments. To help users and managers set appropriate expectations, a "level of service" paragraph should be included in contracts. This clause should cover regular scheduled maintenance outages, durations of possible non-catastrophic outages, and recovery procedures if the system becomes unavailable due to catastrophic failure.

The provision of e-Government services has a longer-term impact on the maintenance of public project records. There have been anecdotal accounts of contractor-provided data being lost during or after the conclusion of a project when contractors purchase commercial services with project funds. These losses have been reported to occur during the discovery phase of claims processing. A less suspicious type of data loss can occur following the conclusion of projects if the contractor stops paying for the project-based commercial service. While some commercial service providers have indicated their willingness to provide data disks containing the files exchanged, this data set is only part of the data that should be actively preserved for those who will build, maintain, operate, and all-too-often litigate the project. The impact of rapid access to historical building data has been anecdotally discussed, but not directly experienced by the author. The impact of having the data available during the "litigation phase," on the other hand, has been directly experienced by the author.

Because e-Government systems for facility delivery have been operational for over a decade, several post-construction litigations have included ProjNet<sup>SM</sup> data. In one case, a party indicated that they were not informed about the resolution of an inquiry submitted during the bidding process. The ProjNet<sup>SM</sup> team, however, was able to show that the user named in the claim had obtained a report that displayed the disputed data two days after the technical resolution of the issue in question. Another dispute included a claim that a designer did not have the opportunity to communicate cost impacts because a check box was not available on the specific version of the Design Review and Checking System (DrChecks<sup>SM</sup>) screen used by the designer. The most interesting part of this claim was that the technical issues surrounding the issue, its resolution, and verification of compliance were never in question. It has been said that the court case goes to that party with the best documentation. Where e-Government systems are used, the issue of what documentation is available and who holds it is no longer in question. The data should be available to all parties in the litigation, and accessible well after the conclusion of the project. It is reasonable to expect a reduction in protracted litigation where documentation of the technical dialog and agreed-upon problem resolutions is available to all members of the project team.

Many public works and civil infrastructure projects affect, and sometimes displace, large numbers of citizens. A key insight on the use of e-Government facility delivery systems for these large projects is that all stakeholders, including political and non-governmental organizations, must participate in the projects. e-Government systems were used to assist in coastal and environmental restoration programs in Louisiana, Mississippi, and the Florida Everglades. In the review of these projects, technical advisory boards, including local political bodies and non-governmental organizations, have been able to fully document the resolution of their issues. In a conversation with the author of this paper, the project team members stated access to issue resolution documentation was a primary reason for the success of the e-Government application.

Transparency in communications directly discouraged later suggested changes and requests for design deviations suggested by influential developers or political constituents.

A final impact of e-Government systems is that the nature of dialog about technology is beginning to change. While software engineers use tools such as the Unified Modeling Language to communicate about communication between software entities, these tools are only just beginning to be widely understood and used by project stakeholders to optimize their modes of communication (i.e., business processes). Many software vendors fixate on ever-larger markets that require an ever-increasing number of features and options, but there is a point of diminishing returns on such “improvements.” Either they become too expensive for users who are not interested in many of the new features, or they become unstable due to their own rapidly increasing complexity. One key impact of e-Government systems is the growing awareness that business process modeling is the essential element for software designed to support facility delivery (East 2008).

## 7. CONCLUSION

The nature of successful e-Government applications is significantly different than traditional government information systems. e-Government applications must support multiple tiers of contractors, provide basic technical support for all project stakeholders, and be economical to create and operate. e-Government technologies can be justified by citing quantifiable benefits felt directly by the users of these systems. While the short-term costs and benefits of e-Government applications can be established, the longer-term impacts of these systems on the process of facility delivery are just now beginning to emerge.

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## EFFECTIVE SEMANTIC WEB-BASED SOLUTIONS FOR CIVIL ENGINEERING

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### ABSTRACT

The World Wide Web (the Web) has become widely recognized as the primary channel of communication and dissemination of information in industry. It has made immense amounts of information available and has been gradually accepted by users who now readily incorporate it into their daily lives. In civil engineering, despite the wide use of the Web, its use is still limited by the users' willingness and ability to share their knowledge. The Semantic Web challenges this problem as it adds meaningful descriptions to information in a manner that facilitates automated analysis and extraction by computer systems. While many scholars in the field realize the importance of using such technologies to promote collaboration with various parties including the general public, research that is conducted on the Semantic Web and similar technologies is often disconnected from its application. Nevertheless, there is general consent that this collaboration is essential for the creation of sustainable solutions in civil engineering. This paper reviews and analyzes current research being conducted on this area in Europe and North America. We also propose methods that involve the Semantic Web to improve usability and effective information flow in city-scale projects.

### KEYWORDS

Civil Engineering, Semantic Web, Sustainable Engineering, Project Collaboration, Information Flow, Information Technology and Usability

### 1. INTRODUCTION

The field of civil engineering has been revolutionized by the introduction of different forms of technology and specially automation through computers. However, these computer-based automation technologies were adopted by civil engineers at different stages. Furthermore, the way these different technologies were integrated varies from one user to another. This variance is partly due to a disparity in skills and, sometimes, level of comfort and willingness to change. These factors present a recurrent problem in civil engineering where a technology lag has been created due to slow user acceptance. In addition to acceptance, issues like security and confidentiality come into focus with technologies that are based on the Internet. Communication over the Internet is one the most important components of most current automated systems in which the Web is used as the platform for document exchange.

The World Wide Web (the Web) has become widely recognized as the primary channel of communication and dissemination of information in industry. The Web is the current platform for most communication and involves over one billion fixed Internet users and billions of documents and pages. These figures exclude the number of mobile users that access the Web. In general, it has made immense amounts of resources instantly available across the globe and has been gradually accepted by users who now readily incorporate it into their daily lives. However, this incorporation, as mentioned above, is not expressed by all users in the civil engineering industry as some still prefer tangible means of communication like paper design documents and facsimiles. In civil engineering, despite the wide use of the Web, its utilization is still limited by the users' willingness and the experts' ability to share their knowledge. Naeve (2005) elaborates on how the Semantic Web handles this problem by adding meaningful descriptions to information in a manner that facilitates

automated analysis and extraction by computer systems. Integration of the Semantic Web is already under way in several fields in which taxonomies and relationships are being standardized (Sheth et al. 2007).

Efficient collaboration has been the focus of our research since we identified these problems, especially in city-scale projects. Most of the problems faced in city-scale projects arise due to the need for concurrent coordination with more than one party. These parties include the public, government bodies and other construction entities. Once this coordination has been achieved, city-scale models can easily be extended to span projects that involve international collaboration. While many scholars in the field realize the importance of using such technologies to promote collaboration with various parties (El-Diraby and Gill 2006), research that is conducted on the Semantic Web and similar technologies is often disconnected from its application (Robertson et al. 2007). In addition, despite the prevalence of technology as a means of improving construction processes, steps need to be taken to promote further integration through coordinating with users and facilitating active participation of the public.

Nevertheless, many scholars agree that this collaboration is essential for the creation of sustainable solutions in civil engineering (Barrett 2008; Robertson et al. 2007). This paper reviews and analyzes current research being conducted in the area of collaboration in Europe and North America. Although several other regions are already leading a technologically-advanced and prospering construction industry, this review will limit the context of comparison and research scope by excluding regions other than those mentioned above. In order to identify the deficiencies within this scope, a review of current automation technologies is necessary. This paper will review current technologies before describing state-of-the-art approaches involving the Semantic Web. We also recommend improvements in areas that would help speed up the integration process.

## 2. CURRENT AUTOMATION TECHNOLOGIES

The field of civil engineering has seen the successful integration of technologies such as computational intelligence, modeling and simulations and finally the Web. The integration of technology was brought about by a growth in the industry, and the technology, in turn, promoted further growth. This growth is evident in several fields of civil engineering. Project management, for instance, currently involves extensive use of communication and automation technologies.

Unfortunately, this automation is being utilized within a generally fragmented industry. This fragmentation is a problem due to the large size of the civil engineering industry, and is hindering further growth foreseen by researchers. The size of the construction industry, as one aspect of civil engineering, in the UK alone represents 9.9% of its GDP which makes it one of the largest industries in the UK (Barrett 2008). With an industry that shows such diversity, great inconsistencies arise in various processes. These inconsistencies in processes as well as data can be directly translated to significant losses in funds and time. Barrett (2008) suggests that rather than considering this fragmentation a problem, researchers should look at it as an attribute of the industry. This approach helps in dealing with the fragmented nature more positively and perhaps justifies why the integration process has been a hard one all along.

Other than fragmentation, and despite evident automation, the second important deficiency is the difficulty of acquisition of knowledge. For example, a case study from Greece shows that determining the failure reasons in waste management could be a very hard task due to the parties not cooperating (Dokas and Panagiotakopoulos 2006). In this case, an expert system was successfully used to enhance the knowledge acquisition process. Nevertheless, little thought was given to global application and if, in fact, it could be communicated globally.

Expert systems are also used in the infrastructure industry in the U.S. which has the largest highway system in the world. Within this complex system, engineers use expert systems to automate the process of evaluating existing bridge systems to prevent future disasters (Issa et al. 1995). However, despite the significance of this system as a rating model, its effectiveness and field of application could be reduced by lack of transferability across different bridge systems. A simple discrepancy such as incompatible rating units could act as a barrier against seamlessly communicating data on an international level.

As can be seen in the previous examples, the general trend revolves around problems that are based on lack of cooperation and difficulty of data acquisition. As a remedy to these problems, while keeping the advantages

of an automated system, applications involving the Semantic Web have been proposed. Despite being a relatively new concept, some of these applications are already in operation.

### 3. THE SEMANTIC APPROACH

The Semantic Web comes as a natural evolution of the Web. It adds a semantic aspect to the current syntactic Web that is based on resources, mostly in the form of documents. In the context of the Semantic Web, these documents can be described and then easily analyzed using technologies based on the Extensible Markup Language (XML). The main advantage of this approach is that a user would be able to receive relevant data and trends without manually carrying out any comprehensive identification. In turn, this saves human resources and time, which both translate to a reduced cost.

One important point to note is that the aforementioned data inconsistencies that arise are a consequence of changes in data trends as well and not just underperformance on part of the users. We are subjected to immense amounts of information that becomes overwhelming even for adept managers. Naeve (2005) describes how the Semantic Web makes information suitable for identification and machine processing. This facilitation is achieved by relating the descriptions of different sets of information. In other words, the Semantic Web automates the fetching of information. This taxonomic automation of the search and analysis processes was the missing link in most of the applications mentioned above. Taking the case from the previous section as an example, the waste management fault expert system in Greece could be an area where the Semantic Web would be used in the integration and deployment of the expert system. This integration is especially useful in developing countries where expert knowledge may be lacking or not immediately available.

It is increasingly demonstrated that the applications of the Semantic Web have seen a boost over the past two years. This boost was accompanied by standardization of many of the concepts involved in the Semantic Web, hence, the technology became more usable. Following are case studies that deal with some of these applications. These cases give an idea of the general trend, our current ability to identify and deal with the deficiencies and level of progress. The main areas covered by the following cases are related to virtual organizations and risk assessment in construction.

Virtual Organization (VO) is a term that generally describes collaboration between companies within the context of a specific project. The term can also be used more specifically to describe business collaboration or the exchange of skills between companies (Gehre et al. 2007). The InteliGrid platform is a European Union project that uses research aimed at establishing a grid-based VO environment. Dolenc et al. (2007) explain how this project uses grid technology and semantic interoperability to provide a prototype that can be used by the engineering industries. This line of research represents a powerful integration approach in which the computing power of grids is used to collaborate between higher-level business processes. Gehre et al. (2007) further discuss the management of VO processes using Semantic Web concepts. Their research effectively brings the user into context by designing end-user applications with graphical user interfaces to facilitate testing. Their model provided a proof of concept and also indicated that more “flexible semantic human-computer interaction” needs to be developed.

Another area that could make great use of the Semantic Web is privatized infrastructure finance where private-public interaction occurs. El-Diraby and Gill (2006) extend the application of the Semantic Web to this area where construction meets external disciplines like finance. The collaboration with different disciplines requires bridging through a transfer of knowledge. The main aim of this knowledge transfer is to assess and communicate the risks in an efficient way. For instance, the taxonomy developed by El-Diraby and Gill (2006) would enable a construction company to communicate the evaluated risks to financial institutions efficiently. In addition to the assessment of risk, the suggested tool also provides the user with the possibility of documenting best practices. These documented results can later be analyzed by the system to detect certain patterns and create appendices accordingly. El-Diraby and Gill (2006) acknowledge the limitations of the proposed taxonomy as it is difficult for a single ontology to cover a full domain. The taxonomy, however, represents a successful attempt at connecting the financial and construction industries. Dealing with such gaps between industries typically provides significant challenges when applying the Semantic Web due to the complexities of creating common ontologies or integrating them.



The cases described above showed the diversity of applications the Semantic Web can be involved in. They also offer proof that integration on a large scale is facilitated by these technologies. In brief, the technology is available and the need for such technology has been established. The problem that is seldom tackled is obviously the user acceptance and promotion. A major question is why Semantic Web technologies do not appear to be catching up with other automation technologies. In the next section we discuss ways of promoting Semantic Web technologies and enhancing their usability.

#### **4. PROPOSED SOLUTIONS**

Many civil engineers, specifically construction engineers, have been using computer software as a major component of the design and cost estimation process. Although other forms of technology may not have been received in the same manner, this existing familiarity with the use of software as a design tool should facilitate the promotion of new technologies. Yet, as mentioned earlier, this familiarity is not expressed by all engineers and a few steps need to be taken to introduce the Semantic Web effectively. The first and most important step is to guarantee access to communication technologies. Unfortunately, the communication infrastructure problem is not a problem that is limited to developing countries. One would find it hard to believe that a developed country like Spain would be falling behind in the availability of communication links. However, one of the recent projects in Andalusia, Spain dealt with the issue of installing fiber-optic cables for better connectivity to smaller regions in the country (Cortes et al. 2006). The issue of stable connectivity is a possible problem in most rural and remote areas around the world. With the continuous development in the construction industry, these remote areas could host several construction projects and even company branches. Therefore, investment in communication technologies in these areas is recommended on the long run for full automation of information flow. If permanent communication lines are not possible, although this is highly unlikely in the presence of satellite communication, offline data repositories should be synchronized frequently. In general, good communication lines promote the use of Semantic technologies as they offer a more stable system.

Besides communication, Semantic Web applications need direct marketing. The public and practitioners alike have to be widely aware of its possible applications so they can relate it to the problems they face and how it would help alleviate some of these problems. They also need to be assured that they can trust this technology and that it would actually promote better performance and lower costs on the short or long-run. Outsourcing the technology aspects of construction project is a very effective approach that provides this trust. Outsourcing companies also provide the required marketing through proven track history as the same technology could be transferred from one project to another upon proven success. The idea of outsourcing all information technology aspects of a project to a specialized company is not a new one and has proven to be very effective. Lin and Harding (2007) explain how outsourcing enables companies to focus on their core competencies. Among the advantages of outsourcing, the civil industry can make use of best practices and case studies that are gained by experts in outsourcing. Outsourcing companies also provide the best available technologies as they frequently update their services and security standards.

Whether a civil engineering company opts for outsourcing or develops its own in-house system, the first stages involved in the introduction of the new system are very important and could determine the overall success of the process. Contingency plans should be created with a design that accounts for some manual processes in case of unforeseen failure. Moreover, a modular structure is essential to achieve some independence among the processes. A modular approach would also mimic the fragmented nature of most projects as noted earlier. These modules would then be easily integrated in a process that follows careful and planned differentiation (Barrett 2008). Many companies start using a pilot approach in which the introduction of the Semantic Web is carried out as a pilot project until the documentation is carried out and the proof of concept is completed. This procedure also gives the users enough time to acclimatize and promotes efficient use of the system.

Thirdly, the role of regulatory authorities and governments is indispensable in introducing Semantic Web technologies in cases where it is perceived useful within their vision for the industry. Barrett (2008) points out that the role of a knowledgeable government is as important as the role of the users. This significant role is especially evident in construction education. Moreover, through the integration of the Semantic Web technologies and knowledge management systems, these governing bodies can design plans to bring the

industry up to their anticipated level of collaboration. These authorities should also provide recommendations and guidelines that fit the direction they want to drive the industry. On the long run, the collaboration systems would also provide them with better means to coordinate with other entities in the civil industry. In Europe, the aim is that by 2030, a more competitive and sustainable construction sector would be achieved through the Strategic Research Agenda (Robertson et al. 2007). On the other hand, it appears that there is little evidence of similar initiatives in North America. Whether the application will catch up with these research plans within the given time-frame will remain subject to uncertainty.

Finally, it is essential to acknowledge that while the semantic automation process needs an investment of time and funds, its gains can be soon realized through collaborative action across the industry. For this reason, planning should take the education of young engineers into consideration to allow for a directed rather than forced evolution of the technologies.

## 5. CONCLUSION

In this paper, we have presented the prevailing trend in today's construction industry. It can be seen that there is a sufficient amount of research being conducted that is, unfortunately, lacking application. It was also shown that more research needs to be directed towards involving the users. Current research has been concentrating on different automation technologies. While automation has been successfully achieved in most realms of the industry, inconveniences due to fragmentation constantly surface. This fragmented structure arises due to the large number of companies that can be involved in one construction project. Research that tried to tackle this fragmentation as a problem was focused on eliminating fragmentation which proved quite challenging. As a result, it has been proposed that this fragmentation should be dealt with as an attribute, rather than a problem, of such an expanding industry that is built on large-scale projects. Alternatively, some research implemented methods that educated users on ways to look for information. While these methods are on the right track, they still do not make full use of the available technological resources.

The Semantic Web is an easily accessible technology that has been emphasized in this paper. It addresses the fragmented nature of the industry, yet applications of the Semantic Web have to overcome the difficulty of integrating different ontologies in a relatively seamless and consistent manner. The current literature provides effective ways of utilizing the Semantic Web in engineering to make processes more efficient in addition to providing value to society. Currently, there is evidence of more resources being employed into developing good communication pathways: both physically and through software.

It is known with certainty that expert knowledge is indispensable, but also of less value if not communicated across the industry. For such communication, the technology is available and under constant improvement. We believe that the future is in the integration of the Semantic Web. This integration will help users confidently catch up to the technology and effectively utilize it. It is not surprising that a lot of the current research deals with the education for engineers and the general public as a way of reducing the technology lag.

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## **INTEGRATING TRUST CONCEPTS IN A DASHBOARD INTENDED FOR THE BUILDING CONSTRUCTION COORDINATOR**

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### **ABSTRACT**

The growing complexity of AEC projects leads to increase the importance of the building construction coordinator's role. Moreover, the uncertainty linked to the environment of the building construction activity makes way for the notion of trust. The coordinator can make use of a multiple tools/views for accomplishing his mission (e.g. planning, meeting report) but these views offer only a limited vision of the cooperation context. So we suggest analyzing data coming from these different views to obtain some trust indicators informing the coordinator about trust in the good progress of the building construction activity. Our approach distinguishes 4 aspects of the activity conditioning the global trust level: task progress, actor's performance, documents required to perform the task, and building elements resulting from the task. Our proposal suggests introducing these trust indicators in a dashboard included in a multi-view interface allowing the coordinator identifying the tasks with a low level of trust and understanding the nature of the potential dysfunctions.

### **KEYWORDS**

Building construction, Coordination, Trust, IT-support, Dashboard, Model-Driven Engineering.

### **1. INTRODUCTION**

The AEC sector has some specific characteristics, distinguishing it from other industrial sectors. Indeed, the heterogeneity of a team of actors constituted for the duration of the project leads to the difficulty to create and maintain durable relationships. Moreover, the execution of a building is in a sense the execution of a prototype and consequently, the uncertainties related to the environment are numerous (e.g. nature of the ground) and risks of dysfunction are multiple. In this article, we will focus on the execution stage and more precisely on the coordination of building construction activity and on the coordinator's role.

The building site constitutes a particular environment and the place of numerous potential dysfunctions that can be firstly, linked to documents (e.g. problems of update), then, linked to interactions between actors (e.g. lack of trust that limits the exchanges) and finally, linked to tasks and their execution (e.g. difficulty of performing a building element) (Tahon

1997). Thus, in such a context and because of the increasing complexity of the construction projects, the coordinator's role becomes more and more important. In the French context, the coordinator is in charge of assuming the scheduling, the coordination and the management of the building construction activities. More precisely, in the execution phase, he is in charge of defining the detailed execution planning as well as its update to maintain the global execution time. He is also responsible for the follow-up and the monitoring of the budget. In order to carry out the different aspects of his mission, diverse tools are at the disposal of the coordinator. We can distinguish them in two categories: current tools and emergent tools. Among the frequently used tools, we can cite Gantt and Pert scheduling methods, or some tools such as word processors allowing writing the building site meeting report synthesizing the points of dysfunction and the taken decisions. We can also identify some other tools more rarely used. Among these, we can mention document management platforms, 4D simulation tools (Sadeghpour et al. 2004; Chau et al. 2005), putting into relation a 3D modelling of a building and its planning and performance evaluation systems (Arslan et al. 2008), which allowing the evaluation of the actor's performance. However, these tools offer only a partial vision of the cooperation context. Therefore, we suggest that a dashboard, which will synthesize data coming from these

different views, could constitute a good decision support system. Moreover, we make the hypothesis that the uncertainty linked to the environment of the building construction activity makes way for the notion of trust. Thus, we propose a dashboard based on the representation of trust to support coordination of building construction activity.

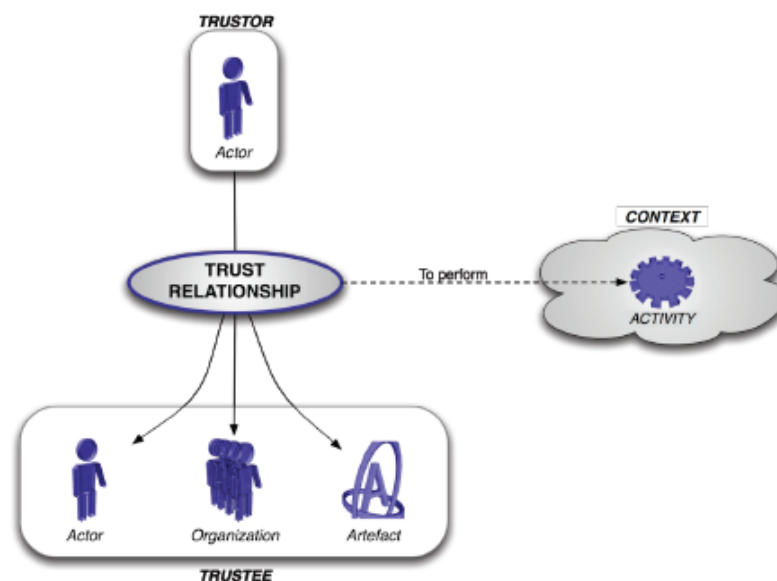
In this article, we will begin by addressing the theoretical aspects linked to the notion of trust. Then, we will focus on the notion of context linked to the cooperative activity. After that, we will identify the trust criteria within the framework of a building construction activity. Finally, we will describe our proposal of a dashboard based on trust.

## 2. STUDY OF TRUST IN THE AEC SECTOR

We will concentrate in this section on the trust within the framework of a cooperative activity performed during the building execution stage. Trust constitutes indeed an essential element for cooperation because the achievement of a common objective cannot be serenely envisaged without trust in a context where there are interdependences between stakeholders.

### 2.1. DEFINITION AND ESSENTIAL CONCEPTS

Even if scholars do not converge on a unique definition, trust is often associated to positive expectations about the behaviour or intentions of another person (Deutsch 1962). Literature describes also trust as a device allowing overstepping the complexity of the environment (Luhmann 1988) and sates the limited character of trust in a given context (Hardin 2000)



The

Figure 1. Concepts of Trust

examination of trust allows highlighting the concepts represented in Figure 1. First, the trust relationship is a relationship that exists between a “Trustor” (Person who trusts) and a Trustee (in whom / in which the trust is reposed). In literature, the trustee can take diverse forms: an actor, an organization or an artefact (e.g. a software, a website...). Then, the second important notion is related to the context in which the Trustor trusts a Trustee. Indeed, we trust somebody in the framework of a particular activity, at a given moment and at a given context, because trust is inserted in a dynamic process and can change over the time positively or negatively in function of experiences. At last, two notions are still important when we talk about trust: the

notions of dependence and risk. The trust relationship generates dependence between a Trustor and a Trustee. So the Trustor becomes vulnerable and has to consider the risk he takes when he delegates an activity.

## 2.2. SOURCES OF TRUST

Our examination of Kramer's works has allowed us to identify principal sources of trust (Kramer 1999). We exclude voluntarily the aspects related to psychology because they are less relevant in the framework of our analysis. So, we distinguish:

- *Trust based on characteristics*. This trust is based on internal characteristics of the individual, such as culture and the group in which he is involved... If we consider a building construction activity, this form of trust between actors coming from a same category is predominant. Architects, engineers or contractors constitute 3 groups well marked inside of which trust naturally exists.
- *Trust coming from a third party*. This type of trust relies on the notion of reputation. If we consider a building construction activity, teams are short-lived and consequently, reputation plays an important role and determines an « a priori trust » based on exchanges with third parties.
- *Trust coming from previous experiences*. This trust is based on past successful references. If we consider a building construction activity, experiences coming from anterior AEC projects strongly condition trust.
- *Trust coming from the role*. This trust corresponds with a trust relative to the performance of an actor according to the role that he plays in an organization. If we consider a building construction activity, roles are clearly determinate. These roles generate precise expectations concerning competences and know-how and condition trust relationships.
- *Trust based on rules*. This type of trust is based on contractual mechanisms, rules, certification organization or norms. In the AEC sector, a large number of certifications progressively appear (e.g. certifications related to competence of actors, quality of the building elements...), standard contracts (e.g. contracts describing the mission of the stakeholders), norms (e.g. norms concerning the execution of building elements). These certifications strongly condition trust within an organization.

## 3. "CONTEXTS" OF COOPERATIVE ACTIVITY

Up to the present, we have determined the theoretical framework of trust in the AEC activities, which our research work is joined in. We have seen that the context is very important within the trust mechanisms. We think that the interest of new generations of ITbased tools is to represent and take into account the context of their users. We will then focus in this section on the notion of context and on its different understandings in IT-supported cooperation.

### 3.1. THREE CONTEXTS OF COLLECTIVE ACTION

Our study of the cooperative activity allowed us to highlight three different types of contexts (Kubicki et al. 2007): the cooperation context, the actor's context and the user's context. Figure 2 illustrates these contexts.

**Cooperation context** (See Fig. 2, [1]) describes the collective dimension of the activity. The generic elements constituting each cooperation context are the following ones:

- Actor. This concept refers to a human resource included in an organization and taking part in the execution of the activity.

- Activity. It is decomposed and structured. Its execution constitutes a common goal for the actors.

- Document. This concept refers to "definitive" or "intermediate" results of the activity.

Documents are required to perform building elements.

- Building element. This concept results also from the activity. Its execution concretizes the common goal of the actors.

The **actor's context** (See Fig. 2, [2]) refers to the knowledge manipulated by the actor and to the cognitive processes which he carries out in preparation for his individual action.

Knowledge mobilization and treatment mechanisms are intimately linked to the actor's business competences and to their point of view on the cooperative activity.

Finally, the **user's context** (See Fig. 2, [3]) is situated between the cooperation context and the actor's context. It considers the actor as a user of computing tools. Such tools consist of supports for perceiving the

cooperative activity context. Taking this context into account is essential when we try to design activity support tools. Indeed, this context allows us to consider the tool as a mediator between the actor and the activity. It highlights the fact that a tool must not only take into account the collective activity but also to adapt itself to its user.

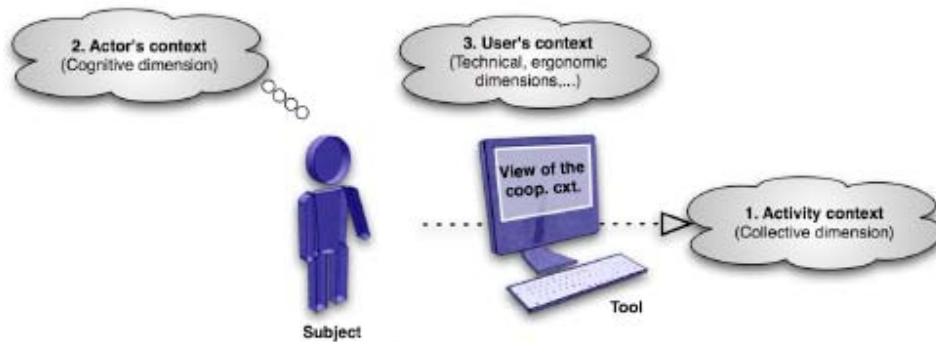


Figure 2. Three contexts for action

### 3.2. TRUST

#### IN THE ACTOR'S CONTEXT

The actor's context refers to the cognitive mechanisms which the actor proceduralizes a part of his knowledge with (related to the cooperation context) in order to adjust his action.

We have, however, to insist on the uncertainty that exists in a collective activity and more precisely, on the achievement of the expected results. This uncertainty comes from the individual's limited rationality (Simon 1959), and from the unpredictability of the environment, which makes that every action cannot be envisaged independently of its context. Seeing that the action is completed in an uncertain context, two aspects seem fundamental: trust and risk. The question of trust is actually central if we are interested in the action in a cooperation context: trust in the good progression of the collective activity, trust in the achievement of the expected results, trust in human resources... Concretely, this concerns the question of trust in each aspects of the cooperative activity (See part 3.1). The assessment of these types of trust seems us essential in order to adjust action on the cooperation context. Let's consider, for example, an activity with a weak level of trust. In this situation, an action performed on the cooperation context could be a control action (e.g. time, resource or documents control), which would contribute to reduce risk and consequently to increase trust.

#### 3.3. SYNTHESIS OF OUR APPROACH ABOUT THE CONTEXTS

We have identified the different types of contexts necessary for each action. The Figure 3 allows us to summarize the fundamental aspects of our approach:

- **Cooperation context.** It is an information source mediated by tools and perceived by the actor.
- **Actor's context.** It refers to the actor's knowledge and only a part of this knowledge is proceduralized in preparation for action. Moreover, it allows the actor to determine the trust in the good progression of the activity and consequently, to adjust his action on the cooperation context.
- **Trust.** It refers to trust in each aspects of the cooperation context (i.e. Trust in the progress of the task, in the documents linked to this task, in the building element resulting from this task and in the actor's performance.
- **User's context.** It is mediated by the tool and allows the user to obtain a contextual visualization adapted to him.
- **Perception of the cooperation context.** It is guided by the tools and the actors' business skills.
- **Action on the cooperation context.** It refers to an action adapted to its context and guided by the trust perception in each aspect of the cooperation context (Progression of the task, actors, building elements and documents).
- **Capitalization.** It is essential in the concept of trust, because trust is built on the basis of previous experiences.

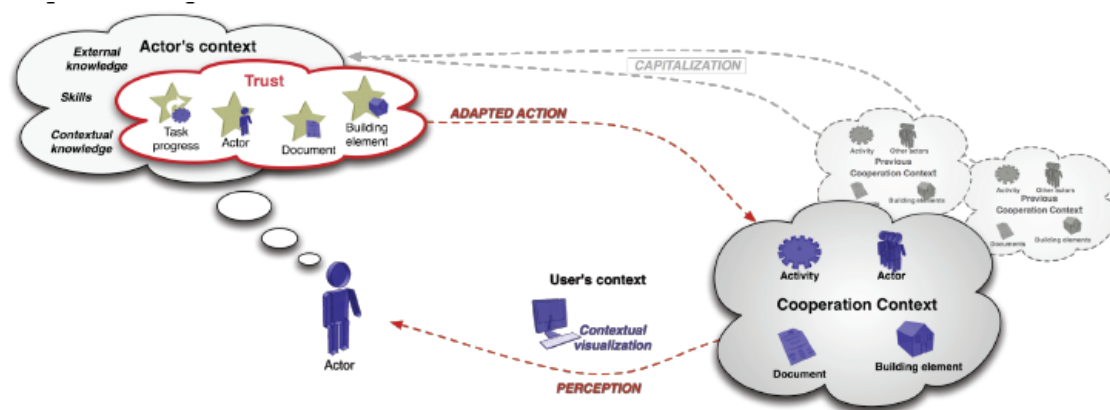


Figure 3. Trust and contexts of action

#### 4. MEASURE OF TRUST INDICATORS FOR COORDINATION IN THE AEC DOMAIN

We have seen that our approach of trust in the cooperative activity lead to four types of specific trust (i.e. task progress, actor, document, building element). We will identify in this section the criteria allowing us to assess trust and we will determine how we suggest making their assessment.

##### 4.1. IDENTIFICATION OF THE TRUST CRITERIA

Our approach for identifying the trust criteria consisted in searching the elements that condition the good progression of the building construction activity. These trust criteria will be then introduced in a dashboard in order to inform the coordinator about the potential dysfunction on the building site. Our approach differs from other studies related to the risks on the building site (Klemetti 2006; Boone 2007; Zou et al. 2007) because our information categorization is slightly different. We suggest structuring information in function of four aspects specific to the construction task: its progress, the actors in charge of the execution, the building elements resulting from the task, and the documents required for the execution of the task. After having defined the trust criteria and categorized them in function of the 4 aspects cited above, we confronted them to professionals coming from the construction sector (architects, engineers and contractors) in order to adjust and validate them. We can now summarize the identified indicators (See Table 1) and identify the sources of information related to each of them.

(1) **The assessment of “Task Progress-Specific Trust”** ( $T_p$ ) depends on:

- *The state of the task.* The trust relies on similarity with a state initially planned or with a state that could be more favourable (e.g. building construction activity in advance).
- *Problems identified during the execution.* A high level of remarks coming from the building site meeting report and corresponding to the task under consideration leads to decrease the trust level.
- *The environment.* The trust is determined by the risk run by the task when there is bad weather forecast, or potential seism...

