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W078 - INFORMATION TECHNOLOGY IN CONSTRUCTION

PAPERS AND POSTGRADUATE PAPERS FROM THE SPECIAL TRACK

The objectives of the Working Commission are to foster, encourage and promote research and development in the application of integrated IT throughout the life-cycle of the design, construction and occupancy of buildings and related facilities, to pro-actively encourage the use of IT in Construction through the demonstration of capabilities developed in collaborative research projects and to organise international cooperation in such activities and to promote the communication of these activities and their results. The aim of W078's work is broad in terms of the design, construction and occupation and occupancy of constructed facilities, but primarily it relates to the integration and communication of data, information and knowledge in the facility's life cycle.

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A Building Information Modelling Based Production Control System for Construction

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Abstract

We propose visual interfaces for BIM-based construction management systems to empower construction personnel on site by providing them with construction process and status information. Computer-aided visualization, not only of the construction product, but also of the construction process, can provide a unique service to support decision-making by workers, supervisors and managers, with the goal of achieving stable flows. The three main user interfaces – for a) detailing of work packages into finer-grained task definitions by the trade managers and preparation of proposed weekly work plans, for b) collaborative planning and integration between the plans of the different trade crews, and for c) day to day communication of product and process information to and from work crews – have been designed and implemented as functional mock-ups. They have been evaluated in three focus group workshops with project engineers, construction site supervisors, trade crew leaders and logistics managers. The findings at this early stage are that the interfaces provide rich information for production control, including monitoring of current process status, and fulfil the guiding principles defined for BIM-enabled production control. However, significant R&D is still needed for back-end integration of the various information system components of the system architecture before the system can be implemented and tested on site.

Keywords: building information modelling, lean construction, production management, visualization

1. Introduction

With few notable exceptions, the majority of academic and industrial research on computer-aided design and visualization in construction has dealt with building design and with pre-construction planning. There has been far less effort to develop Building Information Modelling (BIM) based tools to support coherent production management on site. The neglect of production management on the part of researchers of IT in construction reflects the decline in attention paid to production management on the part of general contractors and construction managers (Ballard 2000). For various reasons, construction companies have adopted a business practice of reducing core staff to a minimum and implementing work through subcontracting (Sacks and Harel 2006). At the same time, lean construction thinking applied to construction production systems has increased awareness of the benefits of stable work, of pull flow of teams and materials to reduce inventories of work in progress, and of process transparency to all involved. 3D visualizations of process status and future direction, delivered to all on site, are either essential or at least highly beneficial for all of these (Formoso, Santos et al. 2002). They can empower people working on site to manage the day to day flow of construction operations with less direct control from higher levels of management, with better quality and less waste (Sacks, Treckmann et al. 2009).

Production control in construction on site can be facilitated through use of the Last Planner System™ (LPS) (Ballard 2000). In prefabrication projects, methods such as the Process Planning Methodology (PPM) have proved effective (Radosavljevic and Horner 2007). Application of the LPS enables trade managers and construction engineers to collaboratively prepare weekly construction plans that are feasible and have a reasonably high chance of being executed as planned. The system works by empowering those who carry direct responsibility for executing work to participate in planning the work. It is based on the principles of flow defined in lean production texts and the Transformation-Flow-Value TFV theory (Koskela 2000) of production in construction.

However, the LPS does not overcome all of the difficulties nor does it remove all of the waste inherent in construction. In practice, percent plan complete (PPC) measures do not reach 100% (research has shown that the best sites achieve approximately 80% PPC (Bortolazza, Costa et al. 2005)). By definition, lean systems are always subject to continuous improvement (Womack and Jones 2003), and the LPS is no exception. One of the reasons for this is that construction systems are uncertain and subject to process change within the time frame of the weekly planning window, so that filtering tasks for maturity on a weekly level cannot ensure complete process stability. Another is that the delivery of product and process information to workers can at times be ineffective or inefficient: product information is provided in the form of drawings and specifications, which contain inaccuracies or errors. Process information is scant, inaccurate and incomplete: trade crews are generally uninformed about delays in material deliveries, unavailability of equipment previously committed to them, or changes in the work plans of crews working in their vicinity. Where they are informed, it is often too late for them to adapt their own plans. Seppanen (Seppanen 2009) provided empirical evidence of the systematic failure of traditional production control to manage short-term decision-making concerning trade crews' progress through a building, resulting in unstable plans and low productivity.

Sacks et al. (Sacks, Radosavljevic et al. 2010) proposed to address these shortcomings by increasing the degree of resolution for planning and responsive re-planning to a daily level, with the support of a production planning, control and feedback information system based on building information models. The system proposed is called 'KanBIM', denoting the implementation of a lean production system with pull flow control (symbolized by the Kanban method) (Ohno 1988) using a building information modelling (BIM) (Eastman, Teicholz et al. 2008) based information system.

2. Background

A BIM-based lean production management system for construction must enable:

1. visualization of the construction process and its status;
2. visualization of the construction product and work methods;
3. support for planning, negotiation, commitment and status feedback;
4. implementation of pull flow control;
5. maintenance of work flow and plan stability;
6. formalization of production experiments for continuous process improvement.

These principles emphasize the role of a KanBIM system in supporting human decision making, negotiation among trade crews to coordinate weekly work plans, reduction of the granularity of planning to a daily level, real-time evaluation of task constraints to compute task maturity, and implementation of the language/action perspective.