(2) **The assessment of “Actor-Specific Trust”** ( $T_a$ ) is coming from:

- *The competence.* It is materialized through various certifications (e.g. ISO, Qualibat1). The fact that an organization is certified constitutes a good warrantee.
- *The performance.* It is coming from previous experience and it is possibly capitalized in some performance evaluation systems<sup>2</sup>. Positive previous experience contributes to increase trust, while negative previous experience contributes to increase mistrust.
- *Attendance at building site meeting.* Stakeholders have to regularly attend construction site meetings to be informed about the state of the construction activity, and about all the decisions concerning the activity that they have to perform. If stakeholders do not attend frequently the building site meetings, they cannot be informed about decisions and therefore, it can be a source of dysfunction.



Table 1. Trust criteria and information sources

|                                            |                                             |
|--------------------------------------------|---------------------------------------------|
| <b>(1) Task Progress- Specific Trust</b>   | <b>Information sources</b>                  |
| State of the task                          | Gantt Planning, Pert Planning, 4D           |
| Problems of execution                      | Remarks in the meeting report               |
| Environment                                | Weather prediction,...                      |
| <b>(2) Actor-Specific Trust</b>            | <b>Information sources</b>                  |
| Competence                                 | Certification (ISO, Qualibat <sup>3</sup> ) |
| Performance                                | Performance evaluation system               |
| Attendance at building site meeting        | Meeting report                              |
| <b>(3) Document-Specific Trust</b>         | <b>Information sources</b>                  |
| State of the documents                     | List of documents                           |
| State of the documents requests            | Documents transmission list                 |
| Availability on the building site          | List of documents                           |
| <b>(4) Building Element-Specific Trust</b> | <b>Information sources</b>                  |
| Level of difficulty of execution           | Technical report <sup>4</sup>               |
| Modifications                              | List of modifications                       |
| Respect of budget                          | Budget monitoring                           |

(3) The assessment of “Document-Specific trust” ( $T_d$ ) required for the task takes into account:

- *The state of the documents.* The fact that all the documents are up-to-date contributes to increase the level of trust.
- *The state of the documents requests.* The requests linked to the documents (e.g. request for modification, for validation, etc...) have to be performed within the time limits allowed. A delay contributes to decrease the level of trust.
- *The availability on the building site.* The documents required for the execution of the building element have to be available on the building site. The trust level increases if all the required documents are on the building site.

1 Qualibat : French organism in charge of qualification and certification of French construction firms ,  
<http://www.qualibat.com/>

2 See for example Rating Source: <http://www.ratingsource.com>

3 Qualibat : French organism in charge of qualification and certification of French construction firms ,  
<http://www.qualibat.com/>

4 We make reference here to the « Unified Technical Documents » (DTU), which are standard norms in the French construction sector.

(4) **The assessment of “Building Element-Specific Trust” ( $T_{be}$ )** relies on:

- *The level of difficulty of execution of the task.* It comes from the coordinator’s experience or from other technical judgment issued by organisms such as the CSTB5 for more complex or experimental technical design. A weak level of difficulty of execution of the task ensures a high level of trust.
- *Modifications in comparison with the specifications.* Modifications during the building construction activity are a source of mistakes at the moment of the execution. Indeed, a modification on a building element implies to take into account its impact on the whole building project and on all the documents. Building elements on which we can identify some modifications have to be more controlled and consequently, considered as having a weak level of trust.
- *Respect of budget.* Modifications on building elements and unexpected events (e.g. delay linked to the nature of the ground) are sources of difficulty to respect the budget. These types of situations have to be more controlled.

## 4.2. MEASURE OF THE TRUST INDICATORS

To evaluate the level of trust in the good progression of an activity, we have adapted

S.P. Marsh's approach (Marsh 1994), which identifies the trust during cooperation to our specific context of cooperation.

We distinguish two levels of trust indicators: the Global Trust and the Specific Trust. Figure 4. Global Trust and Specific Trust

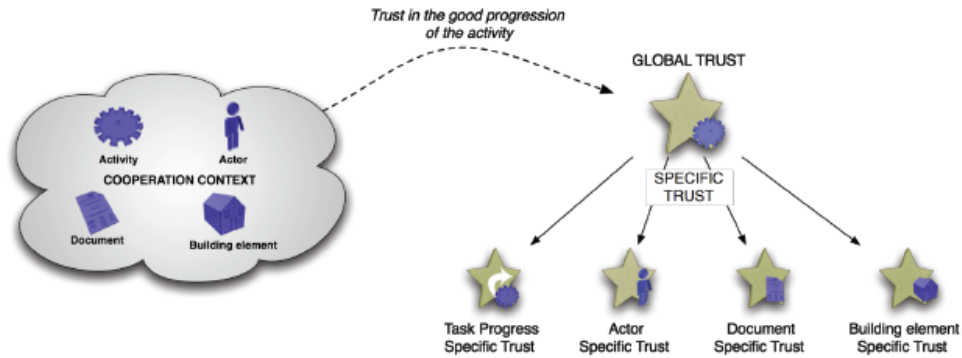


Figure 4. Global Trust and Specific Trust

The Global Trust characterizes the trust in the good progression of the activity in a particular situation. The Specific Trust corresponds to each aspects of the task. We distinguish four types of Specific Trust in a particular situation:

- Task progress Specific Trust,
- Actor Specific Trust,
- Document Specific Trust,
- Building Element Specific Trust.

The Figure 4 illustrates our approach related to the Global Trust and the Specific Trust.

#### 4.2.1. MEASURE OF THE GLOBAL TRUST

$T(\alpha)$  represents the Global Trust in the good progression of an activity  $\alpha$  (The Table 2 summarizes the notions).

$$T(\alpha) = \frac{T_{tp}(\alpha) I_{tp}(\alpha) + T_a(\alpha) I_a(\alpha) + T_d(\alpha) I_d(\alpha) + T_{be}(\alpha) I_{be}(\alpha)}{I_{tp}(\alpha) + I_a(\alpha) + I_d(\alpha) + I_{be}(\alpha)}$$

<sup>5</sup> CSTB : Scientific and Technical Centre for the Building Industry, French organism.

Table 2. Measure of the Global Trust – Summary of annotations

| Description    | Representation                             | Value range |
|----------------|--------------------------------------------|-------------|
| Activity       | $\alpha$                                   |             |
| Global Trust   | $T(\alpha)$                                | [-1, 1]     |
| Specific Trust | $T_x(\alpha) \quad x \in \{tp, a, d, be\}$ | [-1, 1]     |
| Importance     | $I_x(\alpha) \quad x \in \{tp, a, d, be\}$ | [0,1]       |

Thus, the Global Trust results from the trust in each aspects of the task (Progression of the task under consideration, actors in charge of its execution, required documents, performed building elements) and is balanced according to the importance<sup>6</sup>, which is valued by the building construction coordinator.

#### 4.2.2. MEASURE OF THE SPECIFIC TRUST

We have to determine the values of  $T_{tp}(\alpha)$ ,  $T_a(\alpha)$ ,  $T_d(\alpha)$  and  $T_{be}(\alpha)$ .

These values depend on the intrinsic characteristics of the different aspects of the task. In order to evaluate the four types of trust, we make use of the following formula.

$$T_x(\alpha) = \sum_{i=1}^{n_x} NV(C_{x_i})_{\alpha} * \gamma(C_{x_i})$$

$$C_x = \{C_{x_i}\} \quad x \in \{tp, a, d, be\} \quad et \quad i \in [1, n_x]$$

$$\gamma(C_{x_i}) = \frac{1}{n_x}$$

$$NV(C_{x_i})_{\alpha} = 1 \quad si \quad V(C_{x_i})_{\alpha} \in V^+(C_{x_i})$$

$$NV(C_{x_i})_{\alpha} = -1 \quad si \quad V(C_{x_i})_{\alpha} \in V^-(C_{x_i})$$

$$NV(C_{x_i})_{\alpha} = 0 \quad si \quad V(C_{x_i})_{\alpha} \in V^0(C_{x_i})$$

The Table 3 below summarizes the annotations.

Table 3. Measure of Specific Trust – Summary of annotations

| Description                                                                            | Representation       | Value               |
|----------------------------------------------------------------------------------------|----------------------|---------------------|
| Set of criteria for type $x$ specific trust                                            | $C_x$                | Set of Alphanumeric |
| Type of Specific Trust                                                                 | $x$                  | tp ;a ;d ;be        |
| Criterion $i$ for Type $x$ Specific Trust                                              | $C_{x_i}$            | 0 ;1                |
| Number of Criteria for Type $x$ Specific Trust                                         | $n_x$                | [0,n]               |
| Set of Values of Criterion $i$ for Type $x$ Specific Trust                             | $V(C_{x_i})$         | Set of Alphanumeric |
| Set of Positive Values of Criterion $i$ for Type $x$ Specific Trust                    | $V^+(C_{x_i})$       | Set of Alphanumeric |
| Set of Negative Values of Criterion $i$ for Type $x$ Specific Trust                    | $V^-(C_{x_i})$       | Set of Alphanumeric |
| Set of Null Values of Criterion $i$ for Type $x$ Specific Trust                        | $V^0(C_{x_i})$       | Set of Alphanumeric |
| Numerical Value of Criterion $i$ for Type $x$ Specific Trust in the situation $\alpha$ | $NV(C_{x_i})_\alpha$ | -1 ; 0 ; 1          |
| Value of Criterion $i$ for Type $x$ Specific Trust in situation $\alpha$               | $V(C_{x_i})_\alpha$  | Alphanumeric        |
| Type $x$ Specific Trust in situation $\alpha$                                          | $T_x(\alpha)$        | [-1,1]              |
| Coefficient of Criterion $i$ of Type $x$ Specific Trust                                | $\gamma(C_{x_i})$    | [0,1]               |

<sup>6</sup> According to S.P. Marsh, "importance is an agent-centred or subjective judgement of a situation on the part of the agent concerned".

#### 4.3 APPLICATION OF THE METHOD TO MEASURE TRUST INDICATORS

We consider a particular activity (e.g. Shaft column groundwork). We have to identify data related to the task and to the criteria necessary for the measure of trust (See Table 4).

Then, we associate the criterion value to a numerical value:

- [+1]: if the criterion value is a positive value for the good progress of the task.
- [-1]: if the criterion value is a negative value for the good progress of the task.
- [0]: if the criterion value is a neutral value for the good progress of the task (e.g. if we don't have data related to the criterion).

So, if we consider the task "Earthwork", we can identify the following situation:

- The progress of the task conforms to the planning.
- There are some remarks related to the task in the building site meeting report.
- The weather forecast is favourable for performing the task.
- The contractor has no competence certification.
- The contractor frequently attends the building site meetings.
- The building element is not especially difficult to perform.
- There is no modification in comparison with the specifications for the building element.
- The budget is respected for this building element.
- The document is good for execution and available on the building site.

The Table 4 summarizes the situation and explains the measures of Global and Specific Trust.

Table 4. Measure of Global and Specific Trust: example

| (1) Task progress Specific Trust - $T_{ip}(\alpha)$ |                    |         | (2) Actor Specific Trust - $T_a(\alpha)$               |                    |    |
|-----------------------------------------------------|--------------------|---------|--------------------------------------------------------|--------------------|----|
| Criterion                                           | V                  | NV      | Criterion                                              | V                  | NV |
| State of the task                                   | In progress        | +1      | Competence certification                               | No                 | -1 |
| Problems of execution                               | 3 remarks          | -1      | Performance                                            | Positive           | +1 |
| Environment                                         | -6°C               | -1      | Attendance at building site meetings                   | Frequent           | +1 |
| $T_{ip}(\alpha) = -0,33$                            |                    |         | $T_a(\alpha) = 0,33$                                   |                    |    |
| (3) Document Specific Trust - $T_d(\alpha)$         |                    |         | (4) Building element Specific Trust - $T_{be}(\alpha)$ |                    |    |
| Criterion                                           | V                  | NV      | Criterion                                              | V                  | NV |
| State of the documents                              | Good for execution | +1      | Level of difficulty of execution                       | Good for execution | +1 |
| State of the documents requests                     | Finished           | +1      | Modifications                                          | Finished           | +1 |
| Availability on the building site                   | Ok                 | +1      | Respect of budget                                      | Ok                 | +1 |
| $T_d(\alpha) = +1$                                  |                    |         | $T_{be}(\alpha) = +1$                                  |                    |    |
| Global trust - $T(\alpha)$                          |                    |         |                                                        |                    |    |
| Specific Trust                                      | NV                 | Import. | $T(\alpha) = +0,51$                                    |                    |    |
| Task progress Specific Trust                        | -0,33              | +1      |                                                        |                    |    |
| Actor Specific Trust                                | +0,33              | +0,75   |                                                        |                    |    |
| Document Specific Trust                             | +1                 | +1      |                                                        |                    |    |
| Building element Specific Trust                     | +1                 | +1      |                                                        |                    |    |

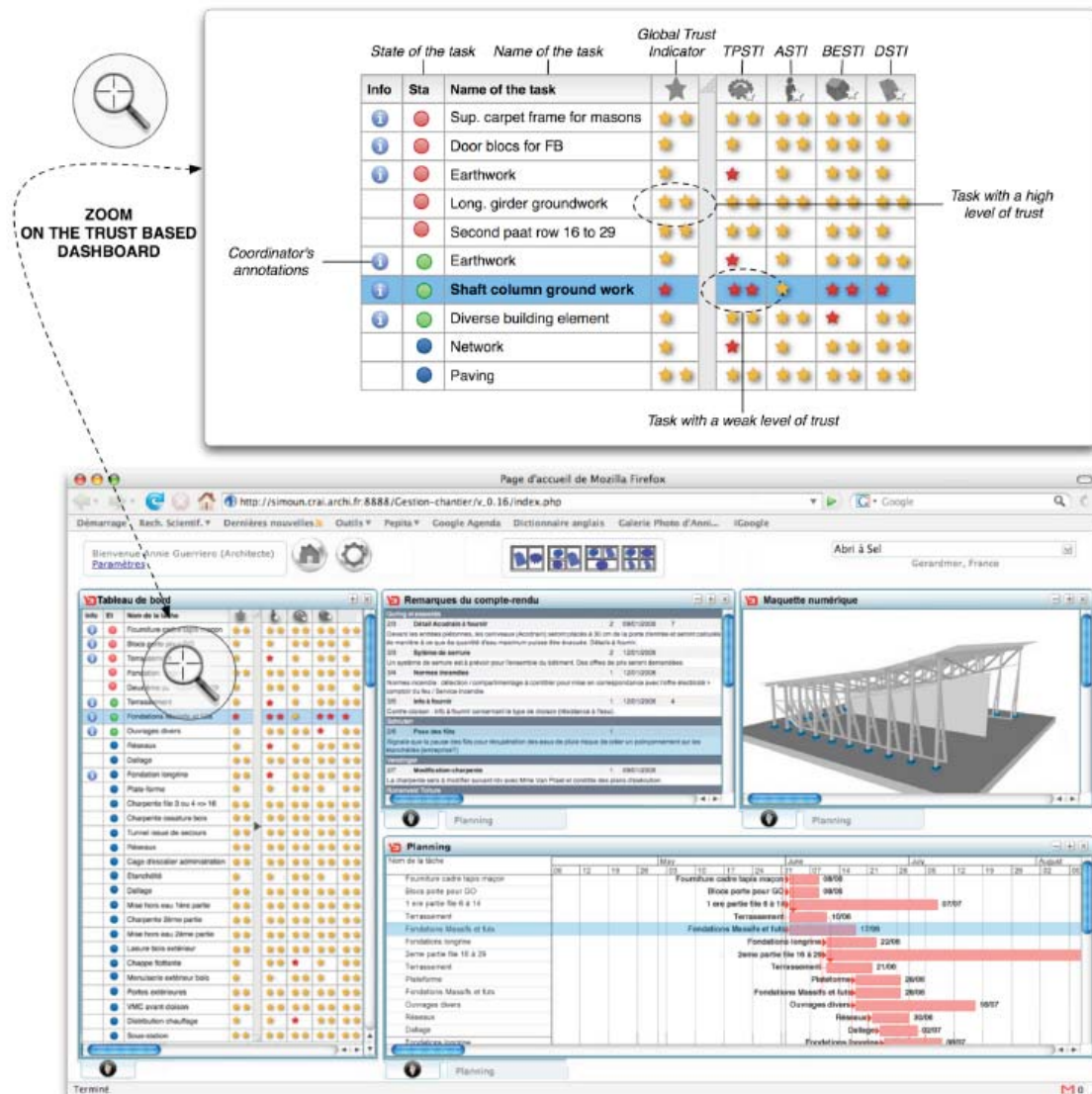
## 5. BAT'iTRUST, A DASHBOARD FOR THE CONSTRUCTION ACTIVITY

### COORDINATOR

We have noted in section 1 that the coordinator disposes of multiple views (e.g. planning, meeting report...) to support the coordination of the building construction activity.

Anterior research works have dealt with relationships between the contents of these views.

These works have contributed to implement a models infrastructure based on the concepts of MDE (Model Driven Engineering) describing the cooperation context model in the AEC sector as well as the models of the concepts represented in the views. They have also led to the implementation of a prototype called "Bat'iViews" (For more information see (Kubicki et al. 2006)). This tool suggests putting into relation the concepts of four dynamic views regularly manipulated by the stakeholders of the building construction activity (i.e. meeting report, 3D view, planning and list of remarks coming from the meeting report) integrated in a multi-view interface. The user can freely navigate between views and the selection of an element of a view allows refreshing the global interface and putting in relation elements of the other views in correspondence with the selection.



Our proposal of a dashboard based in trust is integrated in the continuity of these works. We suggest inserting a new view dashboard based on trust in the multi-view interface in order to guide the navigation of the building construction coordinator. Our prototype called Bat'iTrust allows visualizing the trust indicators calculated based on the method detailed in section 4.2. and information coming from the cooperation context. The aim here is, not to surcharge data entry but on the contrary to extract trust indicators from available information (See Table 1).

The interface of the dashboard (See Figure 5) represents a list of construction tasks to which are bounded the state of the task (i.e. on hold, in progress...), the possible annotations of the coordinator and the following different trust indicators:

- Global Trust Indicator,
- Task progress-Specific Trust Indicator,
- Actor-Specific Trust Indicator (concerns actors in charge of the execution of the task under consideration),
- Document-Specific Trust Indicator (concerns documents required for the execution of the task),

- Building element-Specific Trust Indicator (concerns building elements resulting from the task).

This interface allows the coordinator to rapidly identify the tasks on which there is a potential dysfunction. Moreover, the selection of a Specific-Trust Indicator generates a configuration of views adapted to more easily understand the nature of the dysfunction. If we consider, the example detailed in the Figure 5, the coordinator identifies a weak level of Global Trust for the task "Shaft column groundwork". Then, he notices a low level of trust for the Task-

Progress Specific Trust and he can select the indicator to refresh the multi-views interface and to obtain a configuration of views fitted to the understanding of the problem. In this case, it is a configuration composed of 3 views: the planning, the meeting report, and the 3D mock-up.

Finally, the coordinator can join some notes related to the task in order to make a synthesis of information that he has consulted.

## 6. PROSPECTS AND CONCLUSION

In conclusion, we have characterized the mission of the building construction coordinator and highlighted the potential of a view dashboard based on trust as a coordination assistance tool. At this stage of our research work, we have made interviews with coordinators, and diffused a survey to the professionals coming from the construction sector (architects, engineers, and contractors) to validate and to adjust our trust criteria. A first prototype of Bat'iTrust is under implementation in order to confront our proposal to professionals coming from the AEC sector, to assess its relevance and possibly to adjust it in function of feedbacks. For the moment, our effort is concentrating on the utilization of data coming from two Web-based tools integrated in the same infrastructure of models as our dashboard. These tools comes from CRTI-weB 7 suite: the first one is intended for writing and reading building construction meeting report <sup>8</sup> and the second one allows managing plans <sup>9</sup>. On the short run, our prototype could calculate the value of trust criteria related to building construction meeting report and to plans exchange. Evidently, information sources (tools) necessary for the assessment of the set of trust criteria to which we make reference (See section 4.1.) are heterogeneous. Emergent works about modelling of business services in the AEC sector are important perspectives to ensure to credibility of a proposal such as ours. Our prototype will use besides a set of Web-services interrogating the two CRTI-weB tools. Our aim is to make the prototype as generic as possible, that is to say independent from a given suite of tools.

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<sup>7</sup> The CRTIweB suite has been implemented in the framework of the Build-IT project. This project aims to lead the Luxembourgish AEC sector to electronic cooperation

<sup>8</sup> <http://buildit.tudor.lu/demo> (Login : demo Password : demo)

<sup>9</sup> <http://demoged.buildit.tudor.lu/> (Login : demo Password : demo)

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## **A VISION FOR A FRAMEWORK TO SUPPORT MANAGEMENT OF AND LEARNING FROM CONSTRUCTION PROBLEMS**

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### **ABSTRACT**

Construction projects are information-intensive. The availability of integrated project data and the recording of such data throughout the construction process are essential not only for project monitoring, but also to build a repository of historical project information that can be used to improve future project performance. This paper describes ongoing research and proposes a knowledge-based framework that uses ontological engineering to help retrieve and disseminate construction engineers' tacit knowledge in managing on-site construction problems. A Problem/Action (P/A) model is presented to describe the relationships between relevant concepts describing a P/A pair. The ontology-driven search mechanisms implemented will enable users to query for P/A pairs based on the related "concepts" rather than on mere "keywords" used to describe the problems. The authors expect that the envisioned framework will enable standardized storage and retrieval of construction problems/actions knowledge and apply an automated, semantic reasoning process to manage reported knowledge. This would allow construction engineers to better share and use corporate knowledge when searching for appropriate actions to remedy on-site construction problems. The shared knowledge is also expected to help better predict the impacts of remediation actions in a project life cycle, positively affecting their cost and schedule ramifications.

### **KEYWORDS**

Construction problems, Reasoning mechanisms, Ontologies, Learning, Knowledge Management, Construction Industry

## **1. INTRODUCTION**

Knowledge management systems have been subject of considerable research in civil engineering in recent years. Knowledge management involves creating, capturing, storing, retrieving, and disseminating knowledge. Throughout the construction of any facility, knowledge is gained and lessons are learned, but little of this hard-earned experience is electronically captured in a manner that allows knowledge to pass from project to project and from person to person (Tserng and Lin 2004). Many organizations are now engaged in knowledge management efforts to leverage knowledge both within their organization and externally for the benefit of their employees and customers (Lima et al. 2005, El-Diraby and Zhang 2006).

A knowledge-based system aims to leverage the plethora of knowledge by making it retrievable and sharable among practitioners to help reduce the time and cost associated with rework, waste, and on-site field problem management.

### **1.1 KNOWLEDGE-BASED SYSTEMS FOR CONSTRUCTION**

Knowledge-based systems for construction management target many different construction areas, such as site planning, risk management, document sharing, project control, progress monitoring, and cost estimation. There have been studies of on-site construction problem processing and document and information sharing (e.g. Russell 1993, Russell and Fayek 1994, Kartam 1996, Wang et al. 2007, Zhu et al. 2007). Russell (1993)

developed a computerized program to collect and process site information based on traditional superintendents' daily site reports. In addition, Russell identified a list of problem sources that can result in time, cost, quality, and safety problems at construction sites. Russell and Fayek (1994) developed a framework for automated interpretation of job records to identify problems in activities and suggest corrective actions. The actions were suggested based on activity attributes and problem types. For reasoning, the prototype utilized fuzzy logic combined with expert rules to describe the relationships among the activity attributes, corrective actions, and problem sources. Kartam (1996) presented an interactive knowledge-based system for constructability improvement, where construction lessons were analyzed and classified into the 16 divisions of the Master Format System based on the Construction Specification Institute (CSI). The system included alternative means to information access and multiple views of the knowledge base to improve on-site construction processes. El-Diraby and Zhang (2006) developed a web-based knowledge system to support the representation and utilization of corporate memory in the construction domain. The system used a taxonomy for building construction to retrieve semantically related construction reports and meeting agendas. Moreover, Wang et al. (2007) developed a knowledge-based fuzzy neural network to diagnose problems observed throughout the implementation of professional construction management in Taiwan. Zhu et al. (2007) demonstrated the usability of Industry Foundation Classes (IFCs) for constructing a metadata model for requests for information (RFI) that enhances the retrieval of RFI related information.

## 1.2 SEMANTIC SYSTEMS IN THE CONSTRUCTION INDUSTRY

Human knowledge can be efficiently presented through semantic systems that utilize ontologies to encapsulate and manage the representation of relevant knowledge (Lima et al. 2005). In computer science, ontologies are a technique used to represent and share knowledge about a domain by modeling the concepts in that domain and the relationships between those concepts (Gruber 1993). Specifically, ontologies provide a knowledge representation form using a system of concept hierarchies (taxonomies), associative relations (to link concepts across hierarchies), and axioms (El-Diraby et al. 2005). Thus, ontologies enable reasoning about semantics between domain concepts and can play a crucial role in representing knowledge in the construction industry (Lima et al. 2005, Rezgui 2006).

A variety of semantic resources ranging from domain dictionaries to specialized taxonomies have been developed in the construction industry. Among them are BS6100 (Glossary of Building and Civil Engineering terms produced by the British Standards Institution); bcXML (an XML vocabulary developed by the eConstruct IST project for the construction industry); IFC (Industry Foundation Classes developed by the International Alliance for Interoperability); OCCS (OmniClass Classification System for Construction Information), BARBi (Norwegian Building and Construction Reference Data Library); and e-COGNOS (COnsistent knowledGe maNagement across prOjects and between enterpriSes in the construction domain) (Rezgui 2006, Wang and Boukamp 2007). Amongst these semantic resources, the e-COGNOS project was the first project to deploy a domain ontology for KM in the construction industry and has been tested in leading European construction organizations (Lima et al. 2005).

Practitioners and researchers have acknowledged limitations of the current approaches for managing information and knowledge related to and generated throughout construction projects (Russell 1993, Kartam 1996, Rezgui 2006). Despite the interest and the effort put into knowledge management (KM) by researchers and companies, many of the systems applied are dealing only with abstract documents including reports, manuals, and claims. Little research tackles the tacit knowledge and experience that exists in the heads of engineers and experts, which would have to be semantically formatted in models to allow this knowledge to be shared and disseminated among practitioners (Tserng and Lin 2004).

This paper describes the vision of the authors' ongoing research effort to develop a knowledge-based framework that uses ontological engineering to retrieve and facilitate the dissemination of construction engineers' experience in managing on-site construction problems. The framework will enable standardized reporting of construction problems/actions knowledge and apply an automated, semantic reasoning process to manage the reported knowledge. Problems/actions (P/A) relevant information will be incorporated in this framework together with related decision-making knowledge stored by the construction engineers.

## 2. OBJECTIVE

The objective of this ongoing research is to identify and understand the semantics amongst heterogeneous construction problems' relevant information as well as their complex interdependencies. This understanding will help in the development of ontologies and model-based adaptive mechanisms that can organize

problem/action relevant information according to content and interdependencies. In other words, a semantic knowledge-oriented framework will be developed to allow more efficient representation of tacit knowledge related to construction problems. The Construction Problem Framework (or framework for short) will allow construction engineers to efficiently store, and update their construction problem information. In addition, search mechanisms will allow them to semantically refine their search for remediation actions. The standardized management of semantically rich construction problem/action information will support construction managers' efforts in searching and finding specific documents of interest and learning from information about past problems. Thus, the framework is expected to improve problem management at construction sites. To better elaborate the framework's target functionality, an illustrative scenario is presented in the following section.

### 3. ILLUSTRATED SCENARIO

The following scenario description aims to help better visualize the envisioned framework and its potential benefits to construction professionals.

*Situation:* Bill, a construction engineer, is sitting in his office and thinking of a solution to a construction problem: The concrete samples taken from "Column C12-11 in Building C" do not achieve the required strength. His remediation action will certainly affect the construction process by increasing cost and required time. He has the Construction Problem Framework installed on his laptop.

According to company policy, Bill has to report any construction problem using the Construction Problem Framework, which then stores the collected information in a shared database on the company's intranet. He now uses the framework to create a record of his concrete strength problem and to search for similar problems that have been reported by other engineers in the company to get ideas about how to solve the problem. The Construction Problem Framework provides a number of ontologies that contain semantic descriptions of *products*, *processes*, *resources*, and *unplanned situations* and their relationships. Since the framework requires a specific structure for describing the core data of a problem, Bill can drag-and-drop concepts from the ontologies to describe the problem. For example, 'column' and 'slab' are classified as building products in the *Product* ontology, and 'concrete' is classified as a material in the *Resource* ontology. This not only allows Bill to perform ontology-based searches when recording a new problem but also supports building a database containing the corporate memory of construction problems related to semantically defined concepts. Bill can also add comments and attach sketches and photos in order to fully describe the problem. Now, Bill chooses the concepts 'column', 'cast-in-place', and 'concrete' to describe his problem. The first step is finished.

The search tool offered by the Construction Problem Framework allows Bill to navigate the company's P/A database searching for problems similar to the current problem. Since the system's ontologies specify that the concepts 'formwork', 'rebar', and 'curing' are related to the concepts 'cast-in-place' and 'concrete', the system identifies problem/action (P/A) records that are related to all of these concepts. After retrieving the records, the system allows Bill to change the automatically identified search parameters. Bill indicates that the concepts 'formwork' and 'rebar' are irrelevant to his problem, but he's glad that the system identified the related concept curing for him. Finally, his search results in the identification of exactly three P/A records. He reviews each of these records and finds out that one of the recorded actions can possibly be applied to his problem. To get further details about this potential solution, he contacts Mrs. Miller who created the report and works in the East Coast Division of his company. Now Bill has identified a plan to solve his problem using a slightly modified version of Mrs. Miller's approach. The second step is finished.

Bill considers using Carbon Fibers to support the column instead of demolishing and reconstructing, and calculates the additional cost and time required as relative consequences to this action and updates his problem/action record in the system. After the successful implementation of this solution, Bill updates the problem record a final time to add a solution evaluation, which contains information about the effects of the solution on the project, such as the related cost increase and schedule delay, so other engineers can draw upon his knowledge in the future. The third and final step is finished (see Fig. 1).

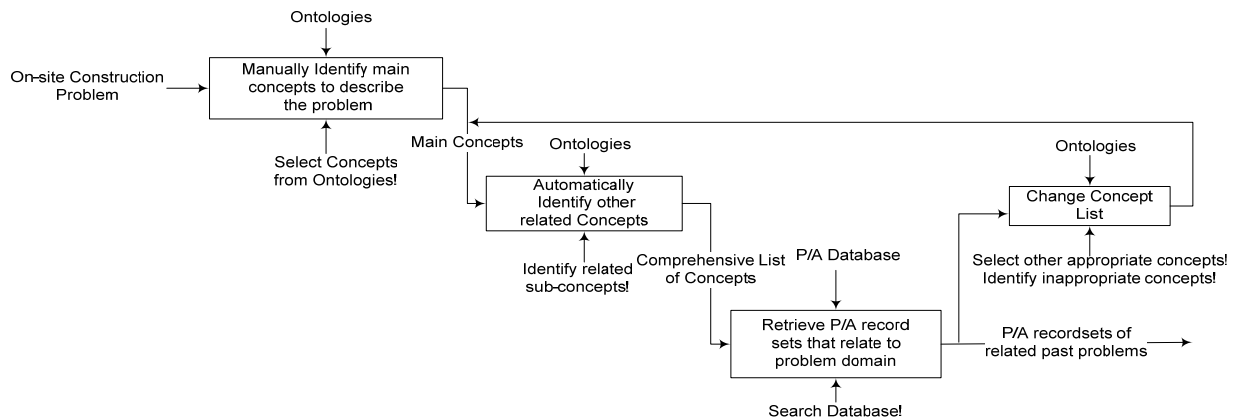


Figure.1: IDEF0 depicting the Construction Problem/Action Information Retrieval Process  
The framework and the framework requirements are identified and described in the following sections.

#### 4. THE FRAMEWORK STRUCTURE

The authors envision the framework to consist of two layers, as illustrated in Fig. 2:

- Service layer: the service layer offers the user interface (UI) functionalities for the system. A set of functionalities is provided as separate services which respond to user requests and forwards them to the knowledge task manager in the system layer. The service layer will allow the user to access different functionalities to store the new construction problem related information, update existing information, search for specific information related to problems, and to maintain and update the related ontologies.  
Since the functionalities are provided as services, they can be easily integrated in a company's existing knowledge management system.
- System layer: The knowledge management system layer supports all the services provided by the system. It processes user requests coming from the service layer. The system layer consists of the following components, which are described in greater detail in the following sections:
  1. Problem/Action Model
  2. Problems/Actions Database
  3. Ontologies
  4. Knowledge Task Manager

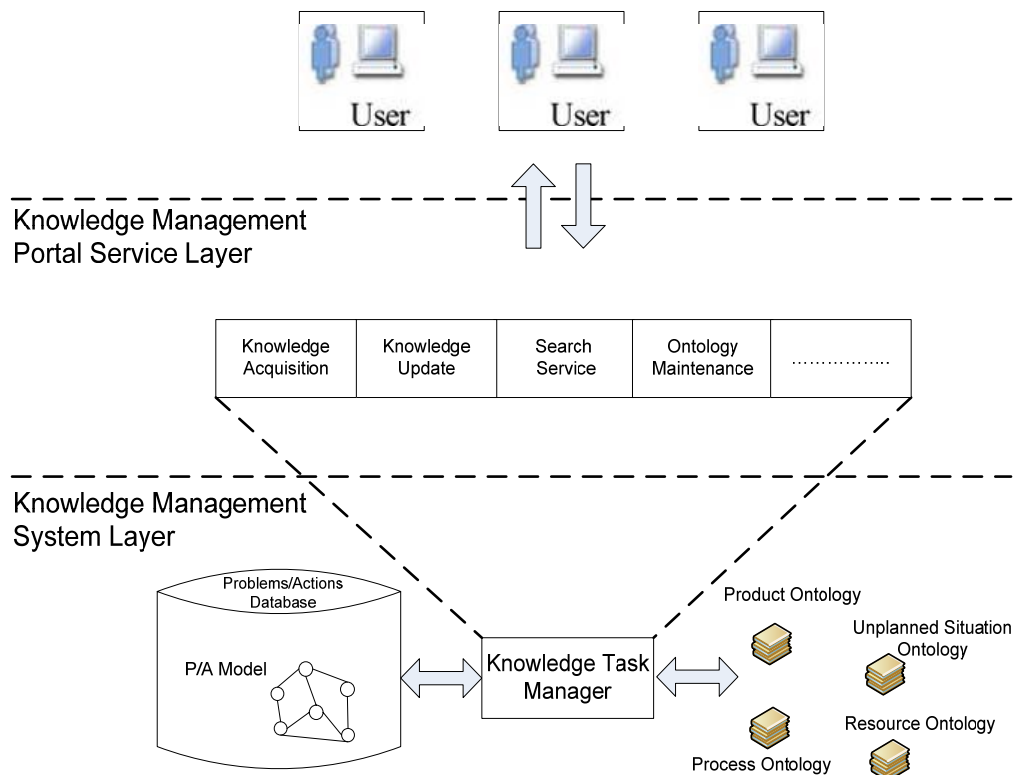


Figure 2: The Construction Problem Framework Main Platform

#### 4.1 PROBLEM/ACTION MODEL

Several researchers have defined construction problems as unplanned situations leading to detrimental effects on construction project aspects (e.g. Mitropoulos and Howell 2001, Levy 2007). A common similarity between construction projects is that each problem encountered is paired with a set of corrective actions taken to overcome the problem. Russell and Fayek 1994 claimed that construction activities can be described in a set of attributes and be incorporated in a model together with problem sources and corrective actions.