Some BIM solutions have expanded their capabilities by adding 4D functionality. Among these are 'Tekla Structures' (Tekla 2008) and 'Virtual Construction' (VICO 2007). Since Tekla's core functionality is detailing steel and precast concrete structures, its construction management tool emphasizes fabrication and delivery control based on planned erection dates. As with most 4D BIM tools, users can link tasks to model objects and use critical path methods to schedule them. To support fabrication and delivery control Tekla allows users to schedule each piece, within the task, individually. 'Virtual Construction' integrates a BIM model with Location Based Scheduling (LBS), which uses an underlying CPM network solver. It is based on a bill of quantities and a set of working rates and costs for resources that are linked to tasks, and enables representation of the schedule as a line of balance chart as well as in Gantt chart form. These tools, and others like them, include 4D model visualization but do not support the collaborative production level planning that is essential for trade managers and crew leaders on site.

Specialized 4D construction planning software, such as 'Synchro Professional' (Synchro 2007), provide project scheduling, construction visualization, synchronization with design changes, supply chain management and virtual construction simulation. They do not have internal scheduling capabilities or an integrated BIM solution but instead allow users to import both schedule and 3D model from various other applications.

A small number of applications have been developed to support Last Planner System™ implementations, but they do not use building models to support visualization. CICLOPS (Evolution-IP 2009) is an internet application that allows its users to collaboratively prepare and control weekly work plans. CICLOPS calculates the percent plan complete (PPC) for each weekly plan and can perform 'Non-Completion Analysis' based on the user's recording of the reasons for tasks being delayed. 'WorkPlan' is a planning tool, developed in research (1999), that applies a database of work packages and constraints to support work planning. SPS (Koerckel and Ballard 2005) is a commercial package that helps reduce supply chain variations.

The LEWIS system (Sriprasert and Dawood 2003) represents the most advanced attempt to date to compile a construction production management system that fulfils the KanBIM principles. However, it falls short in making the process status visible to work teams on site, it does not explicitly facilitate negotiation and collaboration in work planning, and it does not implement pull flow control of work.

Thus most 4D solutions incorporate scheduling tools and a connection to a BIM model, but their core use is for planning and visualizing the process. With the exception of LEWIS, they are not intended for 'real time' production control. They lack the ability to detail work plans with sufficiently fine-grained resolution, and they have no tools for delivery of information to the work face or reporting from it, or for assisting real-time decision-making during the course of production itself.

3. Research goal and method

The KanBIM concept encompasses a holistic approach to embedding lean production control processes through delivery of both process and product information to all project participants, specifically including workers at the work face on site, using a building information model as its backbone. Since no comparable systems exist, and no existing software could be adapted for the purposes of evaluation of the proposed KanBIM system, the research method involved three steps that were performed in three iterations, with the system being refined and re-evaluated in each cycle:

- a) Process analysis and system design;
- b) Programming of functional mock-ups of its interfaces;
- c) Evaluation of the system in focus group workshop evaluation sessions.

System design began with preparation of a detailed 'future state' process flow map of the work flow envisaged for production planning and day to day production control on construction sites. The information system required to support the process was then derived, and defined in a system architecture plan. This step also required selection of the delivery methods (hardware) for each interface.

Functional mock-ups were prepared for the three main user interfaces. The mock-ups sought to provide sufficiently complete functionality to thoroughly demonstrate the system's intended modes of operation. These user-interfaces cover the stages of a) preparation by trades for weekly work

planning meetings, b) negotiation between trade crews prior to and during weekly work planning meetings with the construction management team, and c) day to day interaction with trade crew leaders on the job site. Programming of the functional mock-ups served not only the evaluation step, but was in and of itself a formative activity in testing the assumptions made in defining the work flow and the system architecture, applying to them a rigor that could not have been achieved otherwise.

The user interfaces were evaluated in three focus group workshops which each involved construction managers, trade crew managers, and crew leaders, held in the UK and in Finland. The remainder of this paper describes the first two aspects.

4. The KanBIM planning and control process

The process chart shown in **Error! Reference source not found.** describes the actors in construction site production management, the information they each generate, a set of ‘activity scenarios’ in which information is generated, and the way the information is distributed and recorded in the different information repositories. The process starts with the creation of a Master Plan. In this stage the users compile and maintain a set of high-level activities and subordinate work packages, and schedule them, including trade assignments and buffering. High-level resource levelling must also be done for major equipment and spaces. This is done using existing construction planning tools.