Building on these ideas, the authors of this paper developed an ontological model to describe the structure of construction problems with respect to the relationships between relevant concepts that should be stored in the Problem/Action model to describe Problem/Action pairs. The Problem/Action ontology can be summarized as follows: Construction problem knowledge is encapsulated in a model, where a set of *Construction Problems* reported by a set of *Actors* result from a set of *Unplanned Situations* in a *Project* and refer to a set of *Processes*, which produce a set of *Products* that utilize a certain combination of *Resources*. *Construction Problems* result in *Problem Consequences*, which are identified according to a set of *Technical Topics* and are solved by a set of *Problem Resolving Actions*.

The Problem/Action Model developed out of this Problem/Action ontology combines only 10 concepts. This allows the model to be generic enough to be applicable to all on-site construction problems in general, while being specific enough to support the envisioned ontological engineering approaches described in the succeeding sections, which will support more efficient knowledge storage, retrieval and dissemination. A UML diagram of the Problem/Action Model is shown in Fig. 3.

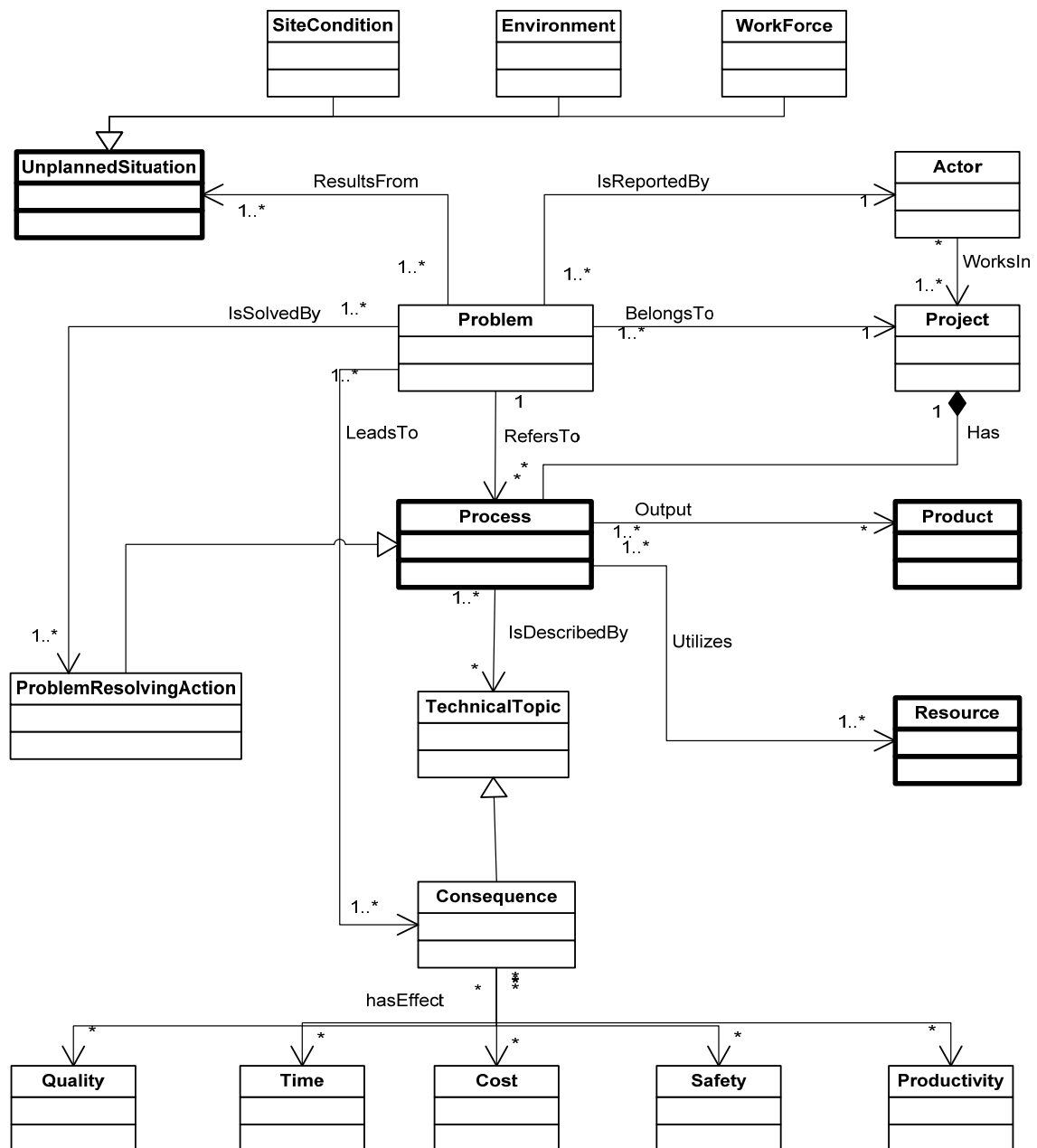


Figure 3: UML diagram of the Problem/Action Model

It should be noted that this Problem/Action model contains six concepts predefined in the e-COGNOS domain ontology, namely Project (PJ), Process (PR), Product (PD), Actor(AC), Resource (RE), and Technical Topics (TT). This allows for integration of the Problem/Action model with other models developed in the context of e-COGNOS.

## 4.2 ONTOLOGIES

Some of the above mentioned concepts used to describe a Problem/Action pair should be extended and represented through a number of ontologies, from which specific sub-concepts can be chosen that will be linked to the P/A pair in the P/A database. The authors propose to use an initial set of four ontologies: *Product* ontology, *Process* ontology, *Resource* ontology, and *Unplanned Situation* ontology. Among the specific sub-

concepts represented in each of these ontologies, the user will only have to select suitable concepts that describe his/her problem. Upon linking these ontologies to our P/A model, the user will gain access to the concept scheme, which provides access to related concepts as well. On the one hand, the relationships between the concepts can help guide the user in choosing the appropriate terms for the problem description. On the other hand, this setup will support the ontology-driven search mechanisms in returning more significant results relevant to the search parameters specified by the user when searching for similar problems in the database.

Various taxonomies have been developed that have the potential to serve as a starting point for developing the required sub-concept ontologies. Among these taxonomies are BS6100, bcXML, ISO 12006-2, IFC, OmniClass, and BCTaxo (El-Diraby and Zhang 2005, Rezgui 2006). The *Product* ontology, *Process* ontology, and *Resource* ontology are predefined in BCTaxo and can be further extended in our framework (El-Diraby and Zhang 2005). The forth ontology representing the *Unplanned Situation* builds on previous research performed by Russell (1993) and Russell and Fayek (1994) to identify problem sources. The later research identified various problem sources and grouped them in 10 categories. A partial list of Product, Resource, Process, and Unplanned Situation taxonomies is represented in Fig. 4.

The ontologies will be stored in OWL (Web Ontology Language) files in the system and will be kept separated from the P/A database. This will allow the administrator to modify and update the ontologies with new concepts without altering the P/A database. A full description of the database functionalities is given in the following section.

#### 4.3 PROBLEM/ACTION DATABASE

The P/A database is a relational database that holds the problem/action pair information. The information in the P/A database will be structured according to the P/A model described earlier. Documents, such as sketches, comments, and pictures needed to describe a construction problem and action will be embedded in the P/A database through links to the files. Similar to MIA's approach (MIA 1998), the data stored in the database will be classified into 2 groups: Administrative data and Problems/Actions data. The database stores administrative data in an *authentication* table that stores user-names and passwords to provide different levels of access and keeps track of different users of the system.

The P/A information for each problem is stored separately in the database. The *problem* and *action* related tables will allow the user to store links to any documents, photos, and sketches related to the problem or the action. Each class of the P/A model is represented in tables. The user will be able to identify the *Product*, *Resource*, *Process*, and *Unplanned Situation* describing concepts using the ontologies. The identified concepts chosen from the ontologies will be stored in appropriate tables in the database.

|                              |                            |
|------------------------------|----------------------------|
| <b>Product</b>               | <b>Unplanned Situation</b> |
| - Software                   | - Site Condition           |
| - Basic Products             | - Cleanliness              |
| - Management Product         | - Site Unavailability      |
| - ConstructionComplex        | - Storage Space            |
| - Civil Product              | - Ground Condition         |
| - Industrial Product         | - Consultant/Architect     |
| - Building Product           | - Payment Delays           |
| - Column                     | - Changes                  |
| - Slab                       | - Site permission          |
| - Foundations                | - Drawings                 |
| - Construction Aid           | - Errors                   |
| .....                        | - Insufficient Information |
| <b>Resource</b>              | .....                      |
| - Material                   | - Workforce                |
| - Concrete                   | - Lowskill Level           |
| - Aggregate                  | - Unsafe Practices         |
| - Cement                     | - Work                     |
| - Sand                       | - Subcontractors Errors    |
| - Equipment                  | - Rework                   |
| - Heavy Machinery            | - Supplies/Equipment       |
| - Drilling Equipments        | - Material Inspection      |
| - Labor                      | - Equipment Breakdown      |
| - Software                   | .....                      |
| .....                        |                            |
| <b>Process</b>               |                            |
| - Design Process             |                            |
| - Operation Process          |                            |
| - Construction Process       |                            |
| - Conc. Construction Process |                            |
| - Cast in Place Conc.        |                            |
| - Earth Removal Process      |                            |
| - Maintenance Process        |                            |
| - Electronic Process         |                            |
| .....                        |                            |

Figure 4: A partial list of Product, Resource, Process, and Unplanned Situation taxonomies

The database server is centralized on the organization's main system. A firewall can be built to protect the system database against intrusion. Project participants may have access to all or some of the problem/action information through the organization's Intranet, as determined by their levels of access authorization (Tserng and Lin 2004). Any information about a construction problem can be stored in and obtained from the system database only through a secure interface that requires each user to log in.

#### 4.3 KNOWLEDGE TASK MANAGER

The knowledge task manager is responsible for processing the service request from the service layer. When the user starts to provide new information to the system, the task manager links the ontologies to the application view to assist the user in exactly defining the product, resource, process, and the unplanned situation information relevant to the problem. Subsequently, the task manager stores the new problem information in the P/A database.

The task manager controls the search process by again linking the ontologies to the application view so the user can define the search boundaries, keywords, and relationships. Once the search parameters are defined and provided to the task manager, it creates a link to the P/A database and searches for existing problem/action records using ontological reasoning mechanisms. Those reasoning mechanisms are described in the following section.

#### 5. REASONING MECHANISM

When the system is implemented at an organization's intranet, users will be able to query for problems/actions based on the related "concepts", rather than on mere "keywords" used to describe the problems. Similarly,



when a user saves problem/action information to the corporate database, it will be classified according to the related concepts, which are defined through the ontologies in the system. The ontology-driven search mechanisms return more significant results than those generated by a traditional keyword search mechanism. To define search parameters, a user will be able to select concepts from the ontologies in the system. Each of the concepts is linked to other related concepts through ontological relationships. These ontological relationships allow the reasoning mechanism to determine what other problem records are filed under other concepts that are related to the concepts chosen by the user.

For example, let us assume that the construction engineer is indexing a construction problem similar to the one described in the illustrative scenario. A number of keywords come to the engineer's mind for describing the problem: Column, Concrete, Strength, Cast-in-place. The construction engineer will then select the concepts related to these keywords. Based on this methodology, the concept Column will be retrieved from the Product Ontology, the concept Concrete will be retrieved from the Resource Ontology, and the concept Cast-in-place will be retrieved from the Process Ontology (see Fig. 4).

The main problem of information search is that the majority of information search mechanisms are primarily based on keywords; and "words" alone don't have meaning or semantics (Lanin and Lyadova 2007). When the construction engineer searches for problems similar to a 'cast-in-place concrete column' problem through a traditional keyword-based search, he/she might end up finding unrelated problems, e.g. "pre-cast Concrete" problems if "Concrete" was a keyword used for the search. If the keyword combination "cast-in-place concrete" is used, problems related to cast-in-place concrete will be retrieved, but "concrete pouring" problems that do not contain the keyword "cast-in-place concrete" in their description, will not be retrieved, even though they are related.

The envisioned approach uses an ontology-driven search mechanism that uses knowledge about the relationships between concepts. For example, when the user selects the process concept "Cast-in-Place" and the resource concept "Concrete", the system will be able to determine that problems related to "cast-in-place concrete" should be retrieved, while problems related to "precast concrete" should be ignored. Additionally, the system can highlight other problems related to cast-in-place concrete, such as formwork problems, rebar problems, curing problems, etc. Through re-adjusting the search parameters, e.g. by selecting the resource concept "formwork" as inapplicable, the user can improve the search results.

Also, the user can generalize his/her query for problems by selecting more general concepts, e.g. "Concrete" as a Resource, "Building Product" as a Product, and/or "Construction Process" as a Process. The system then will return records of problems that encompass not only concrete columns but also slabs and foundations (see Figure 2). In addition, the construction engineer will have access to the personnel (actor) who reports the problem so he/she can contact him/her personally to get feedback on a specific technical issue.

## 6. SUMMARY AND CONCLUSION

This paper presented an overview of a system currently being developed and researched by the authors. The system is a knowledge-based framework that shall help retrieve and disseminate construction engineers' experience of managing on-site construction problems. The framework is envisioned to enable standardized reporting of explicit and tacit knowledge about construction problems/actions and will apply an automated, semantic reasoning process to manage the reported knowledge. The framework can be integrated with different construction semantic resources such as e-COGNOS and BCTaxo. A Problem/Action (P/A) ontological model has been presented to describe the relationships between relevant concepts describing a P/A pair. The Problem/Action model developed combines ten concepts. A set of four ontologies - *Product* ontology, *Process* ontology, *Resource* ontology, and *Unplanned Situation* ontology - will be used to help conceptualize four of the concepts represented through the P/A model.

The framework is envisioned to be implemented at an organization's intranet. Therefore, users will be able to query for problems/actions records based on the related "concepts" rather than on mere "keywords" used to describe the problems. Ontology-driven search mechanisms are implemented to respond more efficiently to construction engineers' queries, thus returning more significant results than those generated by a traditional keyword search mechanism. The standardized management of semantically rich construction problem/action information will support construction managers' efforts in searching and finding specific documents of interest and learning from information about past problems. Thus, the framework is expected to improve problem management at construction sites.

Research related to the ontological reasoning mechanisms and the development of related concept ontologies is ongoing. It has to be identified how concepts in the ontologies should be linked semantically to support the developed reasoning mechanism and how the ontologies can be kept manageable, so that companies can enhance their ontologies, e.g. if new problem types appear which should be described with new concepts. Additionally, it needs to be investigated whether other concept ontologies, aside from the Product-, Process-, Resource-, and Unplanned Situation-concept ontologies, would benefit this system.

Additionally, research should be conducted in linking our P/A model with integrated project models (IPMs) to allow leveraging the project information available in IPMs. This integration is expected to help study and manage the impacts of problems on a project and may potentially help reduce or even avoid problem propagation throughout the construction lifecycle.

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## **CHANGE MANAGEMENT IN CONSTRUCTION PROJECTS**

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### **ABSTRACT**

Decisions are made everyday in construction processes based on incomplete information, assumptions and the personal experience of the construction professionals. Project changes and/or adjustments are inevitable as they are a fact-of-life at all stages of a project's life cycle. Managing changes effectively is crucial to the success of a construction project.

Change management in construction requires an integrated solution to discipline and coordinate the process, for example, documentation, drawing, process, flow, information, cost, schedule and personnel. The construction industrial needs an effective construction change management process. This paper summarizes various aspects of the existing construction change management processes and provides a comprehensive literature review as well as some comments on possible future directions.

## 1. INTRODUCTION

In much of the world, construction is an extremely fragmented industry. For example, in Canada more than 95 percent of construction companies employ less than 10 employees. Except for a few large general contractors, the capacity of most companies in the constructor sector is fragmented, for example, structural design and specialty trades. A construction project can be classified as “one-of-a-kind” production in manufacturing terms, or simply “one-off” projects. Project management in the construction sector faces some critical issues that are very different from other industrial sectors: 1) the team involves multiple players at multiple locations; 2) the construction supply chains are short-term and project-based; 3) different styles of project management and costing systems are used with different product delivery systems, i.e. “design-bid-build”, “construction manager” and “design-build” contracts; 4) unique needs to manage the involved legal contracts and other related documents (for example change orders); 5) the scope has extended to the life-cycle operation and maintenance management of the finished product, in addition to the architect-design-construction process.

Project changes and/or adjustments are inevitable as they are a fact-of-life at all stages of design and construction. In an EPSRC (Engineering and Physical Sciences Research Council, U.K.) report (Sun et al., 2004), it states that *“More than a third of major clients are dissatisfied with contractors’ performance in keeping to the quoted price and to time, resolving defects, and delivering a final product of the required quality.”* It may be inferred that the clients’ dissatisfaction is likely caused by change orders running through the construction projects. The effort of managing change orders has imposed a huge burden on project management, and it is a nightmare that industry people wished they never have to face. Changes in construction also cause serious ethical problems and disputes. According to an ethical survey done in 2004 (available at: [http://www.acce-hq/documents/ethics\\_survey.pdf](http://www.acce-hq/documents/ethics_survey.pdf)), 84 percent of respondents expressed that they had encountered situations that they considered unethical in their business dealings, while 61 percent of respondents stated that the industry was “tainted” by unethical acts. Owners are blamed for bid shopping and for playing tricks in payments; contractors were accused of over billing, front-end loading and playing change-order games.

Change management is a pure application-oriented issue and requires engineering innovation to solve the problem. Based on our investigation of the construction change management area, and a pressing need from industry versus the scarcity of literature and software tools in the domain, poses a promising opportunity for research and development in construction. The following sections of this paper summarize the various aspects of construction change management and provides a comprehensive literature review as well as some insightful thoughts on this topic.

## 2. CHANGES IN CONSTRUCTION PROJECTS

Changes in construction projects are very common and likely to occur from different sources, by various causes, at any stage of a project, and may have considerable negative impacts on items such as costs and schedule delays. A critical change may cause consecutive delays in project schedule, re-estimation of work statement, and extra demands of equipment, materials, labor, and overtime. Changes, if not resolved through a formalized change management process, can become the major source of contract disputes, which is a severe risk contributing to project failure.

Classifications of changes in general terms apply to changes in construction domain. Motawa et al. (2007) summarize that: *“Based on time, change could be anticipated or emergent, proactive or reactive, or pre-fixity or post-fixity. Based on need, change could be elective or required, discretionary or non-discretionary, or preferential or regulatory. Based on effect, change could be beneficial, neutral or disruptive.”* However, since the construction industry is project-based, the best classification is to discuss changes in the context of typical stages/phases in a construction project. Table 1 summarizes stages, sources and impacts of construction changes.

Table 1: Summary of construction changes

| Stage         | Stakeholder                    | Types of changes                                                                                                                                                | Impacts                                                             | Actions                                                                                          |
|---------------|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Specification | Owner/Client/User or architect | Changes to requirements including specification, scope of projects, design brief, etc.                                                                          | Changes in design and construction processes                        | Carefully provide detailed specification documents before bidding.                               |
| Design        | Design/engineering Consultant  | Incomplete/inconsistent drawings; design error/defect; design change; omissions of site conditions and buildability; changes in codes and regulations           | Rework of design and drawing; rework in construction; change orders | Better control of design versions, drawings; site investigation; consider buildability in design |
| Construction  | Contractor/sub-contractors     | As-builts not confirm with as-design; quality defect; unanticipated site conditions; value engineering; materials or equipment not available; inclement weather | Rework; change orders; changes in design                            | Quality control; site operational control; coordinated documents and drawings; daily logs        |

The primary causes of change orders are owner-initiated changes and designer's errors and omissions (Issac and Navon, 2008). The impact of changes to a construction project needs to be evaluated case by case in order to assist with the decision making process. Though some changes may bring in "benefits" to the stakeholders especially to the owner in the long run, most changes, if not managed properly, will result in "negative" impacts, most likely resulting in time and cost overruns. In general, upper-stream changes have larger impacts. Lu and Issa (2005) believe that most frequent and most costly changes are often related to design, such as design changes and design errors.

### 3. LITERATURE

The industrial need of effective construction change management versus the scarcity of meaningful R&D work appears to be a fact in the construction industry. There is very limited research work addressing the change management issues specifically within the construction project management context.

- Sun et al. (2006) designed a change management toolkit for construction projects that includes a change dependency framework, a change prediction tool, a workflow tool, and a knowledge management guide.
- Ipek and Ömer (2007) investigate requirement-design relationships and enable traceable requirement in architectural design. They developed a prototype system called DesignTrack and used LEED requirements as a case study.
- Lee and Peña-Mora (2005) proposed using system dynamics to build dynamic project models to assist planning and control of construction projects. This dynamic project model captures several non-value adding change iterations (rework cycles and managerial change cycles). The simulation is demonstrated using a case study in Road Bridge Construction, and many change option/policy implications are summarized based on this case study.
- Motawa et al. (2007) presented some preliminary results on proactive change management through an integrated change management system composed of a fuzzy logic-based change prediction model and a system dynamics model based on the Dynamic Planning and control Methodology (DPM).
- Charoenngam et al (2003) discussed Web-based project management and a Change Order Management System (COMS) specifically developed for coping with changes in construction projects. Standard web technologies were used and a change order procedure involving workflows, roles/actors, documents, records keeping, and a centralized database were developed.
- Recently, Issac and Navon (2008) have proposed a change control tool (CCT) which creates requirement traceability through links between client requirements and the building design. They believe that number of changes or the impact of changes can be controlled by capturing client

requirements accurately at the beginning of the project and through the requirement traceability that is build up afterwards.

Apart from the project management domain, some other researchers have been trying to address change management issues in various other ways:

- 4D or 5D integration which integrates time and cost models in addition to 3D geometry models. In this way, changes can not only be controlled in the design and engineering stages in the whole construction process, but also be controlled in the built environment life-cycle to some extent. Jongeling and Olofsson (2007) suggest that location based scheduling provides a promising alternative to activity-based planning approaches for planning of work-flow with 4D CAD. In this approach, work schedules are integrated with design models so that changes in design or during construction can be better coordinated. In the latest 5D technologies of Graphisoft, automation extends beyond design changes. ArchiCAD also automates and coordinates the creation of documents, schedules, bills of materials, and quantities estimates through its integrated “virtual building” model based on IFC’s BIM models (available at: <http://www.vicosoftware.com/>).
- Data sharing and interoperation. Bakis et al. (2007) proposed an approach to model the complex interrelations of the different components of the various aspects of the design and the different versions of each component in order to maintain consistency in architectural design. When changes happen, the interrelation models help notification/propagation of version changes.
- Web-based integration and collaboration approaches. Lottaz et al. (1999) proposed using constraint satisfaction techniques to express possibly large families of acceptable solutions in order to facilitate and abbreviate the collaboration and negotiation processes, ultimately to improve the change management and the productivity during phases of design and construction.
- By combining Web services and intelligent agents, collaborative workflow technologies can be used to handle dynamic and complex business processes on the Web and can be applied to construction project management systems for effective and flexible change management. In a recent work, we conducted a comprehensive literature review of collaborative workflows in design and manufacturing integration (Hao and Shen, 2007a).

The concept of engineering change in manufacturing typically deals with any changes or inconsistencies between product design, engineering and manufacturing life-cycles. Engineering change management (ECM) is thus focused on the co-ordination of product life-cycle model (PLM) and the enterprise management model in ERP, as shown in Figure 3. Since engineering change is not contractual, the impact of engineering changes stays generally within an organization and is well controlled via the vast adoption of integrated systems in manufacturing enterprises, such as CAD/CAE/CAPP, PLM, and ERP software tools. Construction changes, on the other hand, are harder to control because of the fragmented nature of the industry as well as a low investment and limited adoption of IT technologies.

#### **4. REWORK, CHANGE ORDER AND CCD**

Most researchers distinguish three kinds of changes: rework, change order, and Construction Change Directive (CCD) (Huang et al., 2007; Levy, 2006). Figure 1 shows the relationship of change orders, reworks, and CCDs.

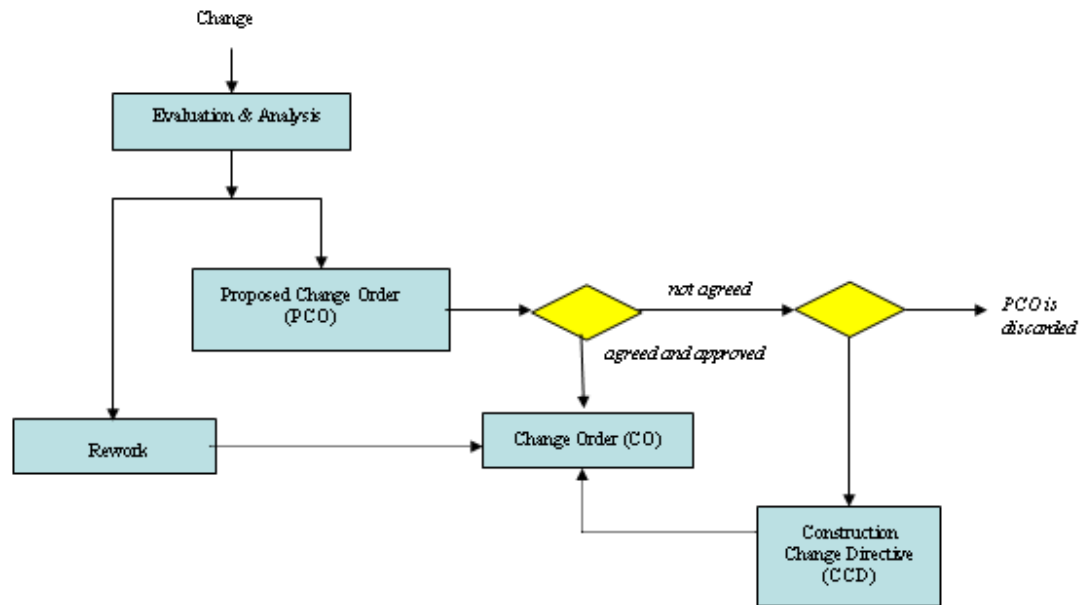


Figure 1: Change orders, reworks, and CCDs

Change order refers to changes that are generated by unanticipated causes, for example, scope changes from the owner, design / technological changes from the architect, and cost and/or time changes caused by supplier problems, design errors, material and operational failures, or by unsatisfactory site conditions. Change orders are common to most projects, and very common with large projects. This type of change has to be negotiated case by case and requires a common (documented) agreement among all the parties involved. The owner or its delegated architect or project manager has the authority to finalize change orders. Once a change order is submitted and approved, it generally serves to alter the original contract such that the change order now becomes part of the contract. The contractual nature of construction changes is a very distinguished feature of the construction industry.

A CCD is issued by an owner or its designate requesting a change in the contract scope when there is no agreement on cost. CCDs are originated from disputable change orders and could become change orders again, once the dispute can be settled. The process of handling CCD is simpler than that of change orders in that it directly starts from the implementation stage once the CCD is issued (see Figure 2).

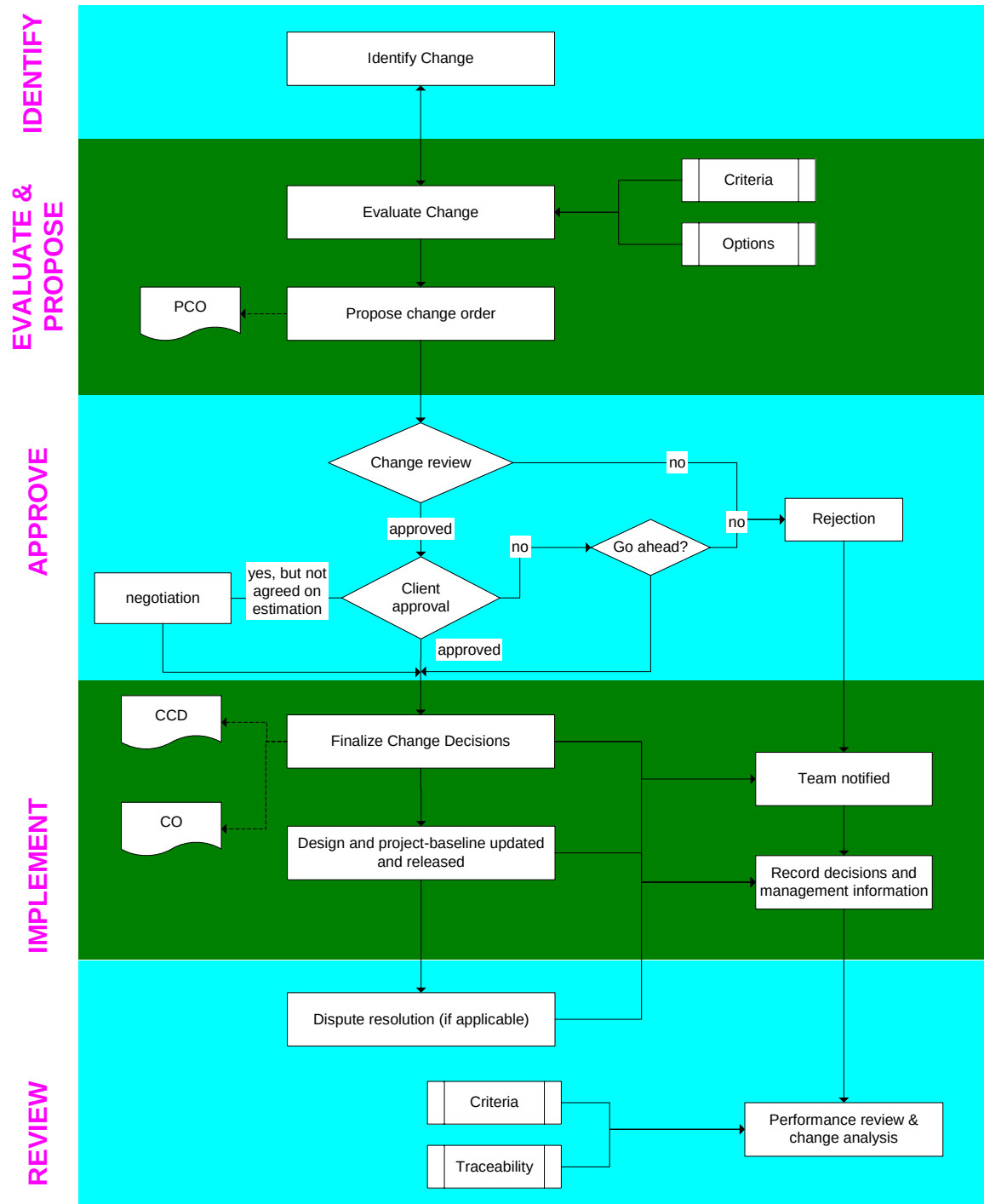


Figure 2: General change process model

Rework refers to re-doing a process or activity that was incorrectly implemented in the first place and is generally caused by quality defects, variance, negligence, and poor design and/or on-site management (Sun et al., 2004). Rework is usually pure waste and should be avoided as much as possible. The only requirement for handling rework is to perform all necessary correction activities to guarantee the conformance of the “as-built” to the “as designed”, which is more or less obvious. However, the decision of rework is a difficult one



since rework is normally accompanied by the demolition of what has already built. In most cases, reworks become change orders by minor adjustments in design, construction processes or use of alternative materials as long as the baseline requirements can be still satisfied by the new alternative.

A number of organization and associations produce standard contract forms. These include the American Institute of Architects (AIA), the Association of General Contractors (AGC), the Construction Management Association of America, and in Canada, the Canadian Construction Association (CCA) and Canadian Construction Documents Committee (CCDC). A construction project management authority can choose to use any combination of these standard documents directly or develop their own documents either as modified standard documents or proprietary in-house contracts. As change orders are part of the contract, all these standards have articles or clauses to obligate the change management procedure.

## 5. A GENERAL CHANGE PROCESS MODEL

Change management seeks to forecast possible changes; identify changes that have already occurred; plan preventive measures; and coordinate changes across the entire project [8]. Small reworks with minor impacts do not need to go through a formal change process. However, changes with noticeable impacts, either reworks or change orders, all require following a formal process in change management.

A generic change process model is considered to have five stages in a sequence: identify, evaluate & propose, approve, implement and review (Figure 2). The process model is conceptualized based on a synthesis of the change process models reviewed in the literature and the characteristics of computational environments.