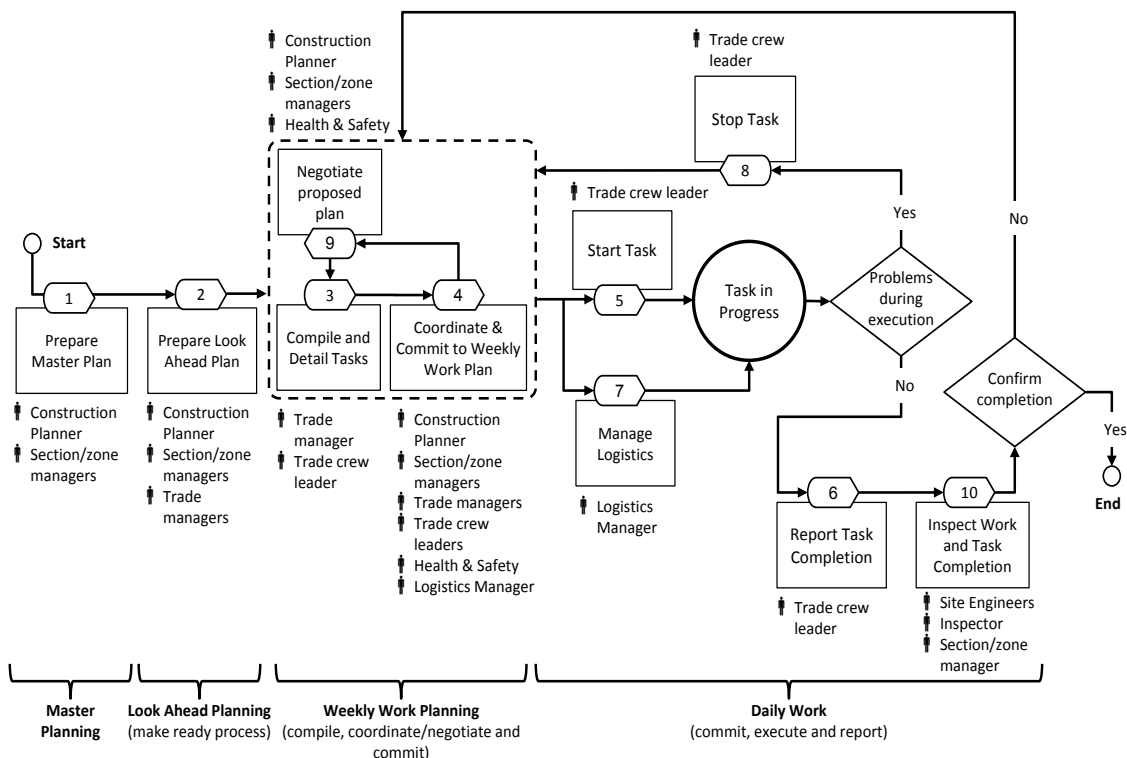


Figure 1: Process flow model for the KanBIM system, showing defined activities 1 to 10

The next stage is look ahead planning (see **Error! Reference source not found.**). It consists of breaking down the high-level activities into smaller, manageable work packages, defining logistic and engineering constraints in the form of connections between activities and assigning equipment and materials. The master plan and the look ahead plan are done by managers of the general contractor (or construction management company) and the principal work package subcontractor managers. Both of these stages are the same as standard LPS, with only one additional requirement, which is that they are prepared using a BIM interface in which building elements are associated with the activities. This capability, available in the existing commercial software described above, allows integration of the product model with the high-level process model. Since 4D functionality is increasingly common in BIM tools, we assume that an integrated product and process model can be prepared and consider it as the starting point for the next stages.

The next step of the LPS process, weekly work planning, is divided here into two stages. First, in activity 3 in **Error! Reference source not found.**, each trade crew details its work packages into a set of candidate tasks that it can perform during the following week, in preparation for the weekly work planning meeting (stage 4 in **Error! Reference source not found.**). This activity starts with a set of candidate work packages that were drawn from the look-ahead plan according to their planned start date and priority. Each work package contains a set of 'task types' representing the different kinds of work needed to perform it according to the production method. For example, in order to erect a drywall, the following tasks are needed: build the wall frame; close the first side with plaster boards; place insulation materials and fix any mechanical, electrical or plumbing (MEP) embeds; close the second side with boards; and apply joint strips, sand and paint. BIM objects can require one or more task types and the associations are recorded with the object's properties.

The work packages are shown using symbols and highlighted object groups in the model. The trade contractor's manager and his or her crew leaders divide the work packages into candidate tasks by selecting a subset of building elements from the work package elements and grouping them into distinct tasks according to their task types. For easier selection and better control of the overall process of dividing the work packages into tasks, all building elements that have not yet been allocated to tasks are labelled 'unassigned' and highlighted appropriately. The user interface to support this activity is shown in Figure 2, which shows a hierarchical work package/task type/task tree, a view of the building model focused on the work package zone and elements with symbols representing its tasks, and a weekly schedule planning area at the bottom of the screen. Tasks are scheduled and assigned to crews by dragging their symbols to the rows of specific crews on specific days. In addition to tasks created and assigned by the trade manager, there are also two kinds of special tasks: tasks that the trade manager assigns to other supporting trades and tasks that are assigned to this trade subcontractor by other trades. These tasks need to be assigned to crews in order to become part of the weekly work plan, in a negotiated process that is explained below.

Since each trade contractor creates its own proposed weekly work plan, the plans need to be synchronized and finalized to form a mutually agreed project-wide work plan. This is done in a weekly work planning meeting (activity 4 in **Error! Reference source not found.**) that is directed by the project planner and in which all trade managers participate. During the meeting the project planner reviews the candidate work packages and tasks for promotion to approved tasks for the

coming week. The interface for this activity is presented on two large screens: a data view (shown in Figure 3) and a corresponding model view. The two screens are merely different representations of the same content (one alphanumerical and the other graphical) and any operation on one, is automatically reflected in the other. For example, when a task is selected in the data view the model view will focus on and highlight its building elements and show temporary equipment; or when the tasks are filtered in one view (by date, space, contractor etc.) the other will show the same results. The interface allows the users to switch between four different aggregation data views (tasks sorted by contractors, work packages, spaces and shared equipment) to eliminate any clashes and to improve plan reliability.