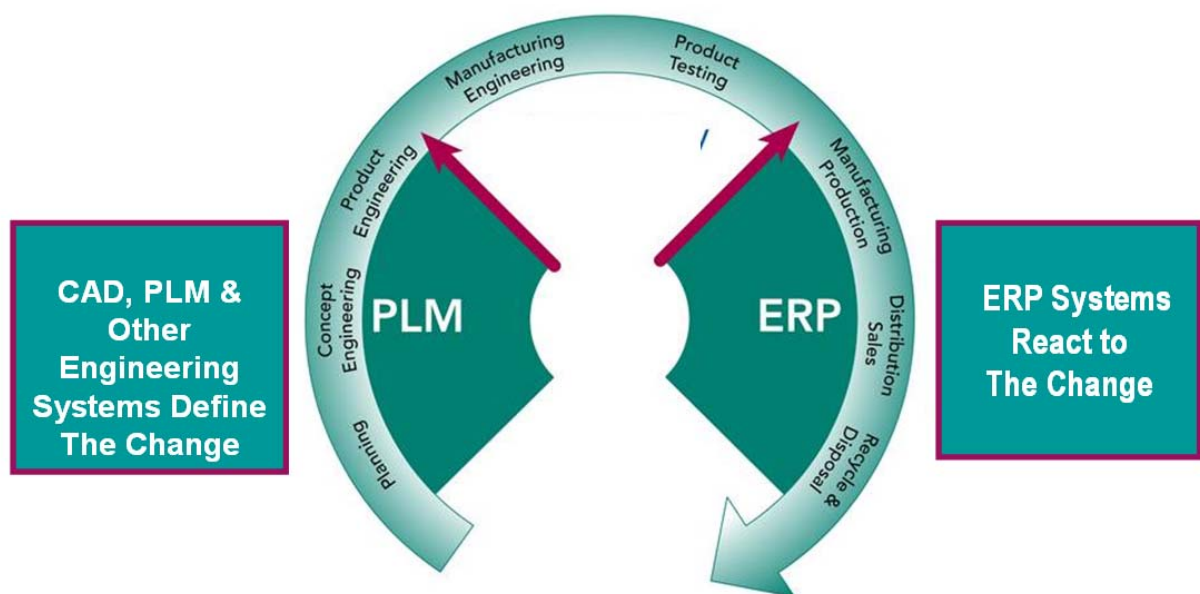


Figure 3: Engineering change in manufacturing

**1. Identify changes.** This requires an effective change management system to build up the relationships of the requirements, symptoms, malfunctions, and various other aspects of changes. It is common for a typical change management system to exclude the identification stage and start with the change evaluation and proposal processes. This is because the initiating role of a change is hard to be taken automatically by the system, or at the least, a computational system is far less “smart” or “intelligent” than people thought. However, from academic or innovative viewpoint, reaching the “intelligence” of such pro-activeness in change management needs a lot of R&D efforts.

**2. Evaluate and propose changes.** Based on criteria and options, the evaluation module calculates all possible impacts that an identified change can have on other processes and team members, in terms of time and cost. Analysis and (if possible) optimization of change options is required for decision-making – whether to go ahead with any of the change options or to undertake further investigations. This stage, again, requires heavy efforts in modeling intelligent behaviors involved in the decision-making processes. The outcome of the evaluation is a proposal change order (PCO) which summarizes the change itself and the impacts of the change – a new updated action plan, cost, schedule, etc.

**3. Approve changes.** Each identified change needs to go through a formal approval process. There are a set of predefined approval processes for different types of changes and construction contracts. Firstly, all the parties involved must agree on the proposed change of work described in the PCO. This is done through a change review process. Next, the approval of the client is required for the PCO to be finalized. This may involve decision making on acceptance, improvement, or rejection of changes. An accepted change modifies the contract while a rejected change may either become a permanently rejected change, or it might still be enforced in the form of a CCD.

**4. Implement changes.** The change management process model requires all the parties involved to keep records of all relevant information on change cases to build a case base for future use. Unlike previous stages, no major decision is expected during the change implementation stage. An operational system is needed to make sure that all aspects are updated, all parties are notified, and all activities are done properly and coordinated well. Everything recorded is linked with each other and to the change cases as well in order to facilitate the change analysis procedures afterwards.

**5. Analyse changes.** Change analysis and system performance is reviewed based on the data collected during the change implementation phase.

## **6. CHALLENGES TOWARDS INTEGRATED CHANGE MANAGEMENT**

Developing an effective construction change management process is a challenging task because it requires an integrated solution for coordinating everything involved for the purpose of the change management in question (see Figure 4). While one may find a couple of project management or construction enterprise management software on the market, change management in construction is a topic that one can hardly get through any resources. The existing change management module, that some software claimed to have, is mostly a feature for change information recording and document approval. Change estimation, impact analysis, post-change analysis, statistics, and more importantly, change traceability are not implemented in most of these solutions.

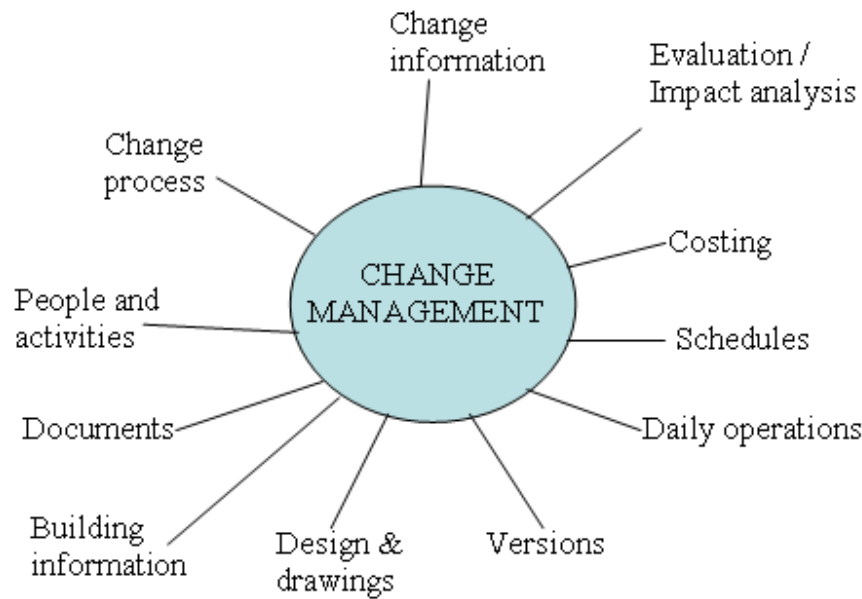


Figure 4: Requirements of an integrated change management system

An effective construction change management system will have the following requirements:

- Consolidating all aspects of change information, including causes, symptoms, sources, impacts, actions, and processes of changes and their linkages
- Evaluating all elements affected by a change, across all design and construction phases
- Automating workflow processes for change review, approval and implementation
- Coordinating changes into operational systems of different parties
- Coordinating changes into a shared project management system
- Coordinating people's activities (including notification, reminding, monitoring, etc.)
- Coordinating the distribution and management of documents and drawings in latest versions
- Day-to-day process and cost recording
- Dispute resolution procedure
- Change traceability and post-change analysis

Change management is a part of project management and enterprise management systems, but it can also stand alone as an independent system or as part of an integrated system with its focus on the construction change itself.

An integrated change management system requires technical supports from different technologies, including Collaborative Workflow, System Integration and Collaboration Technologies, nD Modeling, Web-Based Collaborative Project Management Tools, and Online Document Management Tools.

We have other projects focusing some of these technologies. Shen et al. [18] provides a comprehensive survey on system integration and collaboration technologies in the construction sector. Hao and Shen (2006b) has done a comprehensive literature review of adaptive workflow and distributed workflow technologies. We strongly share the vision that the integration agent, web services, and workflow technologies provides a promising solution for effective coordination of product design, engineering and manufacturing activities across or within enterprise boundaries. Sharing similar ideas, Boddy et al. (2007) proposed an outline architecture for the process driven integration in construction based on the use of agent technologies, Web services / composition, Semantic Web, and higher level protocols in web services stack. Another report by our group (Neelamkavil et al., 2008) is focused on the need for intelligent system in construction process automation. Based on the FIATECH's Capital Projects Technology Roadmap Vision (<http://www.fiatech.org/projects/roadmap/cptri.htm>), this report covers related technologies such as 3D/4D modeling in automated design and engineering; intelligent material management and control for automated

construction supply chains; robotics, mobile devices and RFID, etc. for construction process automation, and project management and enterprise management systems.

## 7. CONCLUSION

Changes are inevitable in construction projects. And, during a construction project, many decisions have to be made, often based on incomplete information, assumptions and personal experience of the construction professionals. Change is a common denominator in all construction projects, though the size, scope, and complexity of projects may vary significantly from case to case. Change management is a critical problem faced by the construction industry. The effort of managing change orders has imposed a huge burden on project management. Changes are identified as the major cause of project delay, cost overruns, defects, or even project failure. More seriously, playing games on changes cause serious ethical problems and disputes in the industry.

Changes in construction projects are very common and likely to occur from different sources, by various causes, at any stage of a project, and may have considerable negative impacts. This paper addresses the types the changes, as well as their stakeholders, causes, impacts and correction actions in the context of typical stages/phases in a construction project. Effectively managing change orders in construction processes is not trivial because change orders are a part of contract and they need to be strictly traced in terms of contracts, documents, approval process, payment claim, etc.

Based on a synthesis of several change process models reviewed in the literature and the characteristics of computational environments, a generic change process model is proposed having five stages in a sequence: identify, evaluate & propose, approve, implement and review. Building an effective construction change management system is very challenging, and one can hardly find a mature software tool on the market, that deals with this issue. Existing change management module, that some software claimed to have, is mostly a feature for change information recording and document approval. Change estimation, impact analysis, post-change analysis, statistics, and more importantly, change traceability are lacking in these solutions. An integrated change management system requires technical supports from different technologies, including collaborative workflow, system integration and collaboration technologies, nD modeling, web-based collaborative project management tools, and online document management tools. We have not arrived at a full solution for construction change management yet. More work will have to be undertaken to develop innovative and practical solutions that are adoptable by the industry.

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## **IMPROVING COMMUNICATION OF SCHEDULING INFORMATION OF EARTHWORK CONSTRUCTION PROCESS USING 4D VISUALISATION MODEL IN ROAD PROJECTS**

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### **ABSTRACT**

Innovative visualization technology applied to construction simulation and optimization has the potential to improve communications and coordination amongst the project stakeholders. In this context and in the drive for innovation in construction management, this paper introduces a framework of a 4D prototype for the automatic generation of visual terrain surfaces during earthwork construction processes. The framework has been designed and developed by integrating road design data, quantities of cut and fill, productivity models, algorithms for modelling terrain profiles and a road profile visualiser. The paper details the prototype of 4D visualization model (4DVM) that has been designed and developed in this research using innovative methodology where 4D models of terrain surfaces are generated based on coordinate data and the productivity of earthwork. The model has been demonstrated with a case study that was used to validate the model. The 4DVM is intended to assist project planners/construction managers in logical decision making processes for construction scheduling and resource planning. It will also improve the communication gap amongst the construction team and consequently improve site coordination and operations.

### **KEYWORDS**

Earthwork operations, innovative methodology, road profile generation, schedule communication, 4D visualization model (4DVM).

### **1. INTRODUCTION**

Construction industry is very traditional and there is a lack of process visualization particularly in construction planning and scheduling. Retik et. al. (1990) explored the potential application of computer graphics to construction scheduling to represent scheduling of construction progress in terms of graphical images at any time during the construction process.

Williams (1996) designed a demand-driven 4D model for the generation of a graphical construction plan based on simulation, visualization, and communication. In a large scale project, a visual representation of the schedule can be extended to monitoring not only the construction progress, but also all the auxiliary activities, including onsite plant and equipment (Adjei-Kumi et al. 1996). Collier and Fischer (1996) demonstrated visual-based 4D modelling and scheduling in a case study of the San Mateo County Hospital. McKinney et al. (1996) proposed a 4D computer-aided design (4D-CAD) tool with visual and communicative functions to facilitate the design process.

Note: \* contacting author

Adjei-Kumi and Retik (1997) applied the concept of virtual reality to visualize construction plans using library-based 4D models. McKinney et al. (1998) demonstrated the capability of 4D-CAD models to identify construction problems prior to their actual occurrence. Andrej, T., Branko, K. and Danijel, R. (1999) introduced a new level of support to engineers throughout the product life cycle to deal with a platform independent language for 3D visualisation and product modelling using roads as an example.

The limitation of traditional techniques such as bar charts and the critical path method

(CPM) to provide information regarding the spatial aspects of a construction plans, have motivated the research effort to incorporate visualisation into project scheduling and progress control (Koo and Fischer 2000). Dawood et al (2002) developed an integrated database to act as information resource base for 4D/VR construction process simulation.

The work has been applied to a building project in the UK.

Kamat and Martinez (2003) described a general purpose visualisation system that can generate accurate 3D objects of construction operations and the resulting products.

Dawood et. al. (2005) introduced innovative visual planning tools aiming to assist construction planners to make accurate and informed planning decisions of the spatial aspect of activity during execution of construction projects and concluded that the visual planning tools need to be practical and add high value to communications. Ragip A.

(2005) introduced a new approach for geometric based modelling and simulation of construction processes.

Several research efforts in the visualisation of construction planning have been conducted and linked to scheduling; they are, however, mostly in the building construction and there has been limited research in infrastructure construction projects. For example, Liapi (2003) focused on the use of visualisation methods during construction of highway projects to facilitate collaborative decision making on construction scheduling and traffic planning, however, this research ignored the visualisation of construction schedules for the intermediate stages of the construction processes.

Castro and Dawood (2005) developed “RoadSim” simulator system, which is a construction site knowledge based simulation system, is used to develop master construction schedules in road projects based on calculated productivity of road earthwork activities under available resources with a different set of equipment and site working conditions. The productivity of earthwork activity provided by the RoadSim has been considered as one of inputs in this research. Kang et. al. (2006) suggested an approach to simulate 4D models for the movement of earthwork activity for the intermediate stage of construction process in civil engineering projects using morphing techniques for the realisation of construction processes in the graphical form. 4D modelling of earthwork operations were developed in a 3DCAD model with equal volume at different stages during construction operations and linked with the construction schedule.

Previous research efforts did not address the interface of production rate, which is based on available resources and site conditions for the development of 4D models. The key issue faced in road construction is variable productivity from one day to another due to the special characteristics of the road construction projects such as fluctuation in daily weather conditions, working conditions in open sky, resource unavailability in time and other unpredictable factors. The study focuses on integrating the variable productivity due to the aforesaid reasons by introducing new approach for the automatic generation of terrain surface with the variable production rate provided throughout the earthwork construction operations.

This paper presents innovative methodology for the development of 4D modelling (3D surface based on coordinate data plus time derived from productivity) of earthwork construction processes applied in road projects. The model generates terrain surfaces road profiles automatically using variable productivity data at intermediate stages during the earthwork processes. The model is intended to assist in improving the communication of road construction scheduling information and to produce efficient construction scheduling and resource planning. The remainder of this paper introduces the framework of the prototype, terrain surface generation, case study demonstration and conclusion followed by acknowledgement and references.

## **2. FRAMEWORK OF THE 4D VISUALISATION MODEL**

The general specification of the framework 4D visualisation model (4DVM) is outlined in figure 1. The framework integrates road design data, sectional quantities of cut and fill, productivity models, algorithms for modelling terrain profiles and a road profile

visualiser. The model assists in generating visual terrain surfaces of road profiles throughout the earthwork operations. The next section describes in detail the input, process and the output of the 4DVM.

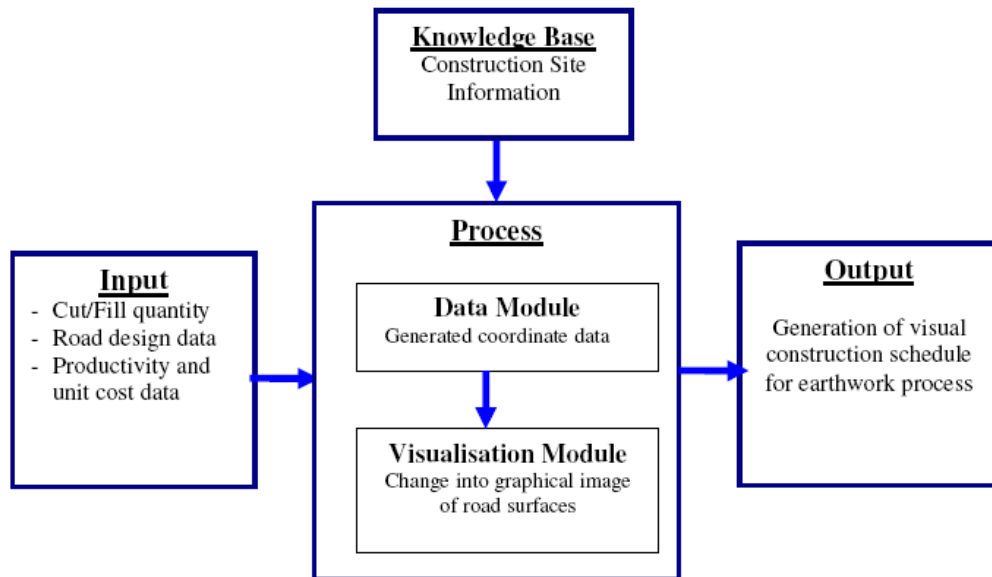


Figure 1:  
Frame  
work  
specifi

cation of 4D visualisation model (4DVM).

## 2.1 INPUT

The sectional quantities of cut/fill of earthwork activity along the working road section, productivity of the activity and construction site knowledge base are key components of the framework. The sectional cut/fill quantities are calculated using the road design data such as L-section and X-section at required intervals of chainage. The productivity of earthwork activity is produced by “RoadSim” simulator developed by the Castro and Dawood (2005). This is based on available resources, equipment sets and site working conditions. This is incorporated with the model to determine the total duration of the earthwork operations. The soil characteristics along the working road section, types of available equipment set for a selected activity, haulage distance of soil, working conditions and all other factors including weather conditions that control productivity has been incorporated within the “RoadSim” simulator.

Additionally, the construction knowledge base assists in identifying the possible location and numbers of site access points, methods of construction for different types of soils, selection of equipment set for a particular activity and soil characteristics. The site operational knowledge-base assists in establishing sequential relationships amongst listed activities during the construction operations. The following section describes and demonstrates the process of a detailed schedule development including the information flow diagram.

## 2.2 PROCESS

The process of the framework includes two modules, these are: data module and visualisation module. The data module processes the Input data to produce a detailed schedule and to generate the coordinate data of terrain surfaces based on production rate i.e. on weekly basis in this study. The visualisation module processes the coordinate data produced by the data module and converts it into terrain surfaces of the road profile in a regular triangular grid. The difference of level with a colour index shows the height of cuts and fills with a red and blue colour respectively. Details of schedule development, mathematical formula derivation and algorithms for terrain generation are presented in sections 2.2.1, 2.2.2 and 2.2.3 respectively.



## 2.2.1 SCHEDULE DEVELOPMENT

The flow chart of schedule development presented in Figure 2 shows the main steps of input, processing and output of activities together with a logical interaction for the development of details schedule. The lists of sections are defined at required intervals along the road using an L-section profile. Road design data such as L-section & Xsection are used to identify list of locations as per the required interval and accuracy. Site information provides possible initial points where earthwork operations can start and the information concerning haulage distance and access routes condition for the transportation of soil mass from borrow pit to site and depositing the extra or unsuitable soil mass at dumping sites. The location of access point is a key factor that affects construction planning and visual scheduling. The mass quantity is calculated at every listed locations of a road project. In this study, "RoadSim" is used to identify productivity information and required resources at selected locations and construction activities. The productivity is used to determine the duration of activities and the precedence relationship between activities is established based on the construction operation knowledge base.

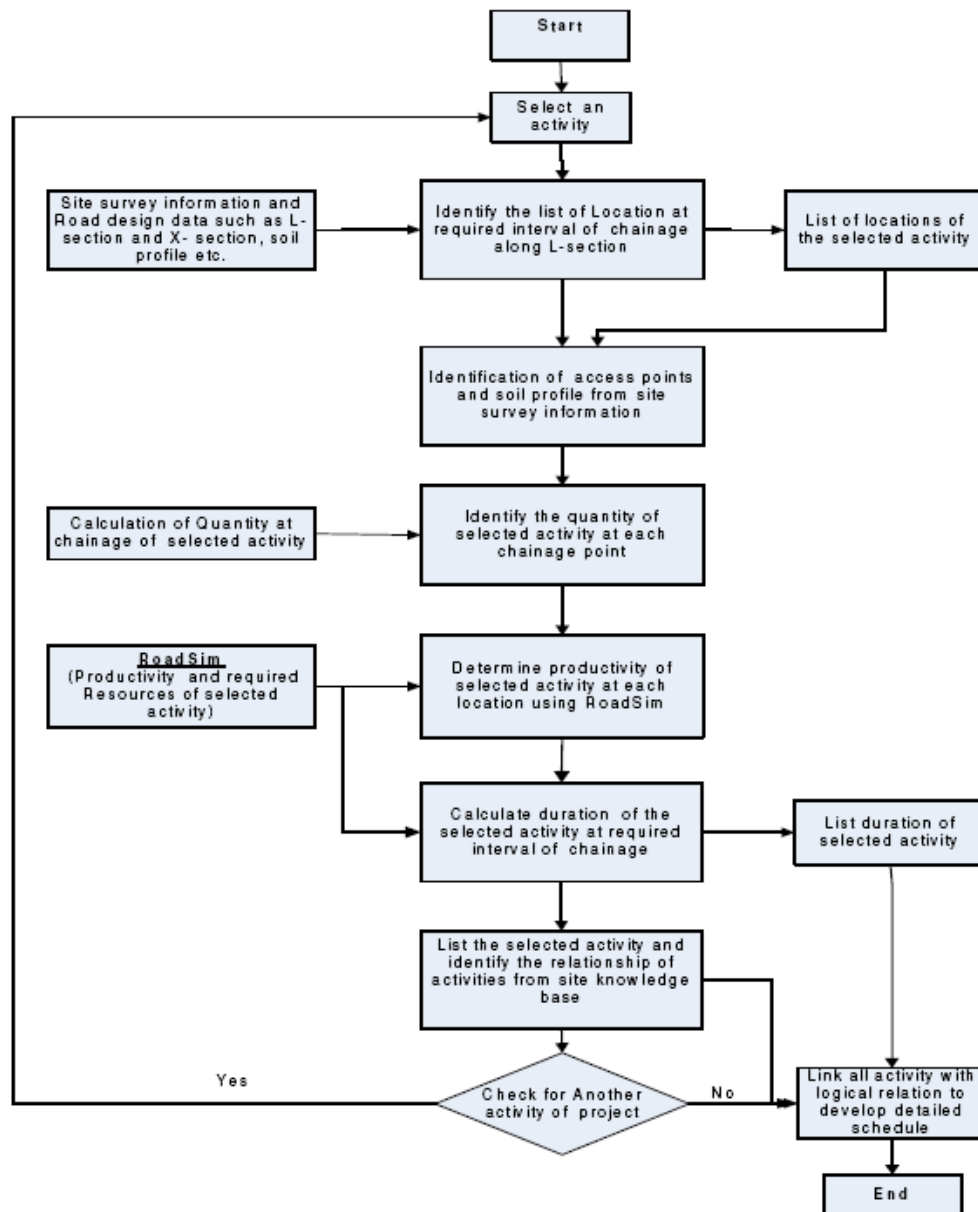


Figure 2: Information flow diagram of schedule development.

## 2.2.2 MATHEMATICAL FORMULA DERIVATION FOR HEIGHT CALCULATION:

The typical cross-sections shown in figures 4 and 5 are commonly applied and are thus considered to formulate the mathematical formula for the shapes shown in case (a) and (b). There are other typical sections that are rarely used and are not considered in this paper.

**Case (a):** A typical road cross-section, which is mostly used in road project as shown in figure 4, is used to demonstrate how the height is calculated at different stages of cutting and filling.

During the derivation of a mathematical formula, the following assumptions are made:

- Road cross-section is considered as a trapezoidal shape having side slope S: 1.
- $A_i$  = Cross-sectional area of trapezoidal at section i. =  $Bh_i + Sh_i^2$
- i = number of section varies from (i = 1.....n) along the road.
- S: 1 = Horizontal: Vertical
- B = Design Width of Road
- h = Height between exiting ground level and design level at a road section.
- $V_i$  = Volume of earthwork for Cut/Fill at section i
- L = length between two sections.

$$A_i = \frac{V_i}{L}$$

$$Sh_i^2 + Bh_i + \left(-\frac{V_i}{L}\right) = 0 \quad \dots (1)$$

$$h_i = \frac{-B \pm \sqrt{B^2 + \frac{4SV_i}{L}}}{2S} \quad \dots (2)$$

**Case (b):** Another typical road cross-section, which is most commonly used for uneven terrain surface having a transverse slope as shown in figure 5. Equation (3), which is found after the derivation of quadratic equation for the section as shown in figure 5 for the calculation of height of the section, is presented below:

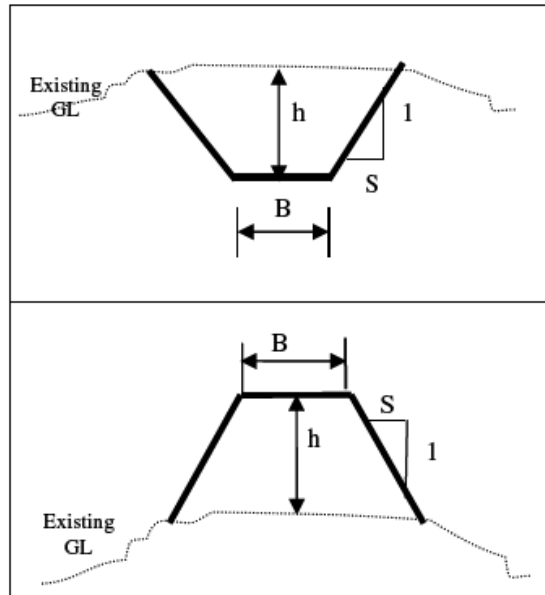


Figure 4 Typical road cross-sections for flat terrain surfaces

$$h_i = -b \pm \left[ \left( \frac{1}{SN} \right) \sqrt{\left( \frac{V_i S}{L} \right) \times \left( 1 - \frac{S^2}{N^2} \right)} \right]$$

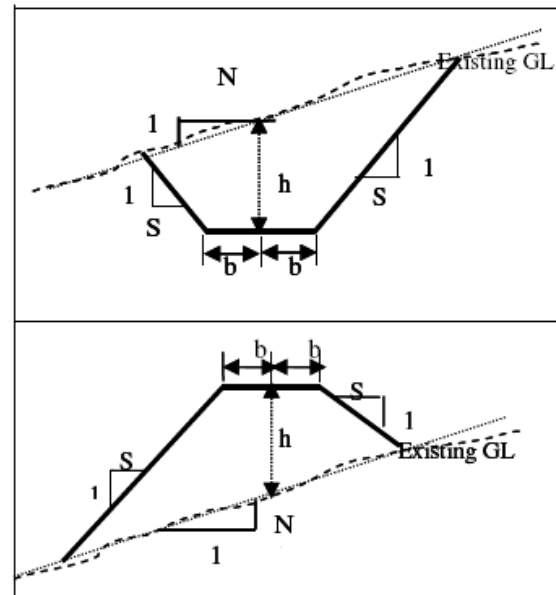


Figure 5 Typical road cross-sections for transverse slope of terrain surfaces.

...(3)

Where:

- $h_i$  = height of cross-section at section  $i$
- $i$  = number of section varies from ( $i = 1, \dots, n$ ) along the road.
- $N$  = Transverse slope of existing ground Horizontal: Vertical ( $N: 1$ )
- $S$  = Side slope of cross-section Horizontal: Vertical ( $S: 1$ )
- $b$  = half width of road section.
- $V_i$  = volume of mass earthwork Cut/Fill at cross-section  $i$
- $L$  = Length between two section.

### 2.2.3 TERRAIN SURFACE GENERATION

To automate the generation of terrains of earthwork activities at different stages of the construction process, a set of algorithms have been developed. This was based on quadratic equations which determine progress for earthwork activity. A flow diagram of the arithmetic algorithms presented in figure 3 is used for calculation of weekly coordinate data of terrain surfaces. Figure 3 describes the stepwise process for the height calculation of cutting and filling sections using the algorithms presented in Equations 2 and 3.

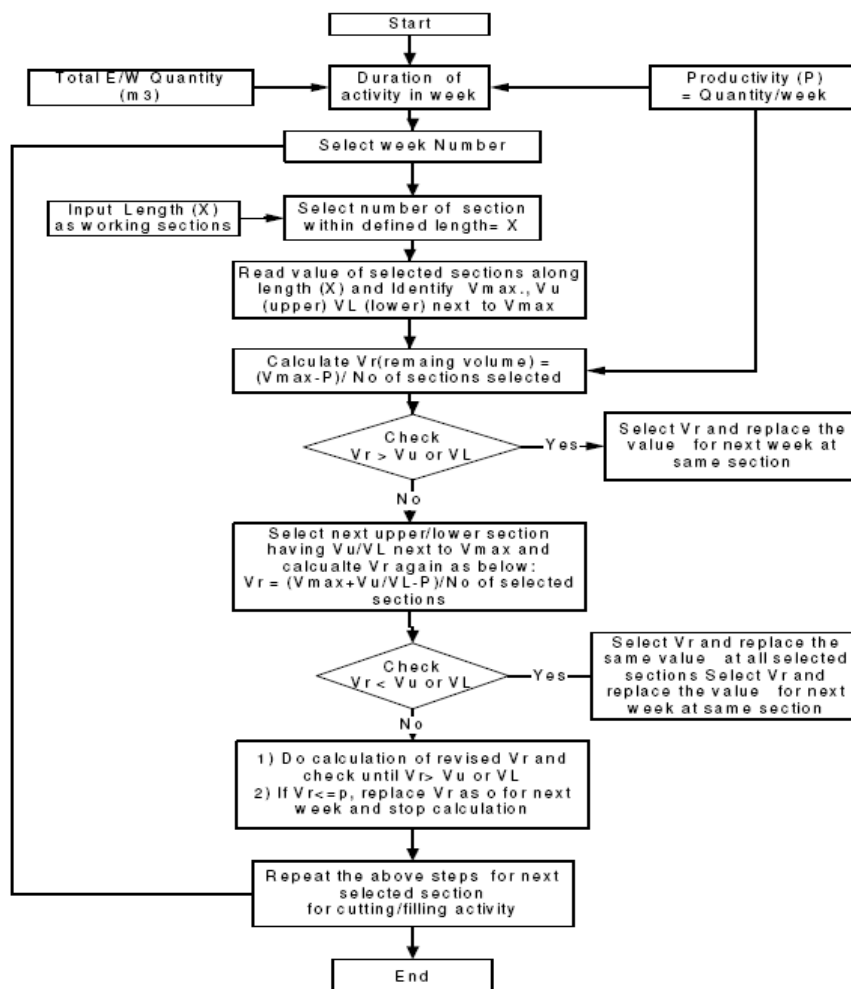


Figure 3 Flow diagrams of arithmetic algorithms of data generation of terrain surfaces.

According to the construction site knowledge rule, top points of cut and fill sections is selected at first to start the excavation operation and excavating horizontally at rate of production based on available resources for a period of time such as a weekly basis considered in the study. The remaining earthwork profile at the excavated section along a road section is determined by reducing the production for a selected period. The

height of the remaining section is identified using equations 2 or 3 depending upon the type of road cross-section. This process is repeated until the final design level of the road is achieved as defined in L-section. The production rate determines the duration for the selected section. Similarly the next working section for cut and fill is selected where soil mass allocation is suitable and the process is repeated to complete the earthwork operations of a road project.

### 3. CASE STUDY DEMONSTRATION

A 1.0 km (98+000 to 99+000) section from station no 1 to 41 of lot no. 3 a road project in Portugal was selected for a real life case study. The 4DVM model for earthwork operations is demonstrated with the case study. For this purpose, road design parameters and geometric data of L - section and X-section is considered and sectional quantity of earthwork is calculated assuming the typical trapezoidal sections having side slopes 1.5:1 and at 25 m intervals along the selected road section. The site access points are identified for cut/fill operations according to site conditions and the construction site knowledge. The site access points and productivity data provided by "RoadSim" system are the key inputs of the model and Equation (2) is used to determine visual terrain model based on variable equipment productivity and soil types.

The outputs of the model are virtual terrain surface of road profiles that were generated on a weekly basis throughout the construction period of 7 weeks to complete the earthwork operations of the road project. The output of the model includes; virtual surface of progress profiles generated by the model during earthwork operations and presented in figures 6 (a) and 6(b). Figure 6 (a) shows the ground profiles and corresponding

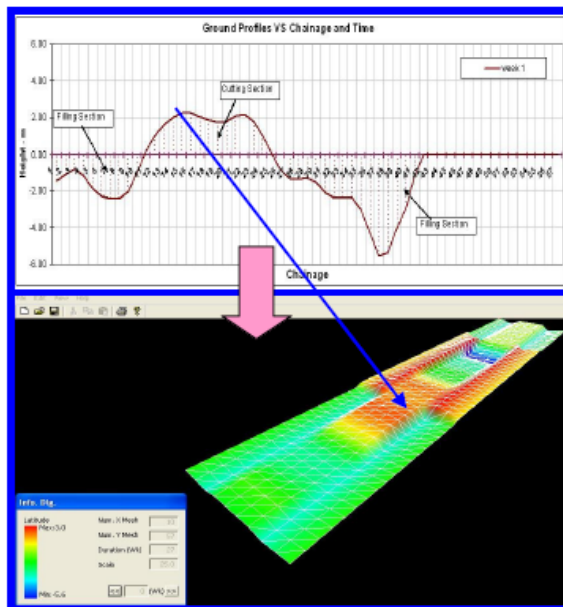


Figure 6 (a) Terrain surface generated by the model at week 1

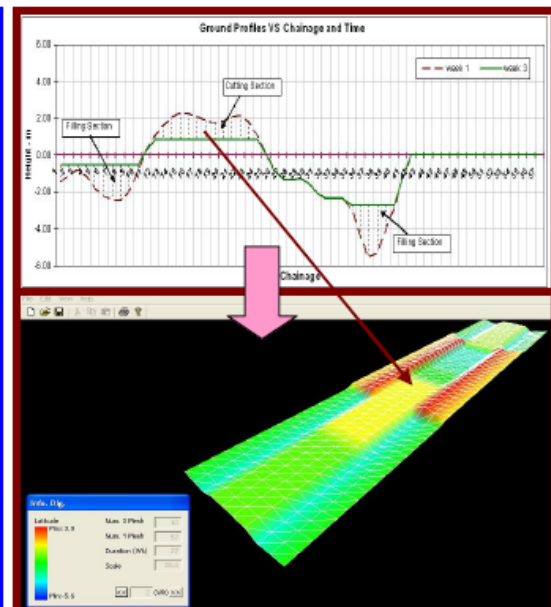


Figure 6 (b) Terrain surfaces generated by the model at week 3.

terrain surface at the end of week 1 and figure 6 (b) shows virtual terrain of earthwork progress profiles generated by the model from week 1 to 3 during earthwork operations including location of transforming the earthwork quantity from cut to fill section.