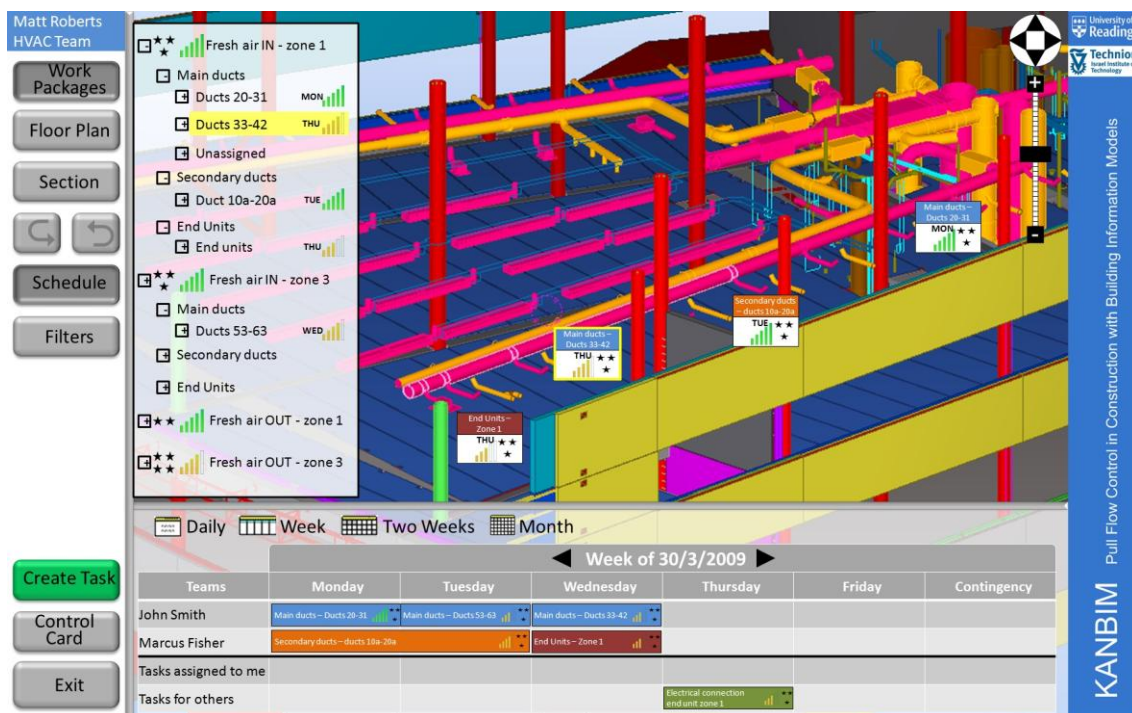


Figure 2: User interface for detailing work packages to tasks and compiling the weekly work plan by allocating crews to tasks

Any conflicts identified must be resolved through discussion and coordination between the relevant trade managers. To resolve conflicts they can change their proposed plans using the same interface used for initial planning (Figure 2). Changes could include rescheduling tasks, assigning more crews or workers, changing resources by changing construction methods, and others. The changes are made while all the participants are online so that the project planner views and all 3D model views will reflect the changed overall weekly work plan.

After applying changes to the plan to make it feasible and acceptable for all the 'last planners', each of them must explicitly accept their part of the plan and commit to executing their tasks. Plan acceptance is shown on the project planner interface and only when a group consensus is achieved is the weekly plan approved as a whole.

The next level of planning takes place on a daily basis, concurrently with execution of the work through each week. This is the heart of the KanBIM process, where the crew leaders are given direct access to the work plan and empowered to coordinate their work with all other crews as and when needed (activities 5, 6 and 8 in Figure 1). The specialized model interface (shown in Figure 4 **Error! Reference source not found.**), which shows each crew leader's specific tasks, is delivered via a large scale touch screen (see Figure 5). This interface not only delivers process and product information on demand, it also collects process information in real-time. Crew leaders use it to report the start of tasks as they are begun, to update ongoing tasks according to actual performance, to report that they have stopped work on a task and report the problem that caused the stoppage, and to report completion of finished tasks.

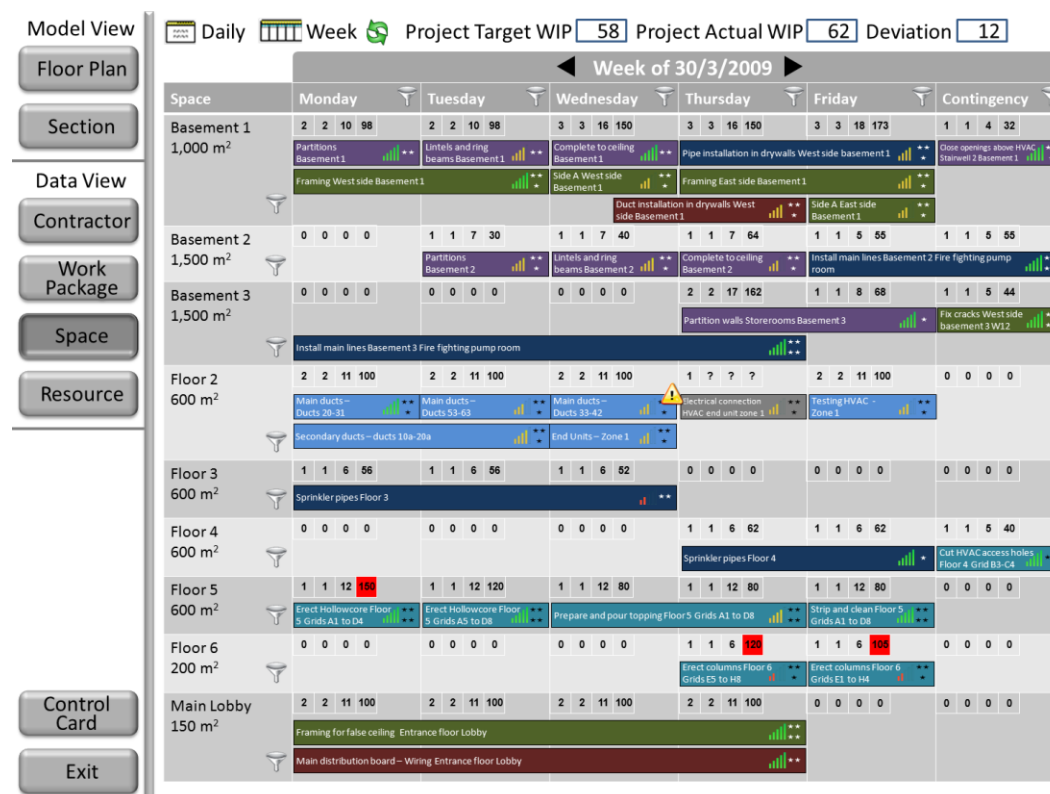


Figure 3: Project planner contractor view interface for creating integrated and synchronized weekly work plans

Problems that adversely affect execution, such as unavailable equipment, can be reported together with details that enable responders to resolve them, such as details of which specific piece of equipment is malfunctioning or missing, as shown in Figure 6. In this way crew leaders can also report design issues directly on the model by using graphic annotation tools and voice messages. The production management server can alert those responsible for solving the issue according to a predefined work flow and create action items for fixing it. In the event that a crew leader needs to change the execution sequence of his/her tasks, they can use this screen to initiate dialog to negotiate the changes with the project planner and any other relevant crew leaders, in order to maintain overall plan stability. Any changes are immediately reflected in all model views, so that all project participants are aware of actual current status.

For learning purposes and to improve project performance, when a task is reported complete crew leaders are asked to report any difficulties even if the task was completed as planned. By pressing the complete button, the crew leader is also pulling an inspector to approve the completion of the task (activity 10 in Figure 1). If the task completion is rejected, the rework needs to be re-scheduled by the project planner and the trade manager.



Figure 4: Trade crew leader work status and reporting interface showing a crew's tasks. The crew leader can ask the system to show neighbouring tasks for a complete picture of the overall work



Figure 5: Work face specialized model interface on a 40" touch-screen mounted on a mobile trolley. The system identifies crew leaders (by RFID reader or by entry of a unique ID code) and delivers specifically tailored information concerning their tasks.

You chose to stop task:
Framing – Internal 4" partition at apartment 16-17
 Please provide the reason for stopping this task

Previous work	Missing materials	Unavailable Equipment
Workspace	Faulty materials	Equipment Fault
Missing information	Safety issues	Wrong Equipment
Design Errors	Team	Weather
Management Instruction		
Stop	Select objects completed	Cancel

A-L-43-R5
 ID-L-73-1-R2
 DW-D-6-R1
 E-W-23

Figure 6: Reporting form for problems during execution which led to stopping a task. The reporting tool enables information flow from the work face to the information servers to update the work status and to raise flags when problems are encountered.

The information for each task is organized in a 'control card' according to seven pre-conditions and constraints: preceding activities, workspace, information (designs and specifications), safety,

materials, equipment and crew. For each pre-condition an independent maturity index (MI) is calculated based on the constraints release status, so that a user can 'see' the maturity status of any given task. Full details are provided in (Sacks, Radosavljevic et al. 2010).

5. System architecture

Figure 7 provides a high-level view of the system architecture. The main database contains the construction model, which is a combination of the product model, the process model and the status model. At the start of any project, they are generated from the design and fabrication models by applying construction methods (recipes), work package aggregation and compiling temporary equipment process related objects. Subsequently, the construction BIM modeller is responsible for synchronization of the database with the design and fabrication models. Interaction between the KanBIM users and the construction model is facilitated by user interfaces such as look ahead planning (based on 4D capabilities), weekly plan preparation (Figure 2), weekly work planning and negotiation (Figure 3), crew leaders' interface for delivering information and reporting status (**Error! Reference source not found.**) and an alert system to support organizational work flow. All of these are based on lean construction processes.

Two separate modules work in the background. The first module generates tasks constraints as soon as tasks are created. As most constraints are predefined at a higher level for work packages, this module details the constraints at the task level. The second module computes the maturity index (MI) and a pull flow index (PFI) for each task. The PFI defines the priority to be assigned to a candidate task according to the need for that task as determined by the maturities of its successor tasks, which reflect the downstream demand, or pull.

The sources of the information the system uses extend beyond the boundaries of the construction product and process mode. Information may reside in different peripheral construction management systems, such as logistics, purchasing, human resources and personnel control, design management systems, fabrication management systems and external databases. Sophisticated information or objects brokers are needed to integrate this information.