### 4. CONCLUSION

The research has introduced an innovative methodology and developed a prototype of 4D visualisation model (4DVM) using the methodology to visualise the earthwork construction process throughout the road construction operations. The developed model used coordinate data to generate terrain surfaces and time as the 4th dimension, derived from the productivity of earthwork activities. This is considered as a new approach

for 4D modelling of earthwork. The 4DVM represents the virtual construction progress profiles of earthwork activities.

The 4DVM generates visual terrain surfaces throughout the construction process of earthwork operations based on productivity data calculated by the “RoadSim”. The model has flexibility to interface with user defined variables such as productivity data and site access points according to topographical constraints; this is considered as the key achievement of this research study. The model will assist project planners/construction managers to analyse “what-if” scenario through visual simulation during the construction scheduling and resource planning processes.

The paper concludes that the new approach introduced by the research to design and develop the 4DVM for automatic generation of terrain surface throughout earthwork operations is considered to be a new methodology to visualise the earthwork construction process. The model will facilitate a logical decision-making process for construction scheduling and resources planning activities and will consequently improve communication gap between construction teams and improve the coordination amongst the project stakeholders.

## ACKNOWLEDGEMENTS

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## CONCURRENT ENGINEERING IN EDUCATIONAL PROJECTS: CASE STUDY SVARTÖBERGET

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### ABSTRACT

Each year, Luleå University of Technology teach 40 civil engineering students and 45 architectural engineering students basic knowledge in the construction process through a simulated real-life situation. In the third year, the grand total of 85 students is brought together and taught their respective professional roles through acting as experts within 6 different fields in the realization of a residential area. Research in the last decades has identified concurrent engineering as a possible method for streamlining the design phase in the construction process. The student project was therefore planned with a concurrent engineering approach, where all student groups start their work at the same time. The pedagogy was to teach students a new approach to working in large projects, with the side effect of testing if concurrent engineering is feasible also in educational projects.

Information is shared between groups through live documents on a project portal. Project coordination and communication is handled by 21 project leaders who meet regularly to exchange information between groups and detect missing information needed from other groups. Project planning is made through a method adopted from lean construction; Look Ahead Planning, which is part of the Last Planner method. IT-support is used to produce data and perform calculations but also as a tool for quality assurance across groups. All data is eventually summed up and presented in a virtual reality model of the new residential area. The VR model is gradually refined and the structure for delivering information into the model is drawn up by 6 appointed IT coordinators.

### KEYWORDS

concurrent engineering, construction process, under-graduate education, last planner method

### 1. INTRODUCTION

The construction process can be characterized through many different aspects such as; lack of common goals, lack of coordination and poor quality management (Lagerqvist 2004). The traditional sequential process in construction, where long time and lack of communication limits the quality of the outcome (Kamara et al.1997), can be replaced by parallel processes using a Concurrent Engineering (CE) approach. CE is an approach to construction that will give higher quality and reduce process time for product development (Prasad 1996).

The competence of future engineers, working in the area of urban planning, architectural and civil engineering, will adopt and develop new technologies within construction. Working in a project based environment requires knowledge not just in the technical specialisation (Barkley et al., 2005). Construction also involves collaboration with other actors with different tasks, information sharing and commission performance (Nordstrand 2000). Collaboration in the Architecture, Engineering and Construction (AEC) industry has been supported by ICT tools for a more integrated process in the early planning and design for about twenty years (Forgber 1999). The AEC industry has only slowly adopted integration technology, but is still far behind the manufacturing industry (Sandberg et al. 2008). It is of importance that the current state in construction is changed to increase the effectiveness of the construction processes. One important ingredient is to educate future engineers in collaborating with other disciplines already during their training.



Figure 1: Luleå inner town with Svartöberget on the far right (Luleå model).

The aim of this paper is to investigate if concurrent engineering is useful in construction engineering education and training. Because of an absence of collaborative learning in undergraduate education for engineers, a project course was developed as a complement to the more traditional education for civil and architectural engineers at Luleå University of Technology. CE, as an approach to the construction process in the course, was implemented with support systems for information sharing, coordination for group processes with internet portals and planning tools. VR models and CAD structure as a mutual platform for buildings, infrastructure and technical solutions from each technical specialisation were used as quality control through the whole course (see figure 1). This paper presents a case study, where the course is described and evaluated.

## 2. THEORY

### *Pedagogical bases*

#### **Collaborative learning in the zone of proximal development**

Collaborative learning in practice is when students in groups strive to reach learning goals. Contents in a project course are based on collaborative learning where participants have to be engaged to work together to reach the goal (Barkley et al. 2005). Working with collaborative learning is a suitable method for older students who can develop into autonomous, articulate, thinking people (Bruffe 1995). The Svartöberget project course had as a goal to support students in collaborative learning and is given to students in year 3 at the university, thus supporting their development into autonomous persons.

Vygotsky (1978) termed that students will solve problem on a higher knowledge level in, collaboration with peers or adult supervision because of the zone of proximal development (ZPD). The ZPD is the zone between the participant's current knowledge level and their wanted knowledge level.

*"The zone of proximal development defines those functions that have not yet matured but are in the process of maturation, functions that will mature tomorrow but are currently in an embryonic state." (Vygotsky, 1978)*

In the Svartöberget project the students are given the opportunity to enter the ZPD both in the technical area and the project process domain through collaborating in and between groups.

#### **Information technology as support for learning**

To educate students in civil and architectural engineering in a city planning project, tools and methods for parallel processing are needed. Computer skills and information tools are often not prioritized. Säljö (2000) states that information technology makes visualization possible in the area of education where simulation of reality activates more sense than text will do. A common method to teach students better computer skills is to use tutorials in software, enabling the teacher to concentrate more on the theoretical height in the course.



### **Concurrent Engineering**

Concurrent Engineering (CE) is a systematic approach with aim to minimize time and maximize quality through design and development processes. CE is a popularly approach to product development and design in the manufacturing industry. CE is today more used as a philosophy combining many types of tools and theories (Prasad 1996). Product developing has forced to be more effective because of today's market and the whole business world. CE is a result of rapid solutions for product design process and need strategic plans for developing products for a changing market. Winner et al. (1988) stated that two key principals for CE are integration and concurrency. In a course were times to wait for different disciplines with a case, necessary of methods and tools are obvious.

Collaborating and communicating is two of the key factors in CE to facilitate environment between individuals and also in the organisation. Interfaces in product design and early steps for planning are a central topic in the CE theory (Prasad 1996). Variables and constraints for the design depend on interfaces that will solve information sharing and connect activities in developing process.

### **3. METHOD**

Case study Svartöberget is a study of a project course where students, supervisors, teachers and course managers all are in one process. People in processes are best studied in a situational context, thus suitable for a case study, where multiple sources are used. The results of the multiple sources, as direct observations, documents and surveys, was combined and analysed as triangulated data (Yin 2003).

Direct observation was possible since the first author acted as the information manager during the course. Direct access to all documents produced was at hand and also control over the information flow in evaluation of the course. Logs of work progress and protocols from group meetings have been used as data in the case study. The project plan for the educational program, the course and the project had a central meaning. Dynamic documents as guides for the student groups at the web portal have also been data for the case study.

A web based survey was issued after the course to collect an evaluation from both students and supervisors. The survey was divided in two sections; the first part had predefined questions to capture the overall idea of the project course and the second part gave the opportunity to express with the respondents own words their opinions. Coding the evaluation result, from the case, give a basis for analyses (Yin 2003). The empirical outcome from the survey was coded into seventeen criterions in the BEACON model (see figure 2).

#### ***Data analyses***

The unit of analysis for the Svartöberget project has been the project itself, the persons engaged in the project and the data produced in the project. The time frame of the project was 5 months preparation time, 5 months conduct and 1 month of evaluation. The results in the evaluation from the students were analyzed with the BEACON model (Khalfan 2007).

BECON is a model presenting the readiness assessment of case studies in construction engineering. The evaluation report from students and supervisors present important grade of different criteria in project based education with concurrent engineering. The grade of importance is split up in percent, where the most important criteria set as 100% and the other criteria's is in relative to the most important for figure 2.

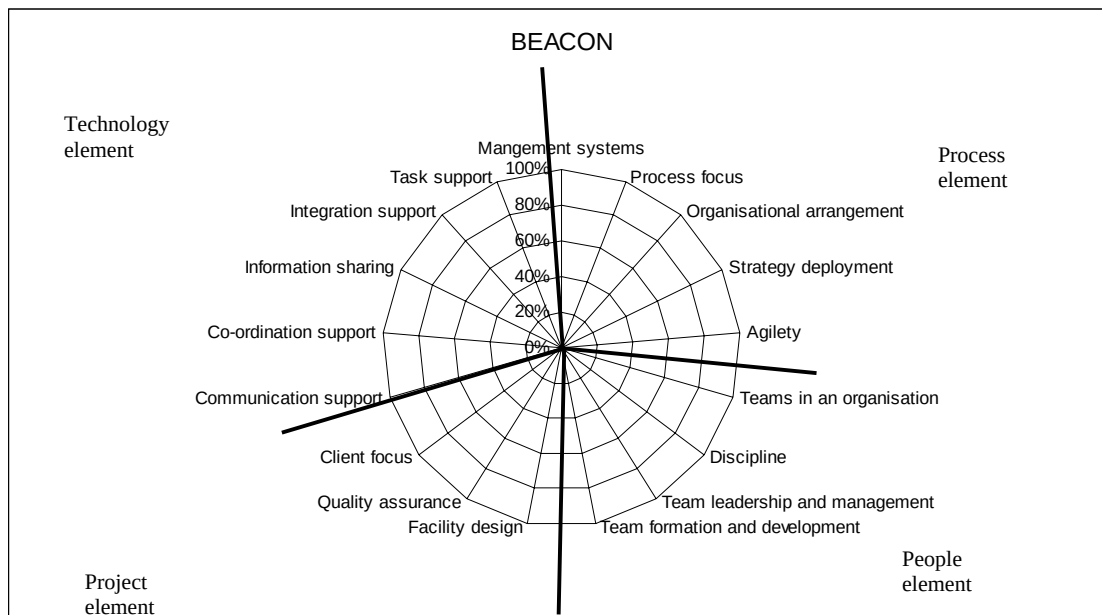


Figure 2: Important grade of CE elements.

### Validity and reliability

The reliability in the study has to be seen as acceptable knowing that 40 % of the students went to the web survey and 50 % of supervisors answered our survey. For validity to describe CE as theory for education in construction engineering can we see that our method for collecting and analyzing data shows results that we search to measure.

## 4. CASE STUDY SVARTÖBERGET

### Preparations

The structure and goal for the course was formed by a group with knowledge in each technical specialisation. The supervisor group was formed one year before the course start-up. In total, twelve persons worked with the planning of the course: one course examiner, one project leader, eight supervisors, one ICT coordinator and one coordinator for group processes. Different specialisations met in the Svartöberget project. To give students a technical height in their specialisation, the course was split up in six parallel tracks: Place Design, Urban Planning, Environmental Technology, Structural Engineering, Geotechnics and Mining and Building Management. The six specialisations were organized in 21 sub-groups with different tasks. The sub-group tasks were planned in relation to their specialisation, but in parallel connected to the Svartöberget project.

The supervisors organized the project so that students will manage the project and also work in parallel. In reality, urban planning is made some month before detailed planning of structures (Nordstrand 2000). For the management group this was a problem that had to be solved, so CE theory was applied. The idea was to start the Urban Planning task one week ahead and hold Structural Engineering two weeks after the rest of the groups had finished.

CAD tools and Internet portals were used as the main ICT tools. The management group had a vision of merging the 3D-models from the different sub tasks into one virtual reality (VR) model for the entire area. The purpose was to support overhead planning, quality control and a project work design. To train the students in building up environments for urban planning projects, a VR model of downtown Luleå (the Luleå model) was created as a template for the Svartöberget project. Technology to meet in the same digital environment was tested in this model. The Luleå model is based on geographical data from 3D coordinates, orthographic photos and basic map data. Buildings in the VR model were created from 2D maps where

corners of existing buildings were pointed out. Photos of facades and roofs were combined with the 3D model to form the Luleå model. An ICT coordination student group was organized in the course to handle information flow and CAD models in the project. One student from each of the six specialisations joined the ICT coordination group and worked halftime with information related tasks.

### Examination

Examination for project courses needs multiple judgment criteria. Technical specifics, common knowledge, project related work and group process reflection became the ground criteria for examination. An object view from the supervisors, with focus on project based education with CE instead of technical results was the plan. The students were examined in five different ways:

- Project work in project
- Presentation, vocabulary and writing
- Group process
- Theory exam
- Practical exam

### Conduct

The 84 students at Civil and Architectural Engineering formed 21 subgroups right after the course start (see figure 3). Each sub-group started with a working process to present a group leader to the management group. Contracts handling work responsibility and conflict handling were signed at the beginning of the course. A client organization that could put demands on the participants in the project was not defined. One group with three students formed an operating group in the project. They handled project related decisions and clarified project tasks to groups and subgroups, figure 3.

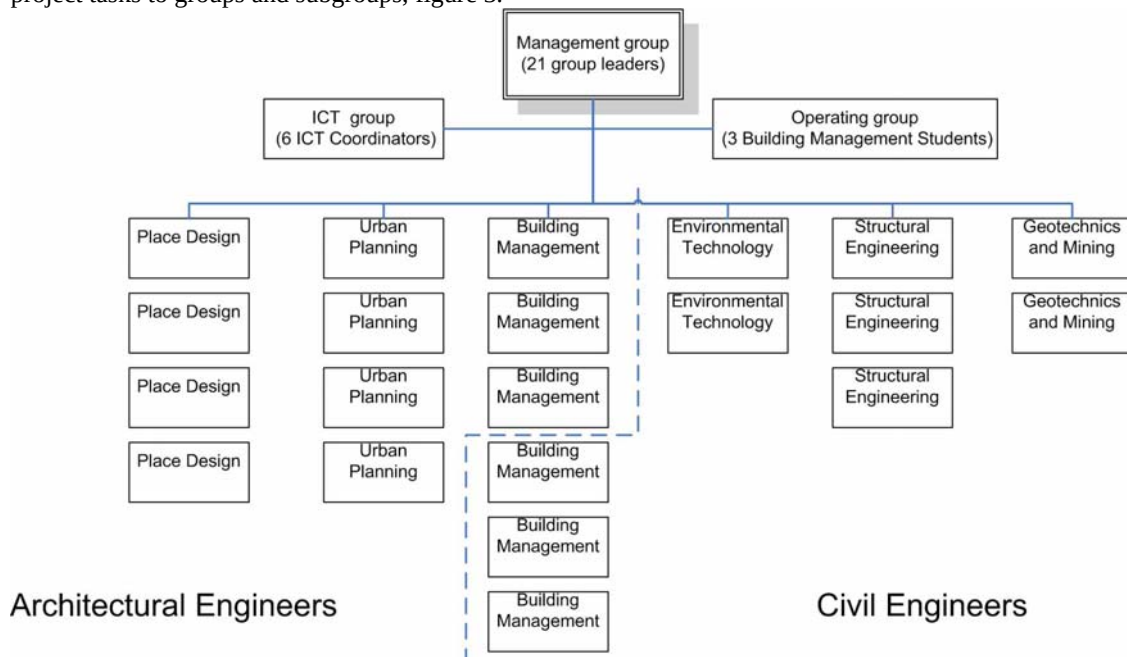


Figure 3: Organisation chart for students groups.

To get an overview and add realism to the project a field study was carried out at the Svartöberget location. All students walked around the area to get their own picture of how the future environment should come across. Another purpose with the field study was to give the students the feeling of how the industrial environment influenced the area.

A planning method for the project work itself was needed, preferably a method that embraced both quality control and a meeting structure. Each group leader had to make an overhead project plan together with their

group. Look Ahead Planning, which is part of the Last Planner method, was chosen (Ballard 2000). Meetings were held every week with follow-ups using the Look Ahead Planning schedule. Five week plans were made and every week the past week was checked to follow-up planned activities in the project. The five weeks planning matched the overhead planning and both were revised continuously.

Scheduling and planning lectures in the course was subordinated the project tasks. Three different types of lectures were used in the course: lectures for all students, specialisation lectures and ICT tool laborations. Common lectures were planned in the beginning as a base to stand on for the students. As basic knowledge in sustainable city planning two lectures were offered. One lecture for ordinary knowledge as social, economical and ecological aspects for city planning and one with practical examples from harbour environment and sustainable planning. Project processes in building construction were split up in four lectures: BIM in design, project processes, market and actors and the role of the engineer. The last six lectures with common theory were given by each specialisation. Finally, specialisation lectures were given, varying between eight and twelve lectures depending on the technical specialisation. Lectures in information technology and information sharing were given trough the entire course. Labs with ICT tools were given as open lectures with no specific examination unless the final presentation.

Working in a project, where all students have small or no experience of working with building and city planning, put pressure on the students to seek knowledge in their own technical area. In the beginning, the management group started to slowly create rules to share and present information in the web portal. The four groups in Urban Planning had to specify the area by separating blocks from roads and define the infrastructure type. In parallel to urban planning, the other groups started to sketch on places, structures and technical solutions for the project, without knowledge of a defined area (see figure 4.).

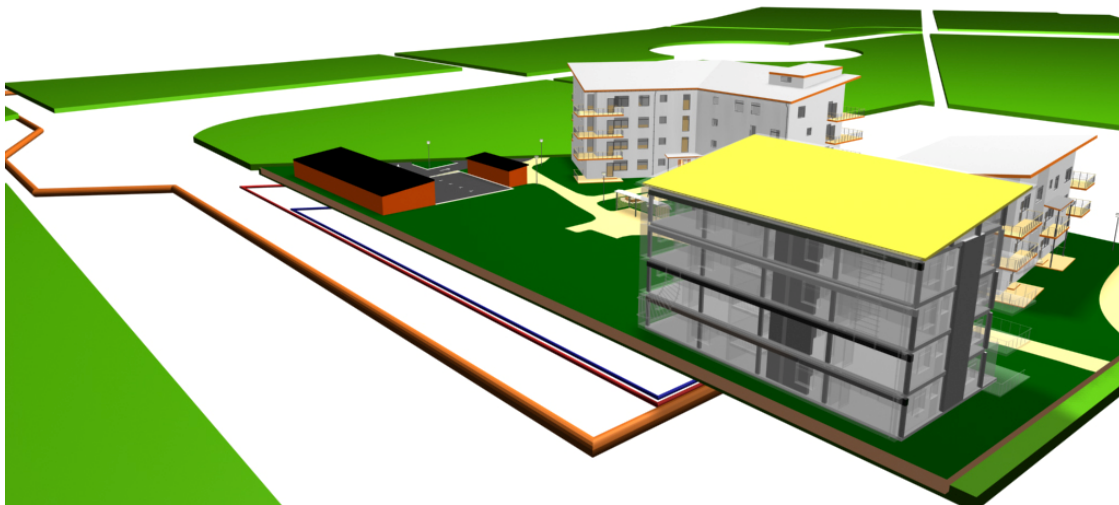


Figure 4: CAD platform for models and visualization

After urban planning was finished, every group fitted their own concept into the plan through iterations. Seventeen students from the Place Design group got one block each and designed the inner and outer environment. Defined boundary conditions for a block was house height, type of building (private, commercial), traffic planning, etc. In the project management group, CE was tested strongest after the urban planning phase. CAD models, drawings and information had to be distributed to sub-groups so all participants could perform their task. Project management meetings were vivid and project tasks were formed by the students themselves to solve a specific problem in the project. New vertical groups developed in the project and new constellations started to work with own tasks that would lead to the final goal. Parallel to the new stage of the project the ICT group carried on their work with ICT strategies.

### **Project presentation**

The last four weeks was dedicated to working on the presentation of the project. Drawings based on 3D models, posters with pictures from inner and outer environment and presentation of calculations for every

building were developed. Every group presented their own project report and as an outcome to the society a CD was made.

All twenty-one groups had to present their work orally. The students planned their own presentation, which ended up in a showroom open to the public where municipality, industry, university and private persons joined together.

### Evaluation

The results of the course evaluation showed that important elements in the project course were separated between students and supervisors, figures 5 and 6.

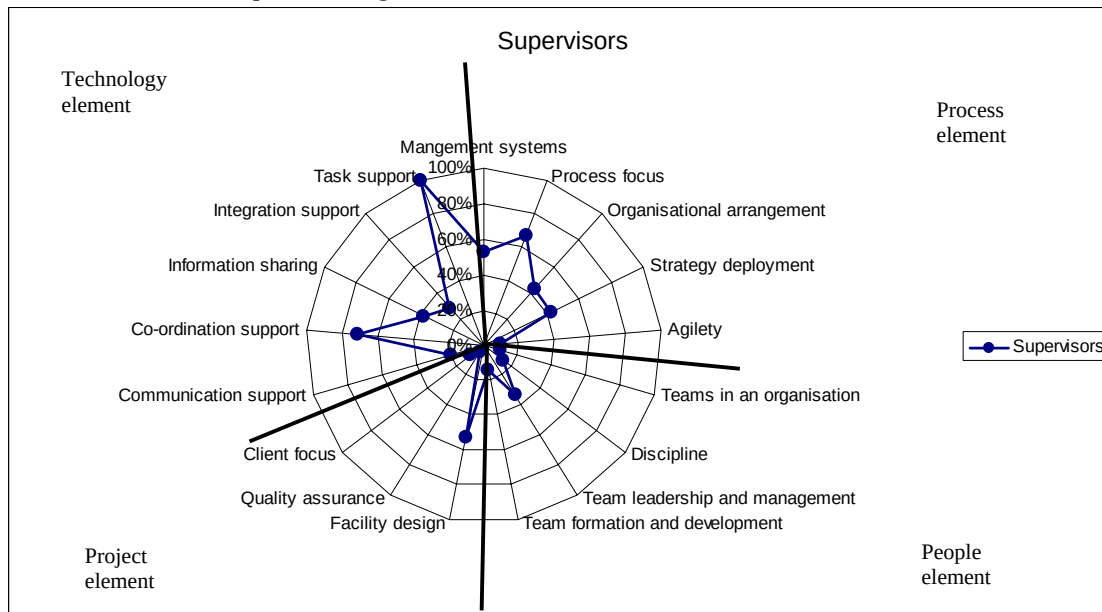


Figure 5: Supervisors important grade of CE elements

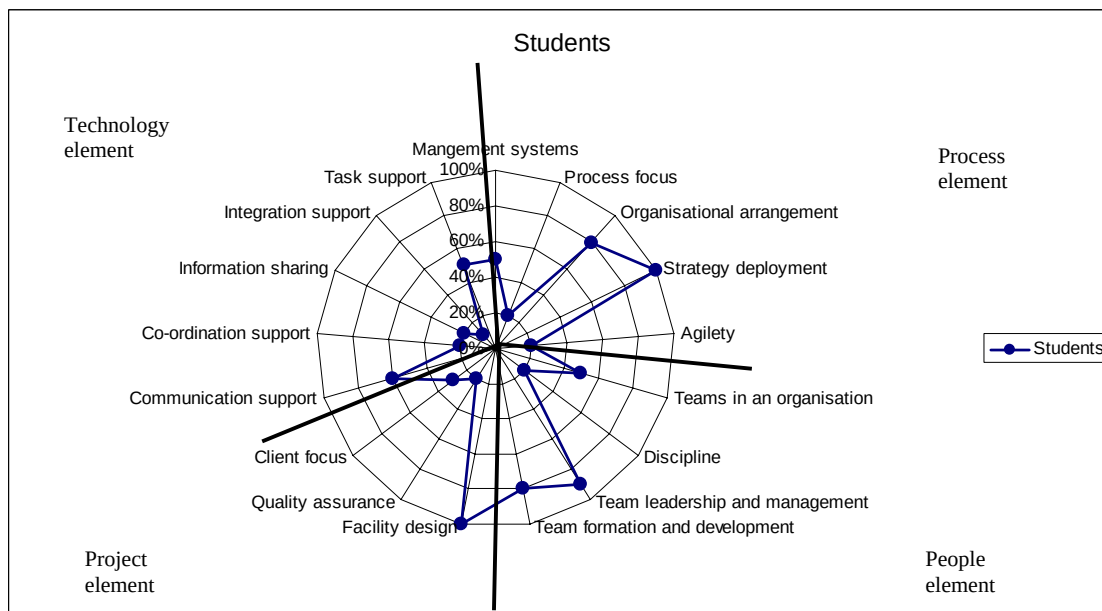


Figure 6: Students important grade of CE elements.

The common favourable opinion of the students is that of the course fills up a gap among a real project in the education. Important negative opinions are the structure and organization with leadership and teams. Undefined buying organization that could put demands on the participants in the project was not clearly defined.

## 5. ANALYSES

The results in substantial aspect were great, with a good outcome from presentation in reports, physical and virtual models. Bruffe (1993) states that students in collaboration will reach longer when problem solving towards a common goal is at hand. During the Svartöberget project, there was an opportunity to give students knowledge in their technical area that they never would have obtained if it was delivered in traditional class room education. With colleagues and supervisors in the project, the zone of proximal development (Vygotsky 1978) was stimulated in several ways. However, the result of the student evaluation shows that support and organization should have been more structured for a chance of even more knowledge development. The most difficult task in course planning was to define the border between the framework of the course and the creativity in problem solving for the students, which led to a strong student request for better structure. Knowledge in the technical area vs. knowledge in the pedagogical area has to meet in a common strategy in this type of course. A strong observation from the course conduct was that this type of collaborative course poses high demands on the supervising teachers. They too have to collaborate and communicate according to a CE process. Unfortunately, this was unsuccessful and teachers had problems stepping out of their own role as a "teacher by the bench" and start acting as a project member.

CE as an approach can be a good method to organize tasks in a project (Prasad 1996). A method model has to be developed for the course with demands on different actors (both students and teachers). Even if students had to wait sometimes in the project, all groups were working in parallel with their own project tasks. Waiting for information in a project is often traced to a customer decision (Koskela 2007). The ICT coordination student group worked in parallel to the project with standards and templates for the ICT tools that was used in the project. A more integrated role for the ICT coordination group, in the operative group would have given an opportunity to coordinate information and avoid problems with information sharing (Amor & Clift 1997). The VR-model, that was the central unit as a quality tool for the project, should support collaboration in the placement of buildings and infrastructure. Functionality in the software partly prevented quality control through the project because of limited interfaces to some used CAD systems.

Analyzing the four elements in CE can result in the answer that *personal element* can be seen as important element for the students but not for supervisors in the course. A resource for group processes was defined in to handle personal conflicts and team leadership. For supervisors was that area solved and focus landed somewhere else. In students view wasn't the project organization ready to control *personal elements*.

The *task support* was much more important for supervisors than it was for students who focus their evaluation on *facility design*. A conclusion of this can be that students were more result oriented; while supervisors looked more at the learning process in the course.

## 6. CONCLUSIONS

Concurrent Engineering can be useful as a collaborative method for educational projects in engineering education. Three important areas that appear in the analyses of the case study to succeed with concurrent engineering in project related education is:

- Setting up a clear goal and define project boundaries for students and teachers
- Define good structures for information handling, especially for supervisors
- Introduce a client role that continuously could define requirements for the product

CE as an approach to construction project related education can be used, if the defined project contains smaller sub-tasks for the students.

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## **TOWARDS LINKING VIRTUAL MODELS WITH PHYSICAL OBJECTS IN CONSTRUCTION USING RFID - REVIEW OF ONTOLOGIES**

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### **ABSTRACT**

Virtual models have in recent years proven their worth in practice relating to building design. Today virtual models of the complete project are created before the project is carried out in practice. The immediate advantages of this are great; it introduces fewer errors, gives a better production basis, improved clarity and enhanced communication methods compared to traditional 2D drafting methods. However, there is still much unutilized potential in the virtual models, especially in the construction and operation phases. It is expected that a digital link between the virtual models and the physical objects in the construction process can improve the information and knowledge handling from design to construction, operation and maintenance. The link can be created by use of Radio Frequency Identification (RFID) technology. This paper describes a review and assessment of existing ontologies relevant in relation to creating this link. The ontologies are categorised according to their applicability to specify technical services, resources, organisational relations, business processes and overall frameworks for ontology descriptions and their relations. It is concluded that, with few modifications the technical service and resource ontologies are applicable for industrial use and the meta, organisational and business process ontologies need further development and industrial maturity to be applicable.

### **KEYWORDS**

Virtual Models, RFID, Ontologies, Project Progress Management, Ubiquitous Computing

### **1. INTRODUCTION**

Virtual models have in recent years proven their worth in practice relating to building design. Today it is practice in Ramboll A/S to create a virtual model of the complete project before it is carried out. The immediate advantages of this are great and the authors' experiences with using this new working method show that it; introduces fewer errors, gives better production basis, improved clarity and enhanced communication methods compared to traditional 2D drafting methods. Other researchers have recently reported about similar productivity gains using virtual modelling compared to traditional drafting (Sacks and Barak 2008, Woksepp, 2007).



Virtual modelling and virtual models are not new inventions; hence the terms have been used in many contexts and also under different names. In construction practice and research names like object oriented model, information model, 3D model, building information model (BIM) and virtual building model are often used interchangeably. In this paper the word virtual model is used to describe any digital object oriented model of a physical object (e.g. a person, a building part, a room, a house, a city or a planet etc.). The term virtual model is used rather than e.g. BIM to reflect that the subjects discussed are not only applicable to buildings, but generally applicable in the construction industry. The virtual model often, but not necessarily, contains a geometrical 3D representation of the objects it models.

There is still much unutilized potential in the virtual models, especially in the construction and operation phases. It is expected that a digital link between the virtual models and the physical objects in the construction process can improve the information and knowledge handling from design to construction and operation. The link can enable automation of information management, resource management and logistic management and can be made with the use of Radio Frequency Identification (RFID) technology. It is created by adding a unique electronic RFID tag to the physical objects and including the ID from the tag in the objects virtual model attributes.

To be able to share information between trading partners, reuse data from one phase in construction to the next, integrate process and product models with enterprise resource planning (ERP) systems, easy access information, communicate through networks, read data stored in electronic tags etc. ontologies play an important role. The term ontology does not have just a single definition. Within knowledge engineering the term has been widely discussed in the 1990's (Guarino 1996). Guarino argues that Tom Gruber's definition is the best known (Gruber 1993): "An ontology is an explicit specification of a conceptualization." For use within IT in construction the similar but more detailed definition by DLI Glossary (1998) is also a good definition: "An ontology 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."

In IT in construction practice it means that ontologies are all the certified and upcoming standards, commonly accepted working methods and services that enable unambiguous identification of entities in heterogeneous systems. Furthermore ontologies are also the assertion of applicable named relationships that connect these entities together. Adequate and widely accepted ontologies are needed especially when developing IT systems where scalability and interorganisational interoperability is of importance. Therefore this paper discusses ontologies for IT systems supporting the linking of virtual models with physical objects in construction by use of RFID technology.

Firstly in this paper, an introduction to RFID in construction is given. Secondly, the method used for evaluation of suggested ontologies is described. This is followed by an overview and discussion of ontologies relevant for fulfilling the potential to digitally link the virtual models and the physical objects in construction within the five domains: 1) meta ontologies, 2) technical service ontologies, 3) resource ontologies, 4) organisational ontologies and 5) business process ontologies. In Figure 1 an overview of the ontology domains and their relations is given. They are further described in chapter 4-8.

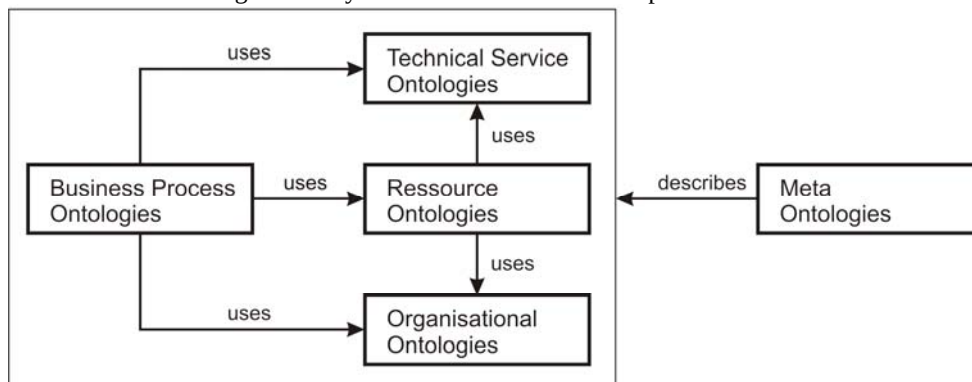


Figure 1: Overview of ontology domains and their relations.

## 2. RFID IN CONSTRUCTION

RFID stands for Radio Frequency Identification and denotes any identification system in which electronic devices occur that use radio waves or pulsating magnetic fields to communicate with identification units fastened to objects. In the 1970's and 1980's RFID was first introduced in the industrial sector to keep track of railway wagons and auto chassis's in production lines in the USA. Since then it has spread to other areas such as identification of animals, clothing in laundries, billeting systems, admittance control etc. From the beginning of this century there has been an increasing focus on the employment of RFID. This is, among other things, because of recommendations from the U.S. Department of Defence and the U.S. Food and Drug Administration about using the technology. Furthermore, the world's largest retail chain, the Wal-Mart Stores, Inc., has since 2005 has required of its largest suppliers to use RFID on all their product pallets and larger units. The supply of RFID equipment has gradually increased, and there is now a higher degree of standardisation in the area than earlier.

The most referenced components in RFID systems are tags, readers and middleware. Tags, also termed transponders, are identification units that are attached to the objects to be localised. The interrogator, the transceiver or the RFID reader, as they are often called, is that component which via the antenna is used for scanning the data contents of the tag. The middleware is the software component which ties the RFID reader together with the other software components in an IT system and, if necessary, also filters the data before it is relayed. RFID is a technique whose applications are far from finally developed and new areas appear in a still increasing pace. (Glover and Bhatt 2006).

As early as in 1995 it was stated that automatic identification of objects using RFID technology, was a promising technology for the construction industry (Jaselskis et al. 1995). However, 13 years later the applications of RFID in the construction industry are rare and mostly used in prototype projects or for theft and access control but not in interorganisational applications (Erabuild 2006). The reason for this should be found in the lack of widely used ontologies and the shortcomings of virtual product and process model applications used in the construction industry rather than in shortcomings of the the hardware for RFID systems. The true benefits and complexity of automatic identification systems does not arise from the hardware itself, but from possibilities to get information in the right place, at the right time in a usable form.