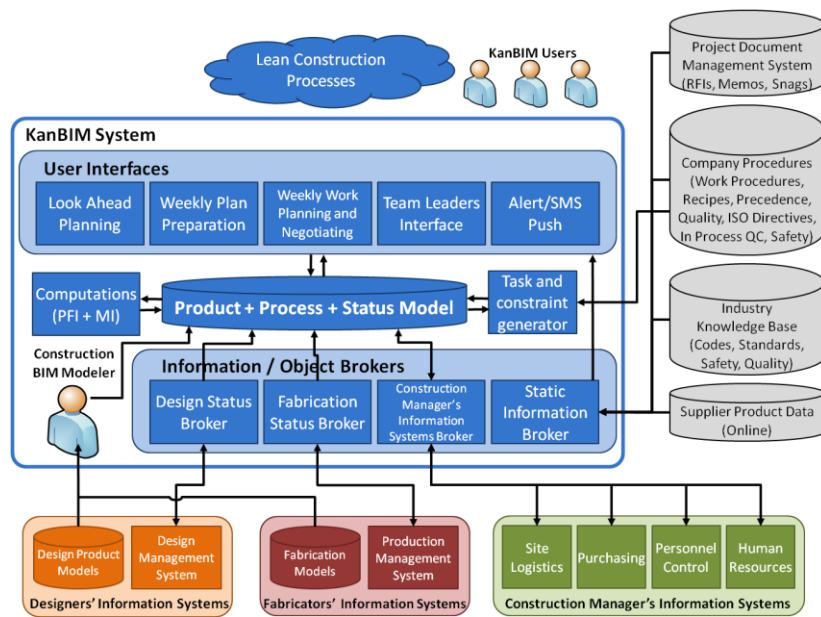


Figure 7: System architecture schema

6. Conclusions

The principles for development of a KanBIM system have been classified in seven main areas (Sacks, Radosavljevic et al. 2010): process visualization; product and method visualization; computation and display of work package and task maturity; support for planning, negotiation, commitment and status feedback; implement pull flow control; maintain work flow and plan stability and formalize experimentation for continuous improvement. Some of the ways in which the KanBIM system, as specified to date, fulfils these principles, are discussed below.

During plan execution, current status visualization is attained using the set of graphical symbols shown in **Figure 4**. The symbols describe the current task status: ready, not ready, task in progress, task stopped, etc. Symbols that represent deviation from plan are supplemented with additional information, such as maturity level or partial completion indicator.

The BIM is the foundation of the KanBIM system database. A 3D model view serves as a background platform in all interfaces for conveying project data and navigating through it. The challenge is to make product and process information ubiquitous at the workplace without encumbering crew leaders or workers with hardware that may hamper their comfort, safety or productivity. This can be achieved using personal digital assistants, mobile phones or other portable wireless devices, but these all have limitations, particularly with regard to screen size. The primary solution suggested for implementing KanBIM interfaces is to use large format all-weather touch-screen monitors which do not impose physical restrictions on workers, enable discussion among crews who can all view the same model or animation together, and provide the essential function of easy-to-operate online feedback. This format also enables easy navigation and data access.

The KanBIM system deals with plan stability on two levels: the planning process and the execution. In planning, it uses the maturity index as the main parameter for deciding which work package or task will be done during the week. In task detailing (stage 3 in Figure 1), a task can initially be assigned to a weekly plan even if its maturity is not yet 100%, but this implies a commitment on the part of the trade manager to release all constraints by the planned execution date. During execution, the KanBIM system works to maintain plan stability by applying the principle of 'sticking to plan' while at the same time enabling rapid negotiation and thorough coordination of any necessary changes to the plan. The pitfalls of potential negative impacts on other trades and the danger of 'making-do' and subsequent rework mean that plan changes must be negotiated and recorded. The system enables negotiation by facilitating ad-hoc toolbox meetings within a crew with real-time information, or conversations between all those who might be influenced from rescheduling the task so that the new plan will not compromise their work.

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RCM-Plan: A Computer Prototype for Improving Planning Reliability from a Lean Production Viewpoint

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Abstract

The creation of reliable work plans level is perhaps one of the most relevant stages in construction planning process. However, current practice and research in construction are characterized by developing this process in an informal fashion in which decisions are based mainly on intuition and experience of project personnel. This paper introduces RCM-Plan, a computer prototype designed to support operational planning using the so-called Reliable Commitment Model (RCM). RCM is a statistical modelling approach based on lean production principles, which produces reliable predictions of work plans, capacity and other production variables for short term-periods using common field information such as workers, buffers, and planned progress. Thus, RCM promotes a more reliable operational planning process and improved performance of work plans. The core functions of RCM-Plan are designed to systematize and automate the procedures associated with the RCM methodology, generating the analysis and information in a quick, easy way and it is instrumental to facilitate the application of the RCM concepts. The capabilities of RCM-Plan are demonstrated using a case study. In addition, limitations and further research related to the RCM-Plan are addressed.

Keywords: computer prototype, lean production, operational planning reliability, RCM-plan, reliable commitment model

1. Introduction

The creation of reliable work plans has received increased attention as a critical issue in construction projects performance during the last decades (Ballard, 2000; Tommelein et al, 1999; among others). The recognition that these plans at the operational level characterize the materialization of a project, namely its production through construction processes, highlights their decisive role for accomplishment of project goals. In practice, a reliable work plan is characterized by a high fulfillment of planned work. However, the decision frame to make and predict work plans has several limitations in traditional management practices (González et al, 2009). Commonly, construction projects outsource most of the work to subcontractors, and work plans are arranged between contractors and subcontractors. Contractors should strive to obtain reliable work plans from the subcontractors. Thus, many of them assign work to subcontractors based on their intuition and experience, resulting in unreliable work plans (Sacks and Harel, 2006). Then, the more unreliable work plans the lower is project performance (Ballard, 2000).

Lean production is a management philosophy focused on adding value from raw materials to finished product. It allows avoiding, eliminating and/or decreasing waste such as waiting/idles times, rework, overproduction, excessive movement, among others, from the value stream. One of the main goals of lean production is reducing variability (Womack and Jones 1996). In construction, variability depicts varying production rates, labor productivity, schedule control, cost control, etc., which is a well-known problem due to its detrimental impacts in project performance on which there is much ongoing research (Ballard, 1993; Tommelein et al, 1999; among others). The Last Planner System (LPSTTM) is a production planning and control system based on lean production principles that was developed to improve planning reliability in construction projects (Ballard, 2000). LPSTM provides the means and tools to deal with variability in projects providing a stable production environment and reducing the negative impacts of variability. This helps create reliable work plans for short-term periods (operational level). However, last planners still create and predict work plans to make their planning commitments using mainly their intuition and experience, resulting sometimes in unreliable commitments (González et al, 2009).

Thus, this paper proposes a computer prototype termed as RCM-Plan to help planners to make more reliable performance predictions based on data obtained on site. RCM-Plan is based on the Reliable Commitment Model (RCM) (Gonzalez et al 2010), a lean tool which enhances the creation process of work plans in repetitive projects. RCM uses statistical models to predict performance and produce more reliable work plans, using information about workers, buffers, actual and planned progress avoiding current decision patterns. The core functions of RCM-Plan are designed to systematize and automate the RCM procedures, generating analyses and information in a quick and easy way. In this paper, planning reliability improvement using the LPSTTM, the RCM conceptual and analytical framework and the computer structure of the RCM-Plan are addressed. Then, a case study is used to show the use of the RCM-Plan to support the development of reliable work plans.

2. Improving planning reliability

The Last Planner System (LPS) is a production planning tool based on lean principles widely used today in construction. LPSTM acts over four project planning levels: (i) ‘Initial planning or master plan’ (strategic level), which produces the initial project budget and schedule, and provides a co-ordinating map that ‘pushes’ completions and deliveries onto the project. (ii) ‘Phase Planning’ a subdivision of the master plan which is transformed in a “pull plan,” with participation of key members of the project team during that phase. (iii) ‘Look ahead planning’ (breakout of master plan – tactical level), which details and adjusts budgets and schedules ‘pulling’ resources into play. (iv) ‘Commitment planning or work plans’ (short-term period – operational level), which regards the activities and schedule work that will be done on-site according to the status of resources and prerequisites (Ballard, 2000).

The traditional management approach for work plans defines activities and schedule work that will be done, in terms of what should be done from a master plan, compromising crews with no real consideration for what they are actually able to do. Then, the crew ability to reliably perform work depends on the stability of the so-called workflow. In construction, workflow can be characterized by crews moving from location to location and completing the work that is prerequisite to starting work by the following crew. In turn, a stable workflow depends on what construction preconditions such as resource (design, components and materials, workers, equipment, space) and prerequisites (complete work of upstream activities) should be available whenever they are needed. However, variability of workflow could negatively affect crews’ performance, causing idle time or ineffective work (Tommelein et al, 1999).

In contrast, LPSTM provides a predictable production environment in projects, decreasing workflow variability and creating reliable work plans to derive maximum project benefits. The overarching criterion in the LPSTM is that activities should only be committed if they can be performed (i.e. all resources and prerequisites that are needed must be available), transforming what should be done into what can be done, from which a work plan can be formulated. Thus, work plans will be based on achievable assignments serving as a commitment to what will actually be done. In this paper, the notion of reliability is focused on project planning, so that Percentage of Plan Completed (PPC) depicts a project planning reliability index. PPC is understood as the ratio between actual completed activities and planned activities in a short term period (typically one workweek). A low PPC means unreliable planning and a high PPC close to 100%, means the opposite.

LPSTM has been applied in numerous projects around the world in the last fifteen years, and a wide range of performance improvements have been reported (Alarcon et al 2005, Liu and Ballard 2008, González et al, 2008a). The main system assumption is that an increase in planning reliability, measured through PPC, should improve project performance. Recently, several researchers have demonstrated a positive and strong relationship between planning reliability and project performance (González et al, 2008a). However, current planning practices at the operational level reduce the ability to achieve reliable commitments to improve project performance. The RCM model is designed to support the planners in making more reliable commitments in the short term planning

process and it can be used within the LPS process or as an individual method when the LPS is not in place.

3. Reliable Commitment Model (RCM) framework

RCM provides an operational decision-making tool for predicting work progress in projects using statistical models. These models use historical information of several production variables such as labor, Bf , and planned progress, to attain a more reliable planning process at the operational level. Since RCM is based on lean principles, it helps to reduce production variability by improving planning reliability and matching work load with labor capacity (more details in González, 2010). In practice, RCM uses multiple linear regression (MLR) to formulate the model, which assumes the following form: (González, 2010):

$$PRP = \beta_0 + \beta_1 W + \beta_2 WIPBf + \beta_3 PP \quad (1)$$

where:

PRP is the predicted progress for a process in a short-term period (typically one workweek). Units may be m^2 , m^3 , linear-meters, houses, apartments, etc.

W is the number of workers for a process in a short-term period. W is the sum of workers in the planning horizon. For instance, if the short-term period is one workweek of 5 days, and there are 5 worker-days, W is 25 worker-weeks.

WIP Bf is the available Work-In-Process Buffer for a process at the beginning of a short-term period. In general terms, a Buffer allows isolating a production process from the environment as well as the processes depending on it. Buffers can prevent the loss of throughput, wasted capacity, inflated cycle times, larger inventory levels, long lead times, and poor customer service by shielding a production system against variability (more details in Hopp and Spearman, 2000). For instance, for a one workweek the WIP Bf for the painting process, which depends on the wall-stucco process, is the available work produced by the wall-stucco process, measured at the beginning of the week, before painting begins. Units may be m^2 , m^3 , linear-meters, houses, apartments, etc.