A number of recently published papers describe various examples of tested RFID implementations in construction: 1) Automating the task of tracking the delivery and receipt of fabricated pipe spools described in Song et al. (2006), 2) inspection and management in concrete test lab described in Wang (2008), 3) on-site tool tracking described in Goodrum et al. (2006), 4) project progress management with virtual models described in Chin et al. (2005) and 5) tracking and locating components in a precast storage described in Ergen (2007). In all the papers it is concluded that RFID technology can be brought to function efficiently even in the harsh construction environment.

## 3. METHODOLOGY FOR EVALUATING ONTOLOGIES

A method based on user scenarios and informal questioning described by Grünninger and Fox (1995) is used to evaluate and select the ontologies illustrated in the following sections. First of all, scenarios for future use were developed based on the method contextual design (Beyer and Holtzblatt 1998). Interviews of future users were made as well as brainstorming and state of the art reviews of available literature. The scenarios are used to capture future needs and, afterwards, to evaluate the ontologies by informal questioning. They reflect future applications of the technologies and work processes to be supported by the ontologies. A characteristic user scenario for future use of RFID in production management and component element installation is described in section 3.1. The scenario is presented using story telling and is based on a working process relating to precast concrete element fabrication and installation. It is supplemented by the rich picture in Figure 2. Similar user scenarios for use of RFID and virtual models can be found in many working processes in construction such as quality assurance, facility management, logistics etc. In Sørensen (2008) a number of potential uses of the link between virtual models and physical objects has been presented. The questions to be answered relating to each ontology or category of ontologies are; 1) Why are they relevant, 2) Who are they relevant for, 3) What are they supporting, 4) When are they used, 5) How are they used.

In order to structure the studied ontologies they are separated into five domains: meta ontologies, technical service ontologies, resource ontologies, organisational ontologies and business process ontologies. A similar split in organising ontologies is also proposed in (Christiansson 2007) and used in the Inteligrid project - Interoperability of Virtual Organizations on a Complex Semantic Grid (Dolenc et al. 2006). See Figure 1 for an overview of the ontology domains and their relations.

### 3.1 SCENARIO FOR FUTURE USE OF RFID IN CONSTRUCTION

A future user scenario is presented below to outline how the ontologies will support a simple method for continuous project follow up and progress management. The scenario is presented using story telling with the following fictive protagonists; John the virtual model coordinator, Jane the construction manager, Michael a precast concrete manufacturer and Paul the foreman.

#### Model generation and precast element management

*John is model coordinator of the design and construction of a new office building. His task is to secure a smooth flow of information between all parties in the project. During the design of the building John is responsible for the 3D and 4D modelling and work in close collaboration with the general contractor's construction manager, Jane, and project manager, Michael, at the precast concrete manufacturer. John is also responsible for adding the ID's from the RFID tags to the objects in the virtual 3D and 4D model stored on the model server.*

*When the concrete elements are ready for shipping Jane is responsible for updating 4D production status information on the model server. She does that by reading the RFID tag in each concrete element with her mobile phone and subsequently presses the button "In transit". Together with the production status information the mobile application automatically updates the model server with data about time, date, user and current location from the GPS. Her mobile phone has Internet access and connects to the service provided by the model server.*

#### On site precast element acceptance and inventory management

*When the precast elements arrive at the construction site Jane uses the RFID enabled mobile phone to identify the elements. While doing the acceptance check Jane writes any comments on the phone and updates the model server with new element data about, production status, location, time, date, and user. For every element she receives information about installation time, date, storey and gridline from the virtual model server. The acceptance checking also includes finish, transportation damages and measurements of window and door holes.*

#### On site element location

*A continued update of the virtual model enables any user of the system to retrieve information about current production status, location, comments and direction of any of the precast concrete elements. Foreman Paul uses his mobile phone to retrieve information about where he can find the next element to be installed and read the comments inputted during element acceptance at building site. In case the element is not in place on the construction site, he is noticed where in the supply chain it is currently located.*

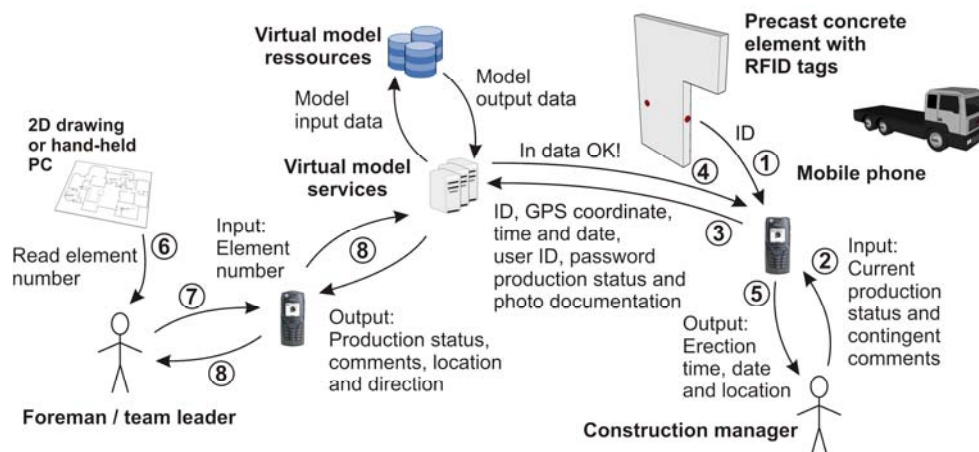


Figure 8: Rich picture illustrating future use of a digital link between virtual models and physical objects in construction for on site element acceptance and inventory management. The numbered events refers to sequence of execution.

#### **Task accomplished update**

*When a precast concrete element is installed Paul updates the virtual model with his mobile phone by reading the RFID-tag and selecting the "Task finished" button. He supplements the input with a photo for the quality assurance documentation. He now receives information about the next task and the location of the elements.*

#### **On-going information retrieval**

*Thus, during the construction process contractors, engineers, architects and the client can follow the project's progress in their own offices by means of a virtual 4D model viewer. For elements where they have subscribed to notification they receive an e-mail, SMS or RSS feed whenever their status change. The structural engineer uses this option to get information about when he has to go to the construction site to do follow-up quality checks, and the construction manager is quickly informed when new elements arrive on the construction site.*

### **4. META ONTOLOGIES**

Meta ontologies are the ontologies for ontologies. They specify frameworks and identify languages for defining ontologies and their relations.

The Semantic Web is the carrier of an evolving meta ontology extension of the Internet. Its vision is to extend today's World Wide Web from being a medium for document sharing to becoming a medium for data sharing - a universal medium for data, information, and knowledge exchange. Therefore it is considered as an important framework for future applications supporting user knowledge handling in construction supported by RFID. The Semantic Web provides a common framework (building blocks for ontologies) that allows data to be shared and reused across application, enterprise, and community boundaries. It is a collaborative effort led by the World Wide Web Consortium (W3C) with participation of a large number of researchers and industrial partners. "The Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation." (Berners-Lee et al. 2001)

Some of the important building blocks in the Semantic Web include the specifications of the Resource Description Frame (RDF) and the Web Ontology Language which are intended to provide a formal description of concepts, terms and relationships within a given knowledge domain (W3C 2004). A triple in RDF consist of a subject, predicate and object. The subject denotes the resource e.g. a web page. The predicate denotes traits or aspects of the resource and expresses a relationship between the subject and the object.

For use in the construction industry and similar interorganisational industries such as automotive and in aerospace the InteliGrid Ontology Framework describes four independent but inter-related ontologies. They can be further specialised in an extensible set of domain-specific ontologies serving particular industry purposes. InteliGrid's Vision is: to provide complex industries that have challenging integration and interoperability needs with a flexible, secure, robust, ambient accessible, interoperable, pay-per demand access to (1) information, (2) communication and (3) processing infrastructure (Dolenc et al. 2007). A comprehensive framework and supporting ontologies are described in the InteliGrid project deliveries but one of the author's major concerns for its success in construction is the projects lack of significant business drivers who can manage to make it industry adaptable.

### **5. TECHNICAL SERVICE ONTOLOGIES**

Technical service ontologies are the specifications enabling communication through heterogeneous networks and also a standardised use of hardware and software from different suppliers. Mature technical communication ontologies such as the TCP/IP protocol for the Internet, GPRS/EDGE for mobile phone communication are used daily by many people and they are also ready for use when linking virtual models with physical objects in construction. In addition 3G mobile broadband will give faster data transfer speeds breeding ground for new rich mobile applications and easier on-site Internet access.

The Internet and WWW, as we know it today, dates back to 1992 and is facing some comprehensive paradigm shifts that will introduce new ICT (Information and Communication Technology) applications. First of all, the introduction of XML cleared the way for separating the storage and the access medium for digital information on the Internet. The following introduction in 2000 of Web services and Semantic Web and its supporting standards (SOAP, WSDL, and UDDI respectively OWL, RDF, RDF Schema) forms the basis of efficient and interoperable future handling of information associated with meta data and data stored in information containers globally distributed on the Internet. SOAP denotes Simple Object Access Protocol, WSDL denotes Web Services Description Language and UDDI denotes Universal Description, Discovery and Integration. See W3C (2002) for an overview of activities, specifications, working groups and recommendations related to Web services.

Another paradigm shift is the introduction of IPv6. The internet protocol (IP) specifies a hierarchical addressing system that enables unique identification of all units connected to the Internet. The present version 4 of IP is from the 1970's and consists of a 32 bit address which will not continue to be sufficient for all units connected to the Internet. IPv6 uses 128 bit addressing which gives 4 million unique addresses per square metre which should be sufficient for supporting the growth of the Internet for at least the next 50-100 years and for allowing a dense integration of IP addresses and RFID. These paradigm shifts form the potential for an 'Internet of things' that is a network where all physical objects such as humans, clothes, machines, building components etc. have a unique identification and where information about them can be structured and used rationally by humans and machines. Great potential is expected from using the next generation of the Internet in interaction with virtual models in the construction industry.

A large number of standards exist for RFID technologies but only a few of them have relevance for the construction industry. Two of the RFID standards for contactless smart cards, ISO 14443 and ISO 15963, working on the HF-band (13.56 MHz) have already become popular in other industries. They were originally developed for ID cards but have experienced a wide spread in general for track and trace, cash less payment, production line optimization and similar purposes, as a cause of cheap tags and good all round attributes. ISO 14443 is developed for proximity coupling (0-10 cm) and ISO 15963 for vicinity coupling (0-1m). Tags supporting both standards are delivered with a pre-printed unique ID, which cannot easily be changed and therefore also can be used for unique identification in interorganisational settings. However it is important to use high quality tags because tags from less reliable manufactures also exist where the ID uniqueness is not definite. The advantage of ISO 15963 tags compared to 14443 tags is their longer reading range which can have significant influence on system performance. From a construction business view point the ISO 14443 also has a significant advantage. It is compatible with the NFC technology (Near Field Communication) which combines the function of a contactless smart card reader and peer-to-peer communication, and is defined in ISO 18092 (NFC Forum 2008). Today NFC is available in smart phones from e.g. Nokia, Samsung and ARYGO for the traditional consumer market making them cost efficient also for the construction industry. The traditional mobile phone is one of few modern ICT technologies widely accepted and used generally in construction, and therefore it can be an important gate opener for introduction of RFID in construction. Another important standard is the ISO 18000 series of RFID standards for item management. The 6 standards in the series defines the air interface between tags and readers on 5 frequency bands from 135 kHz to 2.45 GHz and a common architecture (ISO 2004) but not the data content or the data structure. Currently ISO 18000 is less appreciated for industrial than ISO 15963 and ISO 14443.

EPCglobal is an important developer of ontologies for RFID. EPCglobal develops standards to expedite a commercial use of the technology. EPCglobal is centred on what is called Electronic Product Code (EPC), which is a fundamental ID system for identification of physical objects in an EPC network (EPCglobal 2008). Possibly, it is a successor to the widespread bar codes. EPC uses an URI (Uniform Resource Identifier) in URN (Uniform Resource Name) notation to represent a unique topic with a digital code. A URI is a compact string of characters used for identifying or naming a resource. A URN is a URI that identifies a resource or an object in a specific name space. The name space can be e.g. an ISBN number for books, MAC-address (Media Access Control Address) or IP number for computers or a Serialized Global Trade Item Number (SGTIN) identifier for objects in a supply chain. For a SGTIN-96 identification, in which 96 designates that a 96 bit EPC coding is employed, the URN looks as follows:

- urn:epc:id:sgtin-96:FilterValue.CompanyPrefix.ItemReference.Serialnumber

The filter value is not part of the SGTIN number system but is a 3 bit value that can be used to quickly identify whether the SGTIN-96 ID is a number of a single object or a whole pallet of objects. Furthermore, the SGTIN code identifies the manufacturer, the product type and, finally, the unique object, by means of the serial number. The entire URN is coded into a 96 bit ID saved in the tags.

EPCglobal standards describe components and architecture for what EPCglobal call the “EPCglobal network”. The idea is that this network of standardised and compatible RFID tags, RFID readers and information systems should connect the entire supply chain – from the producer to distributors and transport companies to the retail trade. By means of a network service, ONS (Object Naming Service), it will be possible to route requests for objects to servers containing information about the objects. The ONS-system is hierarchic and similar to the DNS (Domain Name System) where a set of server functions implemented as a large distributed database of URL names and IP addresses. Together with the IP protocol in version 6, the EPCglobal Network makes up the cornerstone of the future 'Internet of things'.

## 6. RESSOURCE ONTOLOGIES

Resource ontologies are dedicated to represent all data sources such as files, documents, databases, product models, and product model views. A prerequisite for interoperability in interorganisational settings is a common resource ontology for representing data, information and knowledge is needed. ISO 12006-2 and IFC are the two major candidates for resource ontologies for the construction industry (Ekholm 2005). ISO 12006-2 is a framework for classification of information within construction but does not provide a complete classification system. A number of national implementations of ISO 12006-2 are available e.g. the North American Omniclass, the Swedish BSAB and the Danish DBK. Unfortunately, there is currently no deeper harmonisation between IFC and ISO 12006-2 or between classification systems based on ISO 12006-2. The IFD (International Framework for Dictionaries) Library for Building Smart (Bjørkhaug and Bell 2007) is an international development addressed to bridge between classification systems and product models. This is therefore an important initiative towards enabling the users described in the scenario in section 3.1 with the ability to retrieve context sensitive information such as installation instructions, maintenance instructions and other virtual model views.

Numbering systems are an important part of the mentioned classification systems and can be used for identification of physical objects in buildings by adding numbering codes to the RFID tag. A digital link between the resources such as virtual models and physical objects can thereby be established. However, it is not advisable to use the code for early object identification because it depends on the object's final placement in the building and the component system of which the object a part. There may also be many RFID tags attached to the same object. The code is therefore dependent on an instantiated virtual model of the project which is not always available when the actual components are produced. The classification system, on the other hand, is important for organising information about the objects and their relationships. It is therefore recommended by the authors in most cases to only have a global unique ID (GUID) in the RFID tag and store all other data in the supporting virtual models organised by the resource ontologies. It is the simplest and most flexible way to secure the possibilities for reuse of RFID tags in interorganisational relations. The exceptions are situations where access to the virtual model can not be establish or the concrete uses require more object related information to be stored in the RFID tags.

For some years paper based documentation will be necessary and thereby also human interpretable numbering or codes on objects will be necessary. A printed barcode supplemented with the object label could be the first step towards both computer and human interpretable codes on drawings supporting workflow 6 in Figure 2. With the current development in flexible display technology (Plastic Logic, 2007) the need for human interpretable general numbering systems will decrease and be superseded by hyperlinks on the views.

The product model ontology IFC in its current version 2x3 supports RFID by use of the *IfcClassificationReference* class, a subtype of *IfcExternalReference*. By adding the GUID from the RFID tag to the IFC model as an *ItemReference* it can be associated with any building element in the virtual model. There is, unfortunately, no inverse relationship between an *IfcExternalReference* and *IfcRelAssociatesClassification* declared in the IFC2x3 schema which would give the possibility to navigate back from an External reference to an *IfcBuildingElement*. Future changes to the IFC Schema would require this to fulfil the motivating scenarios, otherwise the software implementations of IFC should provide this

additional feature. Following, it would also be beneficial to be able to model RFID tags as an object or property set in IFC with properties as; GUID, current location, planned location, time and date for tag readings, user who has read the tag, active/deactivated tag.

Another approach is to add the IFC object's global ID to the RFID tag. It is, however, not recommended because this will make the virtual model less flexible to changes. Often it is also necessary to let both one RFID tag point to several objects in the virtual model and to have several RFID tags to point to one virtual object. Furthermore, RFID tags are often born with a fixed GUID.

Another project from the construction industry worth mentioning in relation to resource ontologies is the SABLE project (Simple Access to the Building Lifecycle Exchange). The objective of this project is to enable easier access to resources stored in an IFC model server by providing a common framework for linking IFC model servers and a standardized interface for client access to the IFC model servers. (BLIS 2005)

Because the extreme complexity in developing an international classification system for organising information in construction, information retrieval based on key word tagging and search machine indexing could be a useful technique for retrieval of information related to objects in a building. Key word tagging has emerged as a popular method for categorising content on a web site. Users are allowed to attach arbitrary strings to data item such as blog entries, photos or items for sale. When web sites supporting meta tagging grow, their structure evolves to an ontology for the data the web site present. The ontology is thereby developed by the users who are using the web site. An ontology created in this way is called a folksonomy (Porter 2005). It is an easy and somewhat useful way to structure and link information but it also has some critical downsides. A folksonomy tag is typically 2/3 of an RDF triple. The subject is known: e.g., the URL for the image being tagged, or the URL being bookmarked. The object is known from the tag. But the predicate to connect them is often missing. To enable machine readable information on folksonomy based ICT tools the information providers must add supplementary semantic expressing the relationship between the subject and object. (Herman et. al 2008)

## **7. ORGANISATIONAL ONTOLOGIES**

Organisational ontologies are a general issue for any industry and concerns defining the concepts such as actors and their relations, hierarchies in projects and organisations, interorganisational relations, etc. They enable administration of rights to information and context dependent information delivery to users. In the Inteligrid project (Gehre et al. 2006) an organisational ontology is developed based on actor and project definitions from the IFC standard, developed by the IAI (IAI 2006), authorisation from the RBAC standard (Ferraiolo et al. 2001) and supplemented with additional concepts from the CIM model (Distributed Management Task Force 2006). It is assessed that this ontology will cover the user needs in relation to the scenario described in section 3. However, it is also recommended to consider using the Web Service Business Process Execution Language (WS-BPEL) extension designated BPEL4People (Agrawal et al 2007). BPEL4People enables the modelling of human interaction processes using BPEL but does not contain a complete organisational ontology. A combination of BPEL4People and the Inteligrid organisational ontology is therefore recommended by the authors for developing interoperable applications.

In relation to Semantic Web the Friend of a Friend (FOAF) Vocabulary gradually developed since 2000 is a different approach to an organisational ontology. Because of its simplicity and roots in the fast expanding world of social networking, FOAF is a potential candidate for the first widely accepted organisational ontology while it also should be considered used in the construction industry. FOAF uses the Resource Description Framework (RDF) for defining persons, their ongoing projects, organisations, interests, personality, relationships etc. (Brickley and Miller 2007)

## **8. BUSINESS PROCESS ONTOLOGIES**

By use of the organisational and resource ontologies the business process ontologies specify services for interorganisational communication and enable a direct relationship between business processes and business requirements. They also support workflow management, but currently no mature ontologies exist ready for use in construction. The Inteligrid project describes a framework for developing interoperable business services, which can be implemented using service oriented business architecture (SOBA) and Business

Process Executions Language (BPEL) (Gehre et al. 2006). The framework describes high-level business process objects but when it comes to more detailed ontologies about actual information delivery, reference is made to the on-going IDM project of the BuildingSMART initiative (cf. Wix 2005).

In Denmark the national Digital Construction project has worked with information delivery to the construction site and to the client in a digital project hand-over process. The use of a production card has been proposed to represent the information needed to conduct a given task, and a XML-schema has been specified for representing the information needed in the project handover to the client. Knowledge from these projects can be valuable in relation to developing future business process ontologies based on functional building systems but they are currently not considered to be mature enough for industrial use. See also Christiansson (2007).

## 9. CONCLUSION

This paper describes a review and assessment of existing ontologies relevant in relation to linking virtual models with physical objects in construction. It has been found useful to categorize the ontologies after their applicability to specify meta ontologies, technological services, resources business organisation and business processes. The ontologies applicability to fulfil future requirements have been evaluated from informal questioning against a proposed future user scenario. Up until now the proposed ontologies structure seems to be well-founded.

The conclusions are; 1) the meta ontologies developed for the Semantic Web and the IntelliGrid Ontology Framework will be important for developing future IT infrastructures for information handling in construction. 2) Many technical service ontologies are already mature and used widely for communication through the Internet and mobile phones. Therefore the barriers in these domains are limited for gaining the potential of linking virtual models and physical objects. When it comes to RFID technology there is also a number of available technical ontologies, e.g. ISO 14443 and ISO 15963 for HF RFID technology and EPC (ISO 18000) for UHF. These standards enable interoperable access to data stored in the RFID tags. Here the critical task is to select the right ontology because they are not compatible. 3) The resource ontology IFC supports representation of identification numbers from RFID tags. However, there is a need for modifications to IFC allowing object information retrieval based on registered RFID tags. A combination of using meta-tagged information based on specified ontologies is proposed with the use of search-engines using automatic full-text indexing and key word tagging. This would function as a way to quickly provide users with in construction widely used information such as instructions, documentation, schedules etc. 4) Various proposals for organisational ontologies such as the Business Process Execution Language for People (BPEL4People), the Semantic Web based Friend of a Friend (FOAF) and project and actor definitions in IFC exist but none of them have gained widely acceptance. FOAF is simple and originate from the widely expanding social networking world and therefore expected to be the first general used organisational ontology. 5) Business process ontologies development is a new discipline requiring new development and specification of e.g. functional building systems before they can be used in relation to linking virtual models with physical objects.

Development of new ontologies starting on meta-levels and increased use of ontologies already accepted internationally will enable the structuring and reuse of information to greatly benefit the whole industry. Nevertheless, it is also one of the most complicated hurdles to overcome for the industry while an increased focus from major universities, companies and property owners is needed for progress in this area.

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## **REDUCING COMPLEXITY OF CUSTOMIZED PREFABRICATED BUILDINGS THROUGH MODULARIZATION AND IT SUPPORT**

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### **ABSTRACT**

Many companies in Sweden using prefabricating strategies are currently meeting the ever increasing customer requirements with ad-hoc solutions that do not fit their production system. This is causing bottlenecks and lower profit margins as a consequence. One solution to the problem is to re-engineer their building systems according to modularization principles used in the manufacturing industries, which have adapted their production to be able to meet mass-customization.

This paper describes the first part in study of modularization of building systems and if methods used in the manufacturing industry can be adapted to the building industry.

The Swedish construction industries using prefabrication strategies are mainly project oriented, and needs to develop a more product oriented development process to benefit from the values that modularization can give. It is also obvious that it is impossible to introduce modularization methods used in manufacturing industries if design requirements are incomplete or changing from project to project. It is therefore essential that the product owner owns the whole process as well. Varying customers' demands can to some extent be handled using modularization principles. However, we don't believe that one solution fit's all; therefore it is essential to target a specific segment of the market. The cost for the development of such modularized building system for the targeted segment of customer must be evaluated against the possible market share.

### **KEYWORDS**

Modularization, standardization, prefabricating, Quality Function Deployment (QFD), Modular Function Deployment (MFD).

## 1. INTRODUCTION

Many of the Swedish prefabrication single-housing industries were established in the mid 60's. Prefabricated houses now dominate the single-house market in Sweden with a market share of as much as 80%. In the 60's and 70's the customer demands were low and architectural designs and technical solutions were standardized (Höök 2005). In the beginning of the 80's competition in the single-housed market inclined and companies were facing new rivalry due to increasing demands on customized solutions, (Hill 1994). Initially well designed standardized technical solutions were transformed using "ad-hoc" solutions necessary to customize the house according to customers needs. This was, according to Brege (2008), one of the main reasons to the fall in profits in the prefabricated single-housing industries in the 80's.

Josephson and Saukkoriipi (2005) states that as much as 35% of the total production costs can be identified as waste in traditional on-site production of apartment blocks. This has inspired several constructions companies in Sweden to implement building systems for the production of apartment buildings. However, the question arises how the building system can be customized in order to be competitive on the market? Adaptation to the increasing demands for customisation is facing many industrial sectors around the world and, according to Ulrich and Eppinger (2008), mass customization methods can be used where the customer can tailor the product according to his/her own needs. Modular Function Deployment (Erixon 1998), is one strategy that can be adapted to prepare a product family for mass customization. One big difference when referring to methods used in the manufacturing industry is that they are developed for product oriented processes where a decentralized product development process are common (Johnson et. al 2006). The building industries are conventionally project-oriented, and methods that are used in the manufacturing industry must be adapted to the building industries way of working. According to Lessing (2006), the focus on the individual project in the building industry has often led to a fragmentation in the process with little continuity and low productivity development. Also, no single actor owns the whole process as opposed to the manufacturing industry, Nordstrand (2003).

The purpose of this paper is to explore methodologies for customization used in the manufacturing industry that in a structured way can evaluate customers demand against the possibility of customization of a standardized building platform.

## 2. THEORY

### 2.1 MODULARIZATION

Modularization is currently a key concept for customization in the manufacturing industry to reduce complexity. Advantages in standardized and rationalized product structures, makes it possible to customize flexible solutions (Ulrich and Eppinger 2008). According to Erixon (1998) modularization is, "*decomposition of a product into building blocks (modules) with specified interfaces, driven by company - specific reasons*". The building industry in general does not have the same interpretation of modularization, which can be confusing. Often modularization is referred to as "*standard building elements or volumetric pre-assemblies*" (Höök 2005). Arranging the main assembly station with several short module assembly lines makes the production system easy to understand. "*Factory in factory*" increase the meaning and personal satisfaction of the production staff due to better understanding of the production system (Erixon 1998). Baldwin and Clark (2000) states that humans needs to divide complex systems to be able to understand and solve problems. When a system is divided into smaller parts, the complexity of the minor parts can easier be solved. The complexity of the system can be concealed behind "*an abstraction and an interface*" (Baldwin and Clark, 2000). The abstraction represents a module with a certain function that can be combined with other modules using a standardized interface. In the manufacturing industry product lead time is vital: "*Six months delay in product introduction results in 33% less profit over 5 years while on time introduction but 50% development expense overrun only result in 4% less profit over the same period*" (Charney 1991). If new house "models" can be introduced faster with the modular building system, the benefits of following market trends would be noticed also in the building industry. It can also reduce components in stock with less capital assets in use.

### 2.2 MFD – A METHOD FOR MODULARIZATION

Modular Function Deployment or MFD is a method that systematically divides products or families of products into modules, based on five key steps. In step 1 the customer needs are recognized by using the Quality Function Deployment (QFD) method, (Akao 1990). After the product properties are determined from the QFD analysis, technical solutions that meet these needs are developed in step 2. When technical solutions

are chosen, a module grouping process is performed in step 3 creating a Module Indication Matrix (MIM). This step identify “*module drivers*” that arrange the technical solutions into similar characteristics. The new concepts and the technical solutions are evaluated using an evaluation chart, step 4, where the identification and evaluation of module interfaces will be an important factor for which concept to select. When the modules are found they can be improved developing module variants with the same interface without affecting other parts (modules) of the product. Step 5, the design process or development of modules/ module variants can then be structured with methods like Design for Manufacturing/ Assembly (DFMA), (Erixon 1998)

### 2.3 QFD - TRANSLATING CUSTOMERS NEEDS INTO PRODUCTS

Designing products that are focused on customers needs is essential to sustain competitive advantage. Mapping the customer needs against the product properties, well defined methods have been developed in industries around the world. Perhaps the most frequently used is called Quality Function Deployment (QFD) that emerges from Japan, (Akao 1990). In the year of 1966 QFD was conceptualized for the first time, as means for introducing customer needs early in the design process. QFD arises from mainly two issues that automobile industries in Japan had. First, design quality started to have a greater determining factor, but there were no books available in those days. Second, QC (Quality Control) process charts were established after the products were built, which made it hard improve the process (Akao 1990). To be able to find the customer needs and structure them, tools called affinity diagrams can be used. The voice of the customer can then be arranged in hierarchy levels where the first level defines the idea, next level provide definitions for the primary level, the third level describes the details for the second level etc. This can also be described in a tree diagram (Eldin and Hikle 2003). When the customer requirements are found a house of quality (HoQ) matrix can be formed and the product properties emerge, see figure 2. The relations are determined and marking scale can be used to define how strong the relationships are, this formation is mainly done by individual judgments rather than concrete solutions. The product properties are weighted and normalized to find the most important properties. The work of finding customers needs and turning them to product properties are often done by a QFD-team where all disciplines are involved. In traditional procurement systems, when design and construction is done by different participants, the general success in using QFD methodology can create a problem. In figure 1, the construction industry, with the project centric way of working is defined. Different parties are responsible for different parts of the project, and “*Cross-functionality*” often used when conducting a QFD can be hard to achieve. The methodology of QFD can be suited for projects/ products where a single part is responsible for every phase and the function requirements can be well defined in an early stage, and not as a parade of trades. (Dikmen et al. 2004).

In the building industry much work in identifying needs have been concentrated on the geometrical shape of the building and arrangement of rooms; often these improvements have been performed by using Quality Function Deployment in the design phase (Gargione 1999, Ozaki 2002). Not much work has been conducted, to the authors’ knowledge, using QFD as a general tool focused on the requirements from a customer’s perspective on the product properties of a building system.

### 2.4 PRODUCT CONFIGURATION AND PRODUCT MODELS

The main advantages in modularisation is that despite the end product can vary in shape and functions, the design and production of components and modules within a product family are the same. The design phase is replaced by a configuration phase where the product is customized by selecting an appropriate set of module variants from the product family. From an information management point of view, this means that the product model used in the configuration phase must also be modular, (i.e. contain all modules and variants of the modules). The result of the product configuration is a specific product model that contains all information for production of the customized product (Jørgensen 2008).

The modularity of the product model can be divided in different types (Gerth 2008):

- Based on structure: Alternative component models where the customer selects one alternative of the companies product model alternative or free selection of components where the customer have freedom of selection of components/modules in a so called addition process of parts not compulsory for the product. The product can then be more customized by adding additional functionality.

- Based on attributes: Specific components/modules can be varied through the use of attributes, either by the use of enumerated or numerical values. Example, color on a module (red, green, blue etc.) or the length of a specific component (6 m).

### 3. THE PRODUCT CENTRIC BUILDING PROCESS

The Swedish building process is generally divided in several steps involving numerous of participants, (Nordstrand 2003). The participants involved are working by them selves with no or little contact to each other, and they are often dissolved when projects are finished. What separates the industrialized building process from the on site construction projects is that they own most of the disciplines and process, still they work on a project basis see figure 1.

To take advantages of modularization techniques it is necessary to go from project focus to product focus. In the future modular building process, figure 1, it is essential to separate product design from project, only then it is possible for companies to gain advantages in continuous improvements of product developments. Modularization methods based on customer focus and process techniques can then be feasible (Lessing 2006).

*“The key, many in modular bridge industries say, is for engineers and contractors to start thinking of bridges in terms of products rather than projects.”* (Shaker and Greenwald 1994).

It is also important to find a market “niche” for the company to be able to meet particular group of customer requirements, (Ozaki 2002). Thereafter the design of the product platform can start since the solution will be based on requirements of the target customer. Time from separate project can then be devoted on product development where the individual project using a configuration process supported by the technical platform. When the organization is arranged as the lower part of figure 1, IT-support and configuration tools will be necessary to implement to organize the building systems and the product structure into interchangeable modules and module variants (Johnson et al. 2006). If the building system is not organized into design rules and configuration patterns much of the ICT support will lose its purpose. Problems that otherwise will be solved using “ad hoc” solutions and many cases special built products”, (Erixon 1998).

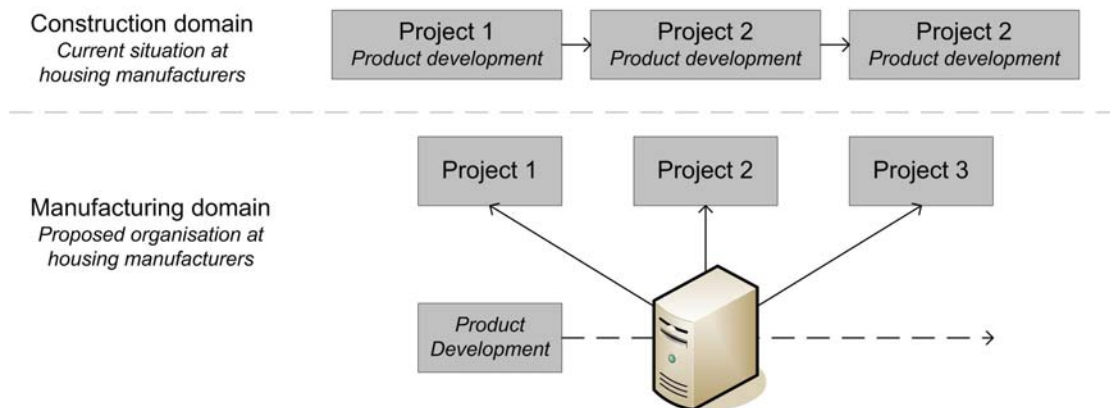


Figure 1: Project and product focused processes. (Johnson et al. 2006).

### 4. CASE STUDY- SMALL PREFABRICATING COMPANY

The purpose of the case study is to illustrate the possibility to apply QFD in construction. The study is made on a part of an already designed building with the purpose of translating demands and needs to design requirements for the specific building part. The next step would be to implement modularization strategies in future designs of the building.

#### 4.1 THE COMPANY IN THE CASE STUDY

The company involved in the case study is working with design and constructing of new small houses for family use. According to the owner, “customers wish to buy a well design/ architect drawn house filled with dreams”. Their new approach to the market is that they are delivering new designed houses in what they call a

collection, 3-5 new types of houses every second year. They deliver complete material and components needed above the foundation including assembling instructions. The assembly of the house is left to be done by the customer. The material is delivered pre-cut together with components, such as fittings kitchen utilities, in a container and with little or no prefabrication what so ever. To sustain competitive advantages, the company needs to modularize the technical solution to find carryover solutions between collections.

#### 4.2 TRANSLATING NEEDS TO PRODUCT PROPERTIES

In every new product design, you have to find the customers needs and what the product is supposed to deliver and this at low cost in order to get an “*economic success*”, (Ulrich and Eppinger, 2008). This first step, as presented previously, can be evaluated using QFD to map customers need against product properties.

The problem is that the overall product properties are the same for most buildings, a building are supposed to withstand water and wind etc. and characteristics that separate the different companies and building systems from each others is the architectural design. Therefore, companies need to select a particular segment of the market in which a specific group of customers are the target for the QFD analysis (Ozaki 2002). The customers in focus, market “niche”, could be the architectural design or “low price” that a company are focusing on. If design is the competitive edge, the QFD will be directed on how the technical solutions can solve the specific architectural design. As an example if the target customers are interested in “old fashioned” architectural design, roof construction will most likely be steep with big bases of a roof. On the other hand, the technical solutions for a flat roof “with a contemporary design” will be different. Market analysis is therefore critical in any new product design.

The other benefit of targeting a specific group of customer is that the product development costs for the architectural and technical design can be shared by a larger volume of houses. When technical solutions can be reused within a specific collection and carried over to the next generation of collections through modularisation, the development costs/per house can be reduced even more. Also, this would most probably lower the production cost over time and give opportunities for industrialized production of certain parts of the building.

The target group in the case study can be said to be the design aware customer who want to own a unique architectural designed building. However, the price matters. From the market analysis, the proposed solution was to engage a known architect to do the design and as a compromise between uniqueness and cost. The design is only going to be used for a certain collection of houses over a limited time. This type of trade marking a product is common in other sector and a well-known example is H&M who uses world famous designer to design specific collections of clothing in a limited edition.

In this paper we will use the roof design proposed by the architect as an example, of how we can translate the functional requirements to roof properties. The requirements are listed on the left side and product properties on top of the OFD diagram in Figure 2.

The requirements part has been divided into 4 categories that will affect the technical design:

- Standard specifications, i.e. regulations from national authorities.
- Market niche, as interpreted by the architect
- General demands, i.e. from the owner
- Production demands.

The link between requirements and product properties is indicated with circle in the QFD diagram. The product properties can now be used to guide the design of technical solutions and abandon old solutions that would be used otherwise.

|                                          |                                                                        | Product property                                                            |   |   |  | Diffusion leakproof construction          |   | Building part may not have any water Leakage |  | No burnable material on the inner side of roof |   | Roof surface must be made of material that are approved by standard regulation |  | Max weight of 150kg each construction |  | Max length of construction part 20 feet |  |
|------------------------------------------|------------------------------------------------------------------------|-----------------------------------------------------------------------------|---|---|--|-------------------------------------------|---|----------------------------------------------|--|------------------------------------------------|---|--------------------------------------------------------------------------------|--|---------------------------------------|--|-----------------------------------------|--|
|                                          |                                                                        | Construction part must be able to resist a moment of at least XX kNm        |   |   |  | Have a thermal resistance of minimum 0,02 |   |                                              |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
|                                          |                                                                        | Construction part must be able to resist a shearing force of at least XX kN |   |   |  |                                           |   |                                              |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
|                                          |                                                                        | Construction may not deflect more than XXmm                                 |   |   |  |                                           |   |                                              |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
|                                          |                                                                        | Product requirements                                                        |   |   |  |                                           |   |                                              |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
| STANDARD SPECIFICATION<br>BKR, BBR, ETC. | Must be able to take care of snow given by standard specifications     | ●                                                                           | ● | ● |  |                                           |   |                                              |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
|                                          | Must be able to take care of wind given by standard specifications     | ●                                                                           | ● | ● |  |                                           |   |                                              |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
|                                          | No deflection bigger then length/150 in the serviceability limit state | ●                                                                           | ● | ● |  |                                           |   |                                              |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
|                                          | Building part must have 5meter bearing distance                        | ●                                                                           | ● | ● |  |                                           |   |                                              |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
|                                          | Construction part mustn't be thicker then 0,5m                         | ●                                                                           | ● | ● |  |                                           |   |                                              |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
| SPECIAL MARKET<br>"NICHE".               | Must have a flat surface on the inner side                             |                                                                             |   | ● |  |                                           |   |                                              |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
|                                          | The incline of the building part must be 10 degree                     |                                                                             |   |   |  |                                           |   |                                              |  |                                                |   | ●                                                                              |  |                                       |  |                                         |  |
|                                          | Possible to integrated spotlights in the inner roof                    |                                                                             |   |   |  |                                           |   |                                              |  |                                                | ● |                                                                                |  |                                       |  |                                         |  |
|                                          | Low energy loss by leakage ore heat radiation                          |                                                                             |   |   |  |                                           | ● |                                              |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
| GENERALL DEMANDS                         | No mould in construction part                                          |                                                                             |   |   |  | ●                                         |   | ●                                            |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
|                                          | No water inside the construction part                                  |                                                                             |   |   |  | ●                                         |   | ●                                            |  |                                                |   |                                                                                |  |                                       |  |                                         |  |
| PRODUCTION DEMANDS                       | Must be able to place in a container                                   |                                                                             |   |   |  |                                           |   |                                              |  |                                                |   |                                                                                |  |                                       |  | ●                                       |  |
|                                          | At most 3 persons assembling the house                                 |                                                                             |   |   |  |                                           |   |                                              |  |                                                |   |                                                                                |  | ●                                     |  |                                         |  |

Figure 2: Example of QFD executed on the roof-construction



#### **4.3 RESULTS FROM THE QFD-ANALYSIS**

The product properties that were extracted from the QFD matrix, showed the possibilities to clarify customer needs that otherwise would be hard to take notice of. For example the early design of the roof construction done by the architect, the ceiling was inclined. But there were no product requirement that specified this from the customer point of view. This construction solution imposed the walls to be cut with an angle of degree; and the reason to separate the walls on the gable flanged end from the rest. By making the ceiling of the house horizontal, the walls could be made in the same height and therefore dramatically reduce product parts. It is easy to see that these kinds of standardizations can in a following investigation of modularization techniques help to locate possible parts to standardize, taking in account only those aspects that are essential for the customer. For example; if the company wish to generate a two story building in the next collection, there will be no difference between the walls on the first floor and the second, this when walls can be made in same heights and the interface are the same. Another important thing that was found when conducting the QFD analysis on the construction part was that the conceptual design did not support the installation of spotlights in the ceiling without going through the vapour barrier, even though spotlights in the ceiling was important for the targeted customers. Design errors like these would most likely have increased the production cost. Performing the QFD that might seem unnecessary and time consuming can easily be justified.

The case study company has built three exhibition houses with the architect's early construction design. Thus the comparison of the total building costs for the new building system cannot yet be evaluated.

#### **4.4 MODULARIZATION PROCESS**

In the manufacturing industry it is common to produce a product that is supposed to perform a certain duty. A car ought to transport something somewhere; a stapler is used to make holes in a piece of paper. The purpose of the product creates a variety of function-requirements. The identified function requirements are then structured in a way that leads to desired solution(s). From a modularisation point of view, the product should be designed in such a way that there exist a one-one relation between each functional demand – and the technical solution. Then, new functionalities can be added, by adding a new module to the existing set of modules. This type of design is common in the software industry (Baldwin and Clark 2000).

A house has also many different functions; however the technical solutions providing these functionalities are more difficult to separate from each other. The house shall offer cooking possibilities, supply with shelter, the rooms must supply users with electricity, the air-flow in the building must be in certain ways, etc. Therefore, a QFD study on the building as hole with different levels of requirements is hard to do, especially when no specific group of customer is targeted. To manage all these different demands in different levels the interfaces between the typical solutions from the market analysis must be found and this can provide the possibilities to perform the product development on a certain construction part. After this is done the product design can be made using modularization methods like MFD. Figure 3 shows the general process and how QFD can be used in the product development process translating functional requirements from the market “niche”, which later can be used in the MFD process finding modular products.

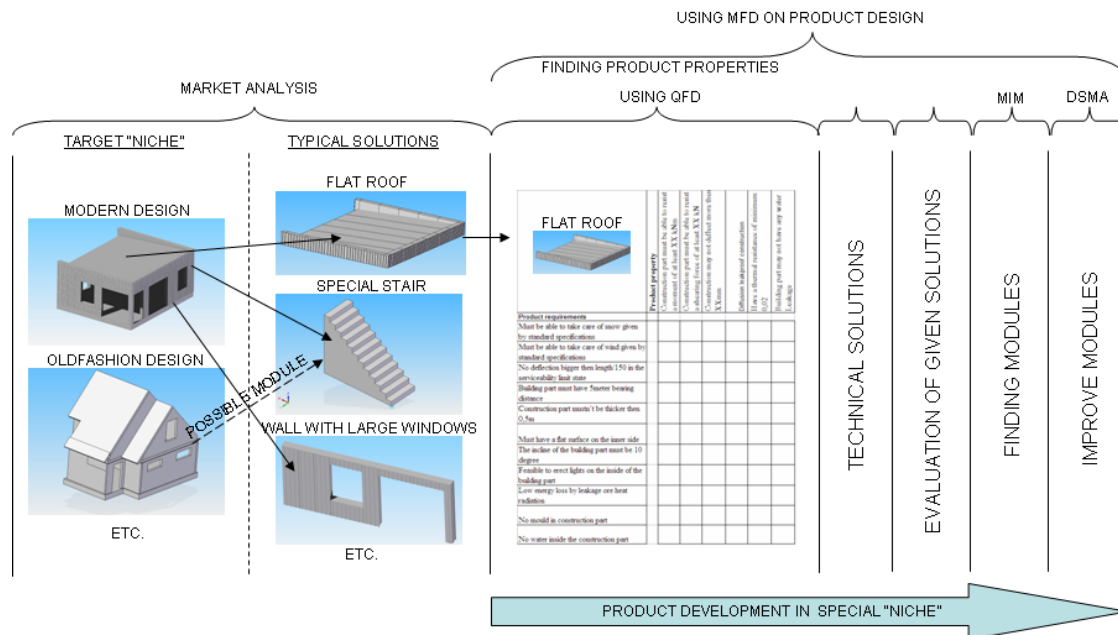


Figure 3: Product development of houses using modularization techniques.

In the product design phase the design properties are converted into technical solutions that are evaluated from a modularization perspective. When the modularization of the technical solutions starts (MIM), reason for modularization must be considered. The purpose in the case study is to minimize the design effort, the assembly instruction for the technical solutions for development of new collections. The building system need to be defined in such a way that interfaces between modules in a collection is the same. Also, if these interfaces can be used in the next collection, the probability is high that the design work can be limited to the development of new variants of the modules making the design work and production of the assemblies more rational. If a house is modularized to have different spans in the building then perhaps the thickness of the "framing of joists" must have different heights. If the heights are different then it would be hard to make the connection inside the house since the interface and structure between the walls inside the house would change. Instead of changing heights of the slabs, the interface imposed by modularization principals need to be inside the walls. This could according to Shaker and Greenwald (1994) instead be solved using several beams with the same height, where the varying requirements on the load capacity of the "framing of joists" can be met by increasing the number of beams in the construction.

## 5. DISCUSSION

Prefabricated house manufacturers are meeting an increasing demand for customizations and their current building systems need to be reengineered to meet the new market demands. The benefits from using standardized prefabricated building systems are slowly being diminished, since the common way to solve the customization today is to use "ad hoc" solutions. The problem has slowly emerged from the beginning of the 80's and many industries in the sector are facing the same problem trying to use a building system, not made for customization.

Some manufacturing companies have attacked these problems and being successful using modularization to adapt their product and production system for mass customization. Why can't construction industries work in similar ways? Much of this problem dissolves from the fact that manufacturing industries are product oriented whereas construction is project driven. Contractual forms and number of participants often working in separated phases over the project life has separated design from production. Ad hoc solution to please a specific customer are causing problem in the production phase. According to Erixon (1998); *"the design phase can determine 75% of the production costs"*. This has led to methods like MFD to put more emphasis on "Design For Manufacture". The problem of not specifying the functional requirements also from a production perspective leads to designs not really adapted for the production system. Methods like QFD can

help to identify design properties that are vital both from a customer perspective and from a production system point of view. Methods like MFD can then be used to identify both process and product “modules” that can be re-used over time from project to project. However, it seems essential that the same actor in the building project is also the owner of the product. The most likely candidate is the building constructor making him the process owner. Then the benefits (but also the risk) of investing in new building system can be calculated over a time span longer than the individual project. Today, you often hear things like “this building is so unique and will only be built once” but many of the parts in the “unique” building are used over and over again in many construction projects.

In the case study analysis it was clearly observably that the actual product properties from which the design is based on can easily be extended adding more functional requirements such as production needs. Often, these step is omitted in normal design in the building industry, since the designers needs to deliver a technical solution on a short notice.

From the functional requirements given by standard regulation, customer demands and production constraint (built by at most 3 persons, delivered in a container etc.), it was relatively easy to specify the product design properties. They gave a number of technical possible solutions that could be screened by the principles of modularisations. A possible modular solution was proposed that can be varied within the actual collection of houses. Also, the QFD method makes it possible to see reason for abandoning traditional technical solutions that would otherwise be used. Construction industries products (houses) are mainly different in the architectural design, and it is essential to have this in mind. Manufacturing industries are mainly separated by their technical solutions.

We believe that going from project design to product design, modularization is essential to meet the customer future demands and at the same time take the advantages of carry over technical solutions from “project” to “project”. Also, this makes it more motivating to use state of the art IT technologies to speed up the design and production phase, i.e. shortening the customer lead time from order to delivery. This is believed to be a major factor in a company competitive edge. (Mortensen et. al 2007)

## **6. CONCLUSION AND FUTURE WORK**

Swedish Construction Industries are mainly project oriented, and needs to go to a more product oriented development to benefit from the values that modularization can give. It is also obvious that it is impossible to introduce modularization methods used in manufacturing industries if design requirements are incomplete and changing from project to project. It is therefore essential that the product owner owns the whole process as well. Varying customer’s demands can to some extent be handled using modularisations principles. However, we don’t believe that one solution fit’s all, therefore it is essential to target a specific segment of the market. The cost for the development of such modularized building system for the targeted segment of customers must be evaluated against the possible market share.

It has also been noticed that QFD and MFD are possible methods to develop such a building systems.

In future work we will study modularization and the adaptation of methods like MFD in the construction industry. Can this method be used to re-engineer existing non-flexible building systems in the building industry in Sweden?

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## **RELATIONSHIPS BETWEEN ON-SITE RFID TAGS – OPPORTUNITIES, BENEFITS AND CHALLENGES**

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### **ABSTRACT**

With the increased interest in Radio Frequency Identification (RFID) in the construction industry and related research efforts, future construction sites can be expected to carry an abundance of RFID tags. These RFID tags at site have the potential to be used in order to improve context awareness during the construction phase. Specifically, semantic information about and between components and resources can be projected onto the RFID tags to create a semantically connected RFID network. Such semantic information might already exist when an integrated project model exists for the project. However, in cases where integrated project models for projects are uneconomical or cannot be made available due to other factors, the semantic information can still be made available for supporting context awareness on construction sites. A wide range of on-site tasks, ranging from actual construction to facility management, can benefit from the relationships represented in the RFID network and the resulting increased context awareness. This paper discusses the opportunities for creating such semantic RFID networks, and highlights challenges and benefits that the authors identified throughout their ongoing research activities.

### **KEYWORDS**

Radio Frequency Identification (RFID), Semantics, Knowledge Management, Construction Industry, Context Awareness

## 1. INTRODUCTION

Radio Frequency Identification (RFID) has been used for many years in domains other than construction (Kern 2004; Kinsella 2005; Lekkas and Gritzalis 2007). The specific characteristics of the construction domain (e.g. harsh working environment, shocks, metallic environment) were factors hindering the implementation of RFID technology in this domain at the beginning. However, technology developments have solved many of these construction specific issues (Jaselskis and El-Misalami 2003; Song et al. 2006). As a result, the application of RFID to the construction domain has increased in recent years. Nowadays, RFID is adopted at construction sites for tool tracking, site access control, facility management and maintenance (Ergen et al. 2007a; Goodrum et al. 2006; Song et al. 2006). It can be argued that RFID applications will gain more interest in construction, possibly resulting in ubiquitous RFID environments on near future construction sites. In such ubiquitous RFID environments, one can expect to see RFID tags being used for different purposes by different parties involved in a construction project. Through these RFID tags, different parties will be able to identify components and resources and share information that is stored on the respective RFID tag or in a database that links additional data to the RFID tag.

Another means for sharing project information with other parties involved in a project is Building Information Modeling (BIM), or more generally Integrated Project Modeling (IPM). Integrated Project Models (IPMs) contain and integrate project information. Thereby, relationships between project constituents, such as relationships between building components and/or processes, can be represented as semantic relationships in the IPMs. The usefulness of this semantically rich information in the construction domain has been proven through the success of BIM and other IPM related technology (Cavallero 2006; Williams 2004). While IPMs are mostly used in the design and planning phases of a construction project, different research has shown that the semantic information in IPMs can also benefit the construction phase (Akinci et al. 2006; Boukamp 2006). Thus, it is desirable to have such semantic information available on-site during construction.

However, not all projects use IPMs. Most IPM efforts focus on building construction, as the name BIM indicates. Thus, most of the time IPMs are not applicable to special construction projects like tunnels, highways or most of the heavy constructions.

As an alternative to relying on IPMs for delivering semantic relationship information to the construction site, the authors propose to create a network of relationships between RFID tags on the construction sites. As tags are expected to become ubiquitous at construction sites and usually identify components and resources, this will allow creating semantic relationships between components and resources without requiring the creation of a full IPM. The objective of the ongoing research discussed in this paper is to investigate the opportunities, benefits and challenges associated with creating semantic relationships amongst RFID tags and making them available to support information technology on construction sites.

## 2. BACKGROUND

RFID technology consists of a transponder (usually called tag), reader, antenna and required software. The basic functionality supported is to read tags with unique identifiers using readers. Since the technology relies on radio signals, a direct line of sight between the reader and the tag is not required. Tags are divided into two main types: Passive tags without an internal source of energy and active tags with an internal source of energy (i.e. a battery). Passive tags are limited in their read range and in their amount of available memory. Due to their increasing popularity, prices for passive tags have decreased as low as a dollar or less and continue to do so. On the other hand, active tags have longer read range and more internal memory available. However, these additional features add to their prices up to several tenths of dollar. Since they too become more and more popular, their production prices fall – but they are still significantly higher than those for passive tags.

After its early applications in electronic toll collection in the early 90's, RFID was brought to construction domain for material delivery and equipment handling (AIM 2001; Jaselskis et al. 1995). Later the usefulness of RFID for material receiving, tracking and management was proven (Jaselskis and El-Misalami 2003). Also, research investigated the application of RFID technology to other processes, such as supporting on-site inspections (Yabuki et al. 2002), tracking of construction components through the supply chain and on sites (Akinci et al. 2002; Ergen et al. 2007b), tool tracking and management and detection of buried asset and location identification by combining RFID and GPS (Bulusu et al. 2000; Dziadak et al. 2005; Goodrum et al. 2006; Hightower and Borriello 2001).

Due to their lower prices, construction industry is currently mostly using passive tags; however, the advanced features of active tags and further decrease in their prices are expected to make active tags more popular in the near future. In summary, because of diversity in the construction industry and different parties involved in a construction project, it seems logical to expect both types of RFID tags from different manufacturers to be used for different purposes at a construction site. While more and more construction related applications are employed that use RFID tags, it can also be observed that RFID tags often remain on the tagged components and resources since it is too cumbersome (and sometimes impossible) to remove them for reuse after the components have been installed at the site (Ergen and Akinici 2007).

### 3. SEMANTIC RELATIONSHIPS BETWEEN RFID TAGS – OPPORTUNITIES, BENEFITS AND CHALLENGES

#### 3.1 OPPORTUNITIES:

Much of the information being accessed and being generated at construction sites is context-specific, i.e. it applies to a specific situation or a specific situation category. For example, reports and lessons learned from construction activities benefit from the identification of a construction context to which the information applies – which then can be used as a storage and retrieval index for the reports and the lessons learned (El-Diraby et al. 2005; Rezgui 2006; Zhu et al. 2007). Also, quality or safety inspection relies on specifications that impose requirements for given construction contexts (Boukamp 2006; Wang and Boukamp 2007). The identification of such construction contexts relies on determining *component or resource types* and *their semantic relationships to other components or resources* (Boukamp and Ergen 2008).

RFID tags attached to components and resources allow for quick identification of these components in an automated way. The IDs stored on the RFID tags can be used to retrieve information about the tagged items from an information repository, such as a database or an IPM. Also, any additional information stored on the RFID tags can be accessed. However, since RFID readers read multiple tags within a reader's read range and given the anticipated increase in RFID tags on construction sites, it becomes difficult to identify specific RFID tags of interest within the group of read RFID tags.

Defining semantic relationships between RFID tags will allow identifying related groups of RFID tags (see Fig. 1), such as components that are “PartOf” a structural frame. It will also enable access to semantic relationships between tagged components and resources on construction sites, which can be used to support automation of construction tasks. A specific example application that can benefit from such semantic information is construction site inspection.

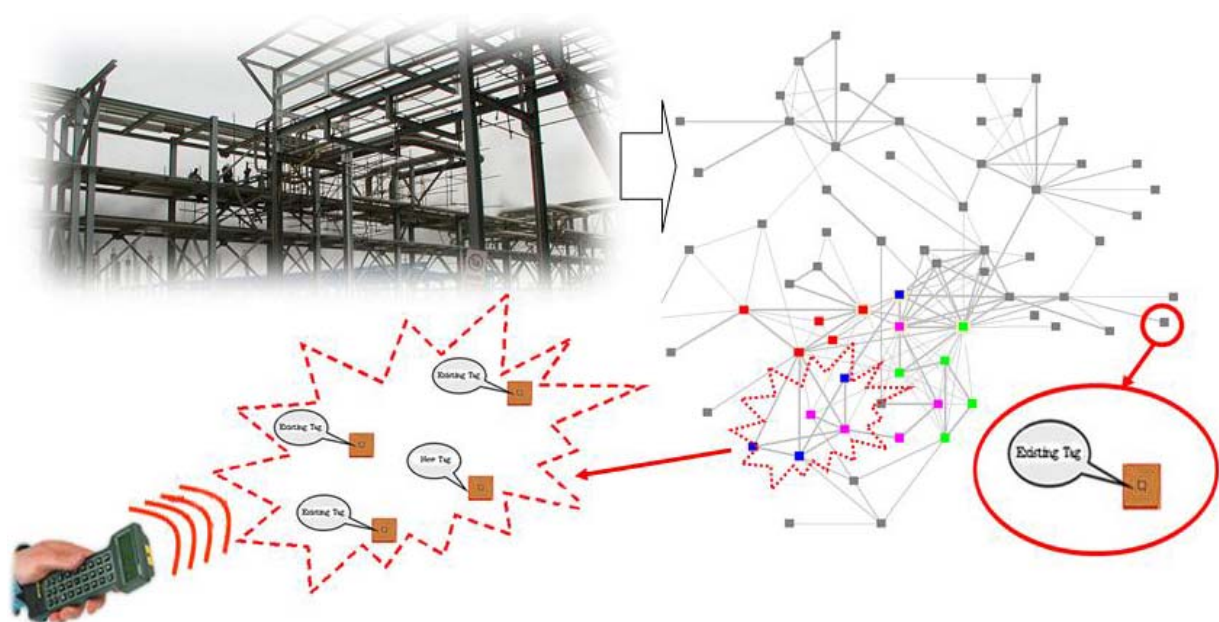


Figure 1: Having defined semantic relationships at site enables the end user to classify hundreds of available RFID tags into smaller groups.

Researchers have long argued that the work with specifications is cumbersome and error prone due to the huge amount of requirements imposed through specifications and the complexity of specifications (Boukamp and Akinci 2007; Burati et al. 1992; Kiliccote 1996). A study identified that different inspectors inspecting a project will draw different conclusions based on their specification knowledge (Hollis and Bright 1999). Approaches have been developed to address these issues and to help automatically identify requirements applicable to a given construction context (Boukamp and Akinci 2007; Kiliccote 1994; Wang and Boukamp 2007). These approaches rely on the availability of semantic information about and between products, processes and resources, which they either assume to receive from digital project repositories, such as IPMs, or through user input.

Making semantic information about and between products and resources available via semantic RFID networks will enable automated identification of these semantics (a) without the need of an IPM and (b) without the need for user input of this information. Thus, an engineer inspecting a site could use a mobile computer (such as a Personal Data Assistant (PDA)) with an RFID reader attached to scan the environment for construction context information.

### 3.2 DEFINING WEAK SEMANTIC RELATIONSHIPS:

Semantic relationships between components' and resources' RFID tags can be of two different basic types: They can be (1) simple spatial relationships such as *CloseBy* or *InTheSameArea* or (2) stronger semantic relationships, like *ConnectsTo*, *IsEmbeddedIn*, or *Supports* relationships.

Spatial relationships between components and/or resources can be determined through reasoning about the proximity of scanned RFID tags. The facts that tags need to be in a certain distance from the reader to be detected and that their signal strength varies depending on their distance to the reader can be used as a means to find their proximity to each other and to the reader. This would be the weakest level of semantics, as it would only be able to specify proximity semantics, such as "CloseBy". However, this weak semantic relationship can easily be identified by observation, e.g. by walking on the site and continuously scanning the RFID tags available. Such basic spatial information can later be used alone or in combination with added higher levels of semantics. With respect to the previously mentioned construction inspection, even this weakest level of semantic information, i.e. topological relationships, can be beneficial to an inspector. For instance, if he/she has to inspect the fire resistance of a wall with an embedded door, he/she may want to read the respective RFID tags of the door and the wall in order to determine the door's and the wall's fire protection rating and compare it to a specified minimum fire protection rating. When scanning the environment for RFID tags, the inspector may find that the RFID reader identifies multiple wall and door RFID tags that are in read range of the RFID reader. As a first step, he/she then identifies the RFID tag of the wall in question. By knowing the fact that multiple doors are in read range of his/her reader, but only one of these doors has a "CloseBy" relationship to the wall in question, gives him/her the ability to more quickly identify the relevant door RFID tag. However, the challenge is to determine how and when to establish these *CloseBy* relationships.

Another application that can benefit from these weak semantic relationships is identifying the location of the RFID reader within the construction environment. By interpreting the relationships between RFID tags, the reader would be able to determine its location on the construction site by distinguishing the components surrounding it and their spatial relationships. Building on the recent research efforts regarding indoor positioning (Lim and Zhang 2006; Song et al. 2007), the authors have performed initial tests that show that depending on the distribution of RFID tags on construction sites, it is possible to uniquely identify the RFID reader's location on the site by relying on such spatial relationships between RFID tags. Factors that affect the results are (1) read range of the tags and readers, (2) number of available tags on site area, (3) spatial distribution of RFID tags on the construction site, (4) performance related reader specifications (e.g. "reads per second"), (5) number of tags being attached to stationary objects vs. mobile objects, and (6) rate of read failures.

Knowing the spatial semantic relationship between two components gives us no information about whether they are connected, embedded, or just happen to be both in the proximity of the RFID reader and have no other semantic relation with each other. Additional rich semantic information about the relationships would lead to more accurate context information.



### 3.3 DEFINING STRONG SEMANTIC RELATIONSHIPS:

As shown in Figure 2, having defined richer semantic relationships can support processes at site even better. In case of the before mentioned example, knowing that a door “IsEmbeddedIn” the wall gives the inspector the knowledge that the door must also have at least the same fire rating as the wall. In the previous example the proximity of these two components helped identify the possibility that one might be embedded in the other, but now, through the richer semantic relationship “IsEmbeddedIn,” the possibility has changed to certainty.

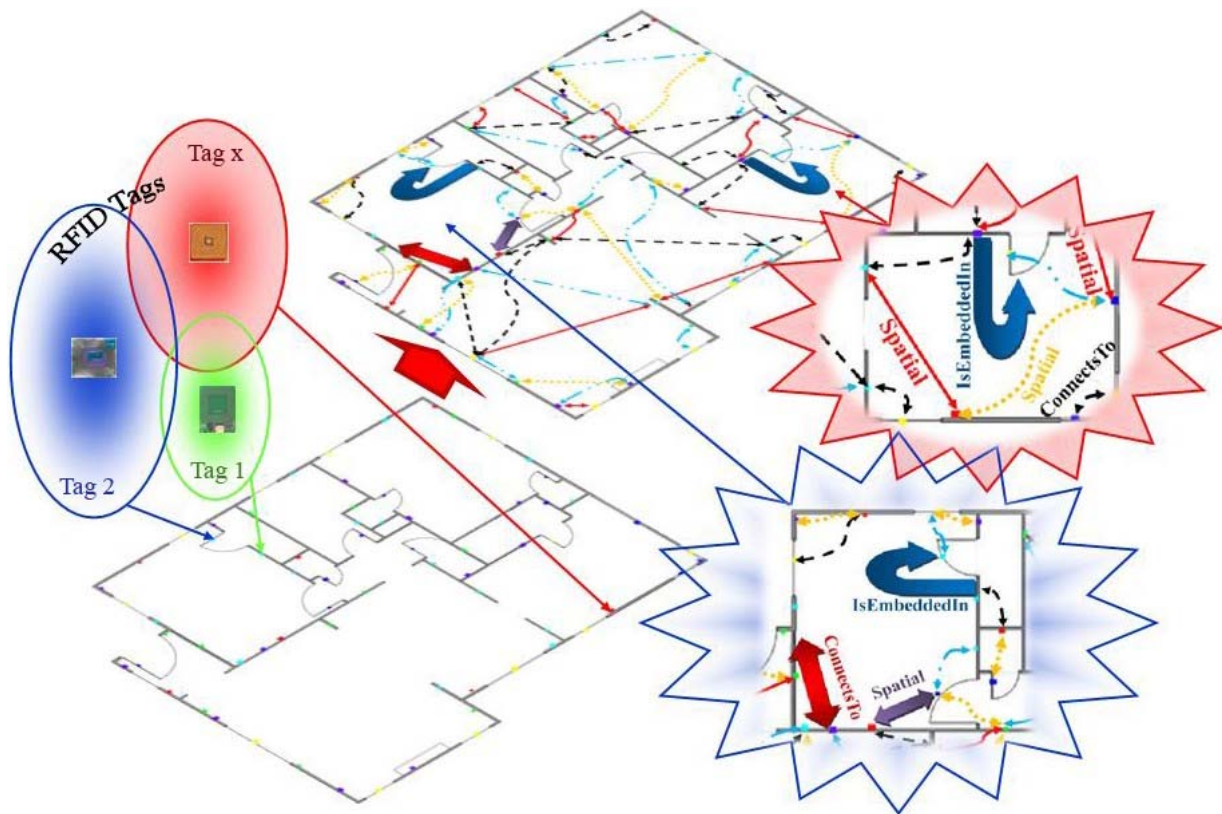


Figure 2: Defining different levels of semantic relationships among the existing RFID tags on a construction site.

Additional semantic information can be added to both the weak and the strong semantic relationships through the use of suppliers' information. Suppliers usually store a component's information either inside each tag or in a separate database for each of the tags' IDs. This information could be used to identify the type of the component and thus increase the semantic richness of the relationship information. Without such information, in the above example, the inspector would potentially only identify that the component tagged with tag 2 is embedded in the component tagged with tag 1. The inspector would not be able to easily identify that tag 1 represents a wall and tag 2 represents a door. This information can be associated with the tag right from the beginning by the supplier, though.

### 3.4 STORING AND SHARING THE RELATIONSHIPS:

Information about semantic relationships between RFID tags needs to be stored and a reader has to have access to the semantic information at all times while moving through a construction site. Diekmann et al. (2007) described two strategies for storing such RFID related information: (1) Data-On-Network and (2) Data-On-Tag.

Using first of Diekmann's strategies, i.e. Data-On-Network, all the generated semantic information would be stored in an external database. At the construction site, the reader should have a connection to the external database to retrieve the semantic information. However, wireless connection to the external database usually

requires expensive equipment and might not always be available at site. Even if available, the wireless network might stop working at times or not be accessible at all places on the construction site. These anticipated difficulties regarding accessing an external database lead to a semi-external approach in which semantic information is stored externally in a database but also copied into a local database stored with the reader. In this case, at areas where the wireless network can be accessed, the shared, up-to-date semantic information can be accessed, while at points where the wireless network is not accessible, the local copy of the database can be used. Whenever a network connection can be re-established, the databases should be synchronized again to ensure that everyone has access to the most up-to-date information.

The second strategy, Data-On-Tag, would use available memory on RFID tags to store semantic information. This has the advantage that it eliminates the need for an external database and that each tag would carry its own updated semantic information. However, a problem for this approach is that in the envisioned scenario, different types of tags may be used by different parties and should be re-used for establishing RFID networks – therefore, it cannot be assumed that all tags have memory available for storing information. In addition, at each reader location, only the semantic information available in the readable tags can be reached, which results in having access to only some of the semantic relationships.

The authors suggest combining these two mentioned strategies. The external database would be used as the priority database and accessed through wireless communication. At specific intervals this external database would be backed up on the local mobile computer attached to the reader for the time when it is not accessible. Also, information about changes made to the relationships between tags should be, if possible, stored on the tags at site.

The idea is to use the local copy of the database for locally accessing the relationship information. When a wireless connection to the primary external database can be established, the two databases should be synchronized immediately, whenever changes are made to the relationships. If a change is made to the RFID network structure, information about that change should be conveyed to the primary external database but also stored on the local RFID tag memory, if possible. This way it can better be ensured that anyone requiring relationship information will be able to obtain up-to-date information – even if a wireless connection to the primary external database is not available.

### **3.5 BENEFITS:**

A network of RFID tags attached to products and resources can provide semantic information about relationships between components and resources. Any on-site task relying on or producing context sensitive information on the construction site could benefit from this semantic information. For example, besides inspections, other domains, such as construction, progress monitoring, and facility management can use the semantic information for retrieving context sensitive information or for storing a context description to the generated context-sensitive information. Quality inspectors can be supported through information technology (IT) tools that gather context information from the semantic RFID network and use it to retrieve context relevant specifications and quality requirements. Progress monitoring inspectors can also be supported through IT tools that gather semantic information between components and workers to identify whether workers are still working on a component and what type of workers are working on a component.

In addition, semantic relationships between tags can also be used to identify missing tags in the network in case a tag is damaged or unreadable. For example, an inspector may be required to perform maintenance inspection of fire valves in ceilings that are not easily found and/or accessible. In such a scenario, the inspector may rely on RFID tags for locating the valves (Ergen et al. 2007a). If an RFID tag of a valve is damaged and cannot be detected anymore, the inspector may overlook the valve and omit the inspection of the valve. Through a semantic “IsEmbeddedIn” relationship between an RFID tag at a the ceiling and the damaged RFID tag at the valve, the inspector could identify that he/she is unable to read the valve’s RFID tag. This becomes especially important in the later phases of a project’s life cycle (e.g. in the facility management phase), when context information still is important, but batteries of active tags have run out of power and are not replaceable or completed finishing reduced the read range of some of the tags behind them.

Even if an Integrated Project Model (IPM) exists that contains semantic information, it can still be advantageous to have the semantic relationships defined in the IPM projected onto an RFID network on site, because not every project participant may have access to the IPM. There are many times when a subcontractor or a contractor has no access or only limited access to the IPM because they either do not have the required technology or because of legal issues (Rosenberg 2006). In these cases, however, similar as in the cases where IPMs do not exist, semantically related RFID networks can be made available to all the parties involved in the construction.

### **3.6 CHALLENGES:**

Before the advantages mentioned regarding defining the semantic relationships between RFID tags can be achieved, challenges and concerns have to be studied and overcome. As mentioned before, we expect to see lots of RFID tags at a construction site that remain attached to many of the components and resources. These tags will be brought to the site by different parties for their own specific different purposes. Thus, it seems logical to expect tags of different brands with different specifications. This highlights the importance of having a standard protocol to communicate with all of these tags with the same reader. Currently there exist a couple of standardization efforts for RFID tags, but a common global standard accepted by all players in the RFID business is still missing. Due to the lack of a common standard, new readers have been developed that can read tags of different brands – however, they are not able to read tags of all brands and they are much more expensive than regular RFID tag readers. Before the development and acceptance of a unique global standard, the problem could be addressed temporarily if the importance of sharing RFID tags information and developing applications, such as the proposed RFID network, during construction is recognized by the client of a project. This would allow dictating an RFID standard for a given project through contractual agreements. In addition to the RFID technology standards, standards for the semantic relationships have to be defined. Specifically, it has to be specified what type of relationships can and should be established, how they should be stored and when and by whom they should be established.

It should be clarified through contractual agreement or even an internal agreement between involved parties who is responsible for creating the semantic related network of RFID tags and keeping it updated. Responsibilities of each party regarding data provision and usage have to be clarified. If required, different levels of access to the data may have to be defined. This can be achieved, for example, through providing different versions of copies of the relationship database to different parties. The importance of an agreement on these issues is amplified by the fact that data is provided by different parties involved in the design, supply and construction process that are using different system platforms, standards, specifications and even are having different points of views which may result in needs for different semantic information.

In addition, sharing up-to-date relationship data with all of the participants will be a challenging task. As mentioned before, the authors suggest combining an external, wirelessly accessible database with a local copy of that database and a list of changes made to the network stored on RFID tags with accessible memory. Mechanisms have to be identified that allow keeping these different sources consistent with each other.

Due to the nature of construction, it can be expected though that the semantic network will change from time to time. It will become difficult to track these changes. Automated approaches may be developed that help managing the changes in the semantic network. E.g. a mechanism may be able to determine validity of defined semantic relationships through assessing the respective RFID tags' proximity at the time of the relationship definition and comparing it to the RFID tags' proximity throughout the remainder of the project lifecycle. When the proximity value changes, it means that at least one of the respective components or resources have been moved, which could mean that a semantic relationship between the respective components or resources may have to be re-evaluated.

Additionally it may be possible to include probabilities for the validity of semantic relationships in the database. Efforts may focus on adding certainty to the relationship information and may, for example, differentiate between final relationships and temporary relationships. This probability information then may be used in other reasoning mechanisms, e.g. to help determine the likeliness of correctness of the context identified through the RFID network.

Another issue which needs to be further studied is the security of the created network. Only authorized personnel should be able to change the RFID network. Thus, efforts need to be put into making the RFID network secure and only readable and changeable by authorized personnel, e.g. through data encryption.

### **4. SUMMARY AND CONCLUSIONS**

The existence of large numbers of RFID tags in a construction environment presents the opportunity to develop semantic relationships between them in order to make semantic information accessible on site. This semantic information can range from weak spatial relationships to strong semantic relations. The authors propose to expand the existing semantic relationships between building components to the RFID tags attached to them. The advantage of such a network of related RFID tags would be increased context awareness at site through automated identification of semantic relationships. The applications of the proposed system at site could range from supporting progress monitoring to improving safety on construction sites. To store the semantic information and enable better synchronization of the information amongst all interested participants

on site, the authors propose to use a combination of an external, wirelessly accessible database, a local on-site database, and spread data-on-tag.

Since the system is based on the RFID tags brought to a site for different purposes by different parties, it is expected to see a large variety of tags with different specifications. Further research is needed to enable interaction with such a diversity of RFID tags. The authors are currently involved in research that aims to define the semantic relationship structures amongst RFID tags that can benefit the safety inspection domain. Also, the researchers are investigating the stability of such semantic RFID networks and the effects of read failures on the ability to interpret the semantic information stored in the RFID network.

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## **THE INTEROPERABILITY ACT FOR EMCOMPASING SEMANTICS IN CONSTRUCTION DOCUMENTS**

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### **ABSTRACT**

Actors generate, share, and ultimately communicate information with other construction project actors. The content of this information is described within construction documents such as drawings, schedules, and specifications. Poor understanding of the content of the documents has been a factor in the escalation of construction project complexity. The result is a lack of efficiency in the communication that has been documented as failures to interoperate among actors during any construction process. As a consequence, actors need to employ additional resources for aiding the understanding of the shared information therefore significantly raising costs and reducing project productivity. Current research efforts are aimed at aiding interoperability by sharing common vocabulary and models among project actors. These efforts have been addressed through the development of common, shared models and construction industry standards. The objective is that multiple construction participants ultimately recognize the shared models and set a universal language. The implementation and use of the models and the common vocabulary provides the possibility of reusing the information within the construction documents by project actors. However, the industry has failed to adopt the commonly shared models and the universal language to effectively share information. The assumption in the construction industry is that the creation of an a priori consensus over the content of what is described within the information is a condition for interoperability. This paper questions this assumption by diverging into another paradigm, the semantics of the represented information. As an alternative, our research focuses on the semantic paradigm. We move away from the attempts to find consensus through common vocabulary and shared models to new methods that benefit from precise meanings. Our assumption is that strategies for exchanging, sharing, and integrating information will not reduce the lack of full automatic interoperability without working first on strategies for understanding the information from other sources. One of the steps proposed here towards this paradigm is the interpretation of the represented information by other construction actors. Our research explores the relationship between the represented information and the interpreter. For this purpose, a parallel of the interpretation of shared information has been made through the Speech Act Theory (Searle 1969). The objective is to understand what background information is pertinent to the conversation and what assumptions and inferences are needed to capture the intended meaning within the expressed utterance in order to parallel the speech act with the shared represented information between two construction participants. This research proposes the interoperability act concept for construction documents. The significant implications of this effort are the characterization of the interoperability act with the purpose of developing new forms of representing semantics within the construction documents, which provide a method to successfully share and communicate information.

### **KEY WORDS**

Interoperability act, construction concepts, interoperability actions, forms of representation.

### **1. INTRODUCTION**

The common practice concerning the sharing, exchanging, and integrating of information for construction projects is that actors or construction participants generate their information independently rather than in a collaborative environment. The fragmentation conditions of the construction industry is one the reasons for

the unsuccessful adoption of collaborative efforts. The resulting non-collaborative practices are also forced by the complexity of the project as multiple actors and multiple roles take part in a construction project. This complexity is reflected and increased when multiple actors that belong to external organizations actively participate in the same project. As these actors do not collaborate on finding strategies to share, exchange, and integrate the information, the format and content that the actors get from others is prone to misinterpretations, rework, and inconsistencies. The poor understanding of the content and format of the documents is an additional factor that significantly increases the construction project complexity. The possible agreements the actors reach on sharing, exchanging, and integrating their information are expensive and difficult to achieve. When two actors attempt to share and to integrate information generated from two different software companies, they need to set up business agreements regarding the functionality of their platforms and the methods of integration. Therefore, a priori agreements or coordination on the automation of the interoperability activities are not typically engaged in. As alternative strategies, the construction industry and government institutions approach the lack of effectiveness in collaboration with solutions that range from standards to common models initiatives. The ultimate objective is to facilitate the exchanging and sharing of information during the construction life cycle by moving all the actors to work in a single, public platform.

### **1.1 STRATEGIES OF CONSENSUS**

The generation of common models, standards, and vocabulary, for example, is based on reaching consensus from experts and members of the community. Its final purpose is to achieve automation within interoperability activities. The resulting consensus sets up rules within a model where the actors are able to generate their information and to plan their interoperability activities (Eastman et al. 2008). The Industry Foundation Classes (IFC) is an extensible reference model that provides broad definitions of objects from where more specific models can be developed to support exchanges within workflow activities (IAI 2008).

The actors, for example, generate their information based on a set of rich classes. The objective is that multiple construction participants ultimately recognize the shared models and set a universal language. The implementation and the use of models and common vocabulary provide the possibility of reusing information by project actors. However, the modelers' view is limited to their social and physical contexts. Therefore, the consensus on setting a common model or vocabulary limits the final user's view or actor's view. The generation of information under the actor's view is limited by the modeler's view.

The set of entities that represent the model has to be further adjusted and extended by the final user to reflect their detailed needs of construction firm for a particular project. The modeler or expert sets up a universal language and common models by consensus. However the social and physical contexts of the individual actors are not embraced through consensus. The consensus strategy opposes the uniqueness of construction projects, as a feature of their nature. This fact is manifested as a fragmentation of the construction industry's workflow (Taylor and Levitt 2004) and the agents' systems (Anumba et al. 2005; Bakis et al. 2007). For example, as multiple actors and project teams participate within multiple workflows, these reference models have to contain thousands of definitions of workflows in order to define the exchanges of information for particular contexts.

An additional limitation of this strategy is that the granularity level of any construction concept is too complex in their levels of detail. The granularity is not possible to be defined a priori by the expert's or modeler's view. This limitation belongs to the realms of the modeling paradigm. It restricts the actor's ability to fully integrate information and, therefore, fully interoperate. A complete automatic interoperation without an actor's intervention cannot be executed. Actors are able to use models and common vocabulary as a reference, but they need to represent their view of the concept to be shared, exchanged, and integrate to others actors. Even if the information is generated from common models, standards, or common vocabulary, an interpretation of the represented information is still required.

### **1.2 RETHINKING AUTOMATION FOR INTEROPERABILITY**

It is commonly overlooked that full automation of an interoperation is not possible and that a subsequent interpretation of the information is needed. A strategy for understanding the information from other sources is a requisite for an interoperation. The act of understanding involves interpretations. This research recognizes that the act of interpretation to generate and to represent concepts under the actor's realm is required for interoperability activities in construction projects. The interpretation takes place within two cases: 1) when the

information that is going to be shared, exchanged, or integrated is generated, and 2) when the information is received and manipulated by other actors, different from the ones who generated the information. The fundamental assumption is that the act “interoperate with” has a purpose of communication and of induction of actions. An interpreter’s or actor’s reaction produced by the interpretation of the shared or exchanged form of representation is expected.

This research explores the relationship between the actor who generates the represented information and the one who interprets the information. An examination of the semantics of the forms of representation of the information that is communicated is performed together with the required elements that intervene for a successful communication. The objective is to explore the understanding of the semantics that is required to effectively represent the information and to define the basic steps for interoperability.

## **2. REPRESENTING, COMPUTING, INTERPRETING**

The fundamental actions of interoperability are the actions related to the representation of information that is to be shared, exchanged, or integrated, the computation of the representation, and the interpretation of the obtained information by the recipients. As was explained in the introduction, the action that is probably most investigated in the past two decades is that of computing the representation. The transition from traditional paper-based to computer-aided-design representations is a representative case. The efforts have been focused on methods to represent and to compute representations in order to facilitate the interoperation. Researchers attempt to generate strategies to automatically interoperate the information with other actors (Barresi et al. 2008; C. Lima et al. 2005; Ducq et al. 2004; El-Diraby et al. 2005; O'Brien et al. 2002). However, the integration of the modellers’ views and the levels of specification of the representations is a paradigm (Amor and Faraj 2001; Mutis and Issa 2007) in AEC domain. This is a problem that is manifested in the semantic association of the representations (Motta 2000; Partridge 2002). As this research focuses on the action of interpreting, a brief examination of the currently used forms to represent information are useful to introduce the interpretative actions.

### **2.1 REPRESENTATIONS CONTAINED WITHIN CONSTRUCTION DOCUMENTS**

The agents of a community generate descriptions of hypothetical objects and states of affairs of their domain through forms of representations with the purpose of communicating them. These descriptions are abstract and are grounded in the possibility of their existence, although they can be imaginary. An architect, as an agent of the construction-project network, can generate the description of a clay tile roof through a set of symbols, which can be systematically expressed in natural language. The syntactic set of symbols can be interpreted as an utterance in natural language and those utterances are indeed systematically interpretable as to what they mean (Harnad 1994). This description is a characterization of the clay-tile roof objects. The characterization can be expressed through the advantages of being energy efficient, fireproof, and long-lasting compared to asphalt or fiberglass shingles. The clay-tile roof description can also include its state of affairs within the space-time region, such as the suitability of its installation in hot and dry climates.

The objective of an architect or designer is to generate a representation of the set of abstractions. A representation is the vehicle where the actor’s abstractions are described. The representations correspond to the descriptions of the architect’s or designer’s concept and are subsequently communicated to other actors in the domain. The descriptions are a characterization of the actor’s concepts. In the preceding example, the architect represents the concept “clay-tile roof” concept through a set of syntactic symbols, “clay-tile roof”. The syntactic symbols are expressed in natural language. This syntactic-symbol representation is a text-based representation of a concept. The architect’s intention through the description of the concept “clay-tile roof” is to make a reference to a similar, existing physical object in the construction domain. The actor who makes the reference is the interpreter of the “clay-tile roof” symbols. In this particular case, the interpreter makes reference to an existing object in the domain, “clay-tile roof”. The architect, however, expresses a concept through a representation to indicate a non-existing concept. Those non-existing objects are the ones other actors will interpret and build in a construction project. A drywall with x and y sizes and specific shape cuts is an example of these types of non-existing concepts.

An architect, designer, or engineer represents information through representations of any forms, including visual, syntactic, and symbolic. These representations, then, are the vehicle of the actors’ abstraction of



specific concepts. In the construction domain, concepts are represented through symbols, models, or visual representations and they are intended to be related to the physical domain, i.e. to be physically realized. The construction participant reifies and finds relationships between the interpreted concept and the physical domain. For example, a drawing of a “glass door” is a metaphor that represents a “glass door” concept. The metaphor or visual representation relates it to an existing object of the physical world, even though it does not exist.

### **2.1.2 REPRESENTATIONS AND THE PHYSICAL WORLD**

The agents in the physical world perform an interpretation and transform physical objects through actions. The actors take materials and objects and perform some action in the physical world according to their interpretation of the representation. Therefore, the actors perform actions that are prescribed within the representations (Mutis 2007). These representations are contained in the construction documents expressed in any format, such as digital or paper-based.

For example, a construction schedule is a document and a representation that contains axiomatic rules, and it is employed for planning activities for a construction project. These activities are actions that are going to be taken in the space-time domain. The space domain corresponds to the physical domain of the construction project and the time domain to the planned order in which the actions (tasks) are executed by the project participants. The construction schedule is a representation that is interpreted by the actors, and it can also be directly manipulated by other agents, such as computers.

The actors’ interpretations are semantic operations and the manipulations of the actors’ representations are “computations” of the symbolic composition of the representations. The operations of some activities performed on the axiomatic hierarchy of the construction schedule are “computational” operations. These operations are based on a systematic symbol manipulation following a set of rules. The “computational” operations are not part of the semantic operations although they are interpretable, but they are manipulations of a systematic set of symbols. The semantic operations are based on the actors’ interpretations. The actors link together the components of the representation in order to perform actions in the construction domain. These links, which can be either connect the representations to the domain or to other components of other forms of representations, are semantics. The agents’ interpretations of and links with objects in the domain, actions, or relations to other representations are semantic operations.

Consider a taxonomical form of representing construction concepts, which can be employed for certain activities, such as estimating or planning. The assumption is that the actors translate their knowledge that corresponds to certain construction concepts into representations. The representation is tantamount to “languages of actors’ thoughts”. In this example, these thoughts are formally represented as a formal form. The resulting concepts represented by this form of representation must bear some relationship to properties, objects, or situations in the external world by virtue of that domain’s nature, in this case, construction industry concepts. This formal representation contains relationships to other objects that are semantics of the intended concept. An initial exploration of the representation as a “language of actor’s thoughts” was explored by Mutis (2007), through the introduction of conceptual role semantics (Greenberg and Harman 2006; Rapaport 2002) in construction concepts. This research further explores the idea of representation as “language of actor’s thought” from the perspective of the philosophy of language.

## **2.2 INTERPRETING REPRESENTATIONS**

The interpretation action in the simplest case takes place within two circumstances, as was explained: the interpretation that the actor performs to originate the representation, and the interpretation that the actor performs when he or she receives such representation. This research inquires after the relationship between the actor and any form of representation to investigate the grounds of misinterpreting representations.

In the interpretation step within the context of a construction project, additional aspects can be taken into consideration for a full commitment to the actions that follow the interpretation.

Consider Figure 1 for an illustration of this step. When a need emerges for information from other project participants during a construction activity, there is a directive act for requesting the information from these sources. As shown in Figure 1, the actors request information through previously defined and identified channels of information flow. The channel defines the method for requesting and providing information, which can be specified contractually or in agreements between contractors and subcontractors. The form of representation of the requested information can also be defined beforehand between the interpreter and the source.

Alternatively, the interpreter relies on the forms, syntax, and vocabulary of the sources for representing concepts as a viable, readable form for performing the interpretation. Once the actor or interpreter has received the information from the sources, an identification activity of the concepts that has been represented is performed. The identification consists of an analysis of the observed representation in order to perform reasoning for identifying meanings. The analysis is defined by the interpreter's intentional nature that motivates the requisition of information. In other words, the interpreter focuses on the representation sections that motivated the request for information and that are useful for his or her activity. The interpreter can also further articulate the sections or parts of the representation to complete the interpretation. The reasoning for identifying meanings consists of finding semantic associations from the observed representation with the interpreter's body of knowledge.

As shown Figure 1, if the semantic associations cannot be found by the interpreter for performing an interpretation, the sufficiency of "details" that describe the representation of the concepts is not satisfactory for the observer. The interpreter or observer searches for additional sources of information in order to find associations for identifying the concepts in the representation. The additional information can be provided by the interpreters' databases, knowledge bases, or even by experts. If the supplied information for finding semantics associations does not satisfy the interpreter for identifying the concept in the representations, the interpreter has to request additional information from the sources in order to have a better level of sufficiency for performing the interpretation. This flow of information is shown Figure 1.

When the semantics' associations satisfy the required conditions for the interpretation, the interpreter commits an action as a result of the interpretation. The conditions are satisfied when the intentionality with the observed representations is accomplished or, in other words, when an action can be committed by satisfying the purpose of interpreting the representation. This action is generally recorded in the actors' systems, or it is a part of a more complex, subsequent reasoning process for the interpreter, which can be manipulated and calculated.

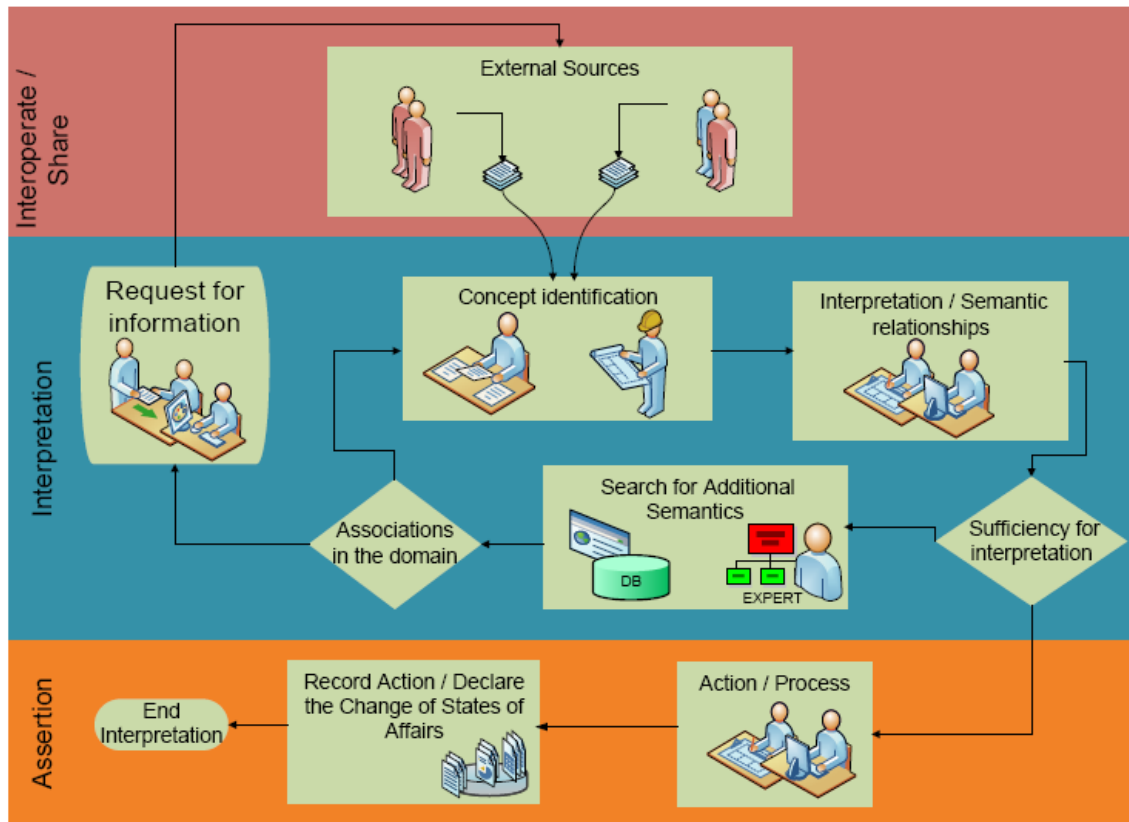


Figure 1. Interpretation process

As displayed in the work flow example in Figure 1, the representation is deficient for interpretation. The actor performs additional actions which increase the complexity of the activity and decreases the efficiency of the actor's activity. This research makes an inquiry within other realms that have advanced on formal investigations concerning the problem of misunderstanding semantics of representations. Speech Act Theory has played a central and exploratory role to inquiry of methodologies to accurately interpret representations in interoperability.

### 3. INTEROPERABILITY ACT

As this research exposes the need of the relationships between (1) the actors that originate the representation and the representation, and (2) the actor that interpreters the representation and the representation, a method for further investigation of these relationships is required. This research borrows a theory from the philosophy of language to examine these relationships and to illustrate the elements involved within interpretations of an interoperability activity. Philosophy of language provides descriptions of certain general features of natural language, which are concerned with semantics and ontological characterization, among others. Natural language is composed of a set of syntactic symbols that are forms of representations. The resulting linguistic characterizations provide the method for investigating the communication and interpretation as well as the essential concepts of the elements involved.

The need for further investigation on the relationships between actions and forms of communication was pioneered by Winograd and Florez (1986) in the computer science community. It is a research shift from the computation of forms of representation to the cognitive understanding of representations in order to

communicate (Winograd 2006), which can be extended in interoperability in specific domains such as the AEC (Mutis and Issa 2007). The characterization represents an analysis of the problems of communication within syntactic forms of representation. This research, then, extends this analysis to the existing communication problem within interoperability. As was explained in the former section, communication problems such as misinterpretations of the forms of representation within interoperability need to be formally addressed. Communicating information embraces actions of exchanging, sharing, and interpreting information. The action of exchanging and of sharing involves additional rules that govern the communication activity. Communication is then a more general term that is used in this research for more specific actions such as the exchanging, sharing, and integration of information.

One of the results from the inclusion of the Speech Act Theory (Searle 1969) in this research is the claim that the interpreting action is an existing condition to fully perform an interoperability activity. In order to have a more comprehensive definition, this research proposes the concept of the interoperability act that defines the complete set of actions that produces the communication among construction project actors independently of the type of representation of the form. The understanding of the interoperability act provides an illustration of the elements that need to be included within the sequence of the actions involved within interoperability. Under the premise that human intervention is included and that it is characterized by the interpretation of information, the production of an effective communication from the source to the interpreter constitutes the set of actions of the interoperability act. To facilitate the explanation, simple syntactic forms of representation are employed. However, the actions involved within the exchanging of information within a workflow are not presented in this analysis. The purpose of this paper is to illustrate the interoperability-act concept in a simplified fashion.

### **3.1 SPEECH ACT**

The Speech Act Theory provides a characterization of linguistic expressions. The speech act defines rule-governed forms of behavior when actors play a role in communicating information through language, specifically through the act of speaking. There are a set of sufficient and necessary conditions for the performance of particular speech acts where certain kinds of behavior, such as intentional behavior, can be characterized (Searle 1985). This analysis is a parallel to the governing rules, such as semantic rules, and the communication activities that takes place within interoperability.

The speech act characterizes what the speaker communicates to the hearer by relying on the mutually shared background of the information or contexts and the intention of the utterance (Searle 1969). In the simplest case, two actors, a speaker and a hearer, participate in a speech act. Thus, when there is an utterance within a communicative act, an understanding of the facts and relevance of the conversation, a setting up of the background information pertinent to the conversation, and assumptions and inferences are needed to capture the intended meaning within the expressed utterance.

In the case of the interpretation step as part of an interoperability activity, what is shared among the actors is not an utterance but a representation of concepts. Some actors are the ones that generate the information and others are the interpreters. In the speech act, there is the hearer and the speaker. It is easy to observe that actors are participants in a construction project, and the project is the environment where the motivated interactions of the actors take place. The actors who share the representations with other peers within the project have a predefined role. The concepts are translated into different forms of representation in order to semantically communicate them and suggest some actions for the interpreter. These actions are the result of the inferences and assumptions made by the interpreter.

The interpreters identify the intention on the representation generated by the sources and assert their meanings. The result of these assertions is the interpreters' commitment to actions on a particular activity. If it was not possible for the assertion to be executed in order to capture the representations' meanings, additional requisitions of information from the sources will be required.

Within the speech act, the hearer asserts and commits him or herself to an action or rejects the utterance in play when its intention was not captured. The speech act defines five categories within the illocutionary act. An illocutionary act is the entire speech act realized by an utterance, which contains elements of reference,

predicate, and illocutionary force. The summarized categories, their explanation and illustration through the parallel with the interoperability act are as follows:

1. Assertive. The speaker tells the listener how the things are. When a representation is created by an actor, a set of conditions are included with it. The interpreter is able to fully identify those conditions from the shared or exchanged representation.
2. Directive. The speaker tries to get the listener to do something. The representation is created with the conditions to get a particular reaction from the interpreter or to force the interpreter to perform a specific action.
3. Commissive. The listener commits to do something after hearing the utterance. After interpreting the representation, the interpreter commits to perform some activity according to the course of action expressed in the representation. The representation has the ability to represent those courses of action.
4. Expressive. The speaker expresses attitudes to the listener. The interpreter captures the force from the representation. The force should indicate the manner of how the course of actions should be executed.
5. Declarative. The speaker brings changes in the world through the utterances. A representation contains expressions that demand changes through the reaction of the interpreter.

### **3.2 A UNIT OF ANALYSIS OF THE INTEROPERABILITY ACT**

A parallel between interoperability and the Speech Act Theory brings about the opportunity to introduce the conceptual propositions of systems of communication. This research proposes a basic unit of analysis for performing interoperability acts based on Searle's Speech Act Theory work and of Lakoff and Johnson's metaphorical concepts (Lakoff and Johnson 1999; Lakoff and Johnson 2003).

When a speaker attempts to deliver a message to the listener the issuance of the utterance is composed of a set of words. However, as the Speech Act Theory advocates, it is misleading to understand that the unit of communication is words, symbols, sentences, or tokens. The unit of communication is the production or issuance of the tokens under particular conditions that characterize the speech act, such as rules of behavior. In interoperability, the unit of analysis will implicate the inclusion of conditions to produce the interoperability actions. As the vehicles or medium for communication of the illocutionary acts are symbols, words, or sentences, in interoperability, the mediums are forms of representations such as drawings or visual representations. However, in interoperability, the act of communicating meanings or semantics is not composed solely of the medium. The act has to be complemented with the conditions and behavior of the interoperability act. The interpreter has to identify the conditions and behavior that the actor who originates the representation requires.

The simplest case of the interoperability act is illustrated in Figure 2. The actor who generates a representation employs the representation as a medium to express or communicate semantics of a particular concept. An explanation of a situation within the set of construction specifications is a representation that is expressed by syntactic forms. The drawing of a metal door of a building is a visual representation expressed by a metaphor. The actor generates the representation with the intention that the interpreter understands the intended semantics. If the interpreter fully understands the semantic expressed within the representation, the interoperability act is fully performed. The interoperability act is reached when the interpreter understands the specific semantics of the representation. This is the minimum unit of analysis. The conditions and behavior expressed in the representation are similar to the ones expressed in the speech act. The minimum unit of analysis for the interoperability act embraces a particular communication of the meaning with similar conditions and behaviors of the speech act.

Figure 2 illustrates the case of when the actor who originates the representation attempts to construct the representation with the original, intended meaning. However when the representation is interpreted, the semantic can be captured by the interpreter. The representation expresses the semantics for the actor who generates the representation. If the interpreter cannot deduce the semantics from the representation, the interoperability act is not reached.

It is important to note that it is not a requirement for the actors to share the same space or synchronically and deliberately be arranged spatially for performing the interpretation within the interoperability activity, as they

are both involved in the speech acts. Also, the direction of the movement of the illocutionary point is the same direction of the exchanged information destination.

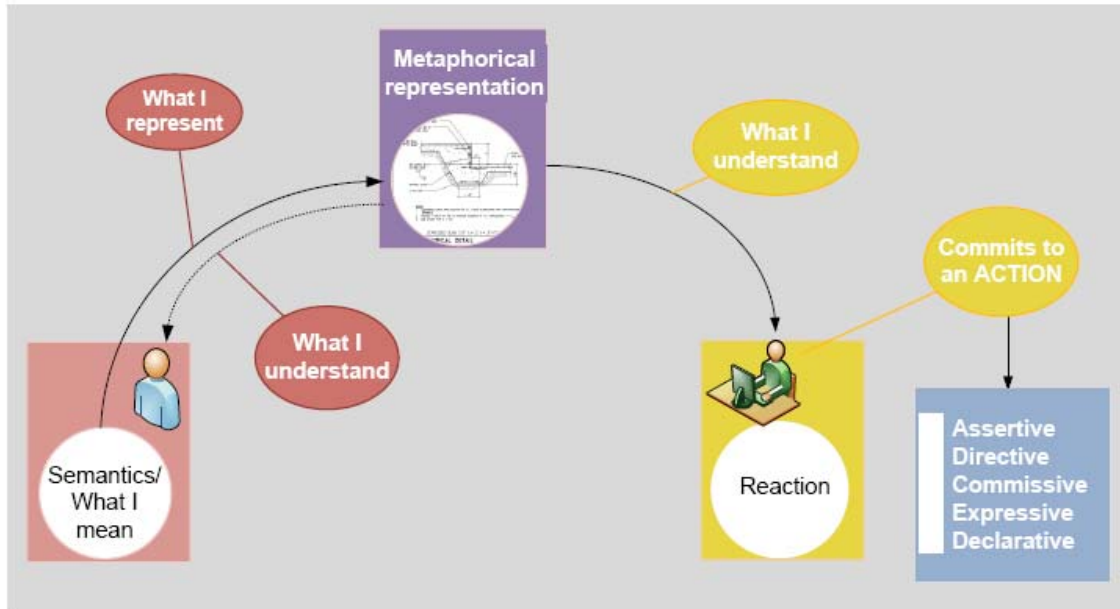


Figure 2. Interoperability Act

#### 4. CONCLUSIONS

Since human intervention is required for interoperability, strategies to interpret the information that is exchanged, shared, and further integrated are required. Therefore, interoperability process demands human intervention and interpretations of an observed representation. The interpretation of a door represented by a series of lines in a CAD solution is an interoperability activity performed by an actor, or interpreter, who plays the role of a cognitive agent. The construction industry and institutional agencies have adopted strategies based on a consensus to approach problems due to a lack of interoperability. This research proposes that efforts should be focused on finding methods for “understanding” the information generated from other construction participants. Strategies for “understanding” what is to be added, processed, or manipulated should primarily be addressed. The study of the “understanding” involves the interpretations of the meanings of the manipulated information.

The research focuses on inquiries concerning how a construction participant sees the real world and how he or she maps the views of the world into representations that reflect these views. For this purpose, this research takes into account aspects concerning the nature of knowledge representation per se, the method for characterizing domain concepts into representations, and the act for interpreting concepts expressed in the generated representations by other actors.

The understanding of the interoperability act provides an illustration of the elements that need to be included within the sequence of the actions involved within interoperability. Under the premise that human intervention is included and that it is characterized by the interpretation of information, the production of an effective communication from the source to the interpreter constitutes the set of actions of the interoperability act. The analysis of the interoperability act is based on the Speech Act theory borrowed from the philosophy of language. This science has considerably advanced the understanding of effective communication and interpretation of representations. A close analysis will help the construction domain to reach answers on the

interoperability paradigm. Under the research shift, our current research efforts addressed developing information processing strategies between two cognitive agents through the construction concept representations. The purpose is to study methods of communication through traditional forms of representation in construction by inquiring on their effects within interoperability.

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