PP is the planned progress for a process in a short-term period. Units may be m^2 , m^3 , linear-meters, houses, apartments, etc.

Only significant variables are selected in the RCM models, since including redundant variables may lead to incorrect analysis of scenarios. Thus, MLR models with the least number of variables and with the highest coefficient of determination (R^2) are selected. Bustamante (2007) demonstrated that good quality models are obtained using this heuristic. Furthermore, the prediction accuracy of RCM is evaluated using two indicators: Process Reliability Index (PRI) and Predicted/Planned Commitment Confident Level (CCL). PRI measures the degree of process effectiveness from a commitment standpoint, expressed as:

$$PRI = \frac{AP_{i,j}}{PP_{i,j}} \times 100 \quad (2)$$

where:

PRI_{ij} is the process reliability index for week *i* and process *j* (%), *i*=1...*n*; *j*=1...*m*.

AP_{ij} is the actual progress for week *i* and process *j*, *i*=1...*n*; *j*=1...*m*.

PP_{ij} is the planned progress for week *i* and process *j*, *i*=1...*n*; *j*=1...*m*.

PRI ranges between 0 and 100%. Note, when AP is higher than PP, PRI is limited to 100%. A low PRI means unreliable process planning and a PRI close to 100% means the opposite. Meanwhile Predicted/Planned CCL is a measure of the planning prediction reliability for a process made by both decision-makers (planned progress) and/or RCM models (predicted progress) and it is expressed as:

$$\text{Predicted / Planned CCL}_{i,j} = \left(1 - \left(\frac{\text{Predicted / Planned PRI}_{i,j} - \text{Actual PRI}_{i,j}}{\text{Actual PRI}_{i,j}} \right) \right) \times 100 \quad (3)$$

where:

Predicted/Planned CCL_{ij} is the commitment confidence level for week *i* and process *j* (%) for both predicted and planned PRI.

Predicted PRI_{ij} is the predicted process reliability index for week *i* and process *j*. Predicted PRI replaces AP by PRP in Eq. (2).

Planned PRI_{ij} is the planned process reliability index for week *i* and process *j*. Its value is estimated by a decision-maker given a planned progress according to his or her experience.

Actual PRI_{ij} is the actual or real process reliability index for week *i* and process *j*. Actual PRI is computed using Eq. (2).

Predicted CCL measures the process commitment accuracy for the predicted progress comparing the predicted and actual PRI. Similarly, Planned CCL compares the planned and actual PRI. When the ratio in Eq. (3) is less than 0, its value is set to 0.

RCM originally was implemented through nomographs, which relate mathematical and graphically planned progress with the other production variables (González et al, 2010). Then, since PRI is given by:

$$\text{PRI} = \left(\frac{\text{PRP}}{\text{PP}} \right) \Rightarrow \text{PRP} = \text{PRI} \times \text{PP} \quad (4)$$

And, if equation (1) is replaced in equation (4), PP can be expressed as:

$$\text{PP} = \left(\frac{\beta_0 + \beta_1 W + \beta_2 \text{WIPBf}}{\text{PRI} - \beta_3} \right) \quad (5)$$

Eq. (5) establishes a relationship between PP and W, WIPBf, and PRI. PP can be either planned by decision makers or estimated by the RCM. Similarly, PRI can be either planned or predicted. Fig. 1 illustrates a nomograph for a repetitive housing project, showing the interaction between the different variables involved. Nomographs are commonly used in engineering disciplines (e.g., hydrologic engineering) and can be easily applied by construction decision-makers, such as project managers, which can use it to plan activity progress for a given resource frame. RCM methodology to estimate

work plans is summarized in Fig. 2. The conceptual and mathematical RCM framework, as well as the implementation methodology, were comprehensively tested and validated in 9 projects (multifamily residential, multi-story building and industrial), 23 activities, and a total of 260 workweeks by González et al (2010).

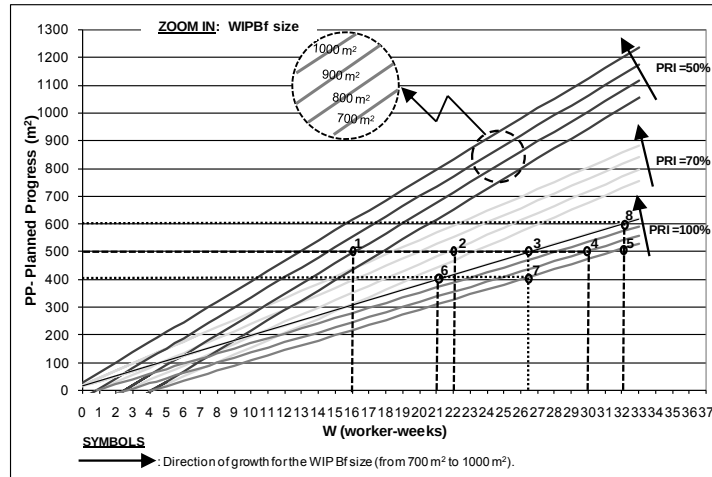


Figure 1: Illustration of a general RCM nomograph to calculate planned progress for next short-term period, given a pre-determined MLR model (with the assumption that it is a reliable model such that $R^2 \geq 0.6$ and $P\text{-value} \leq \alpha=0.05$) and different PRI values (adapted from González et al, 2009)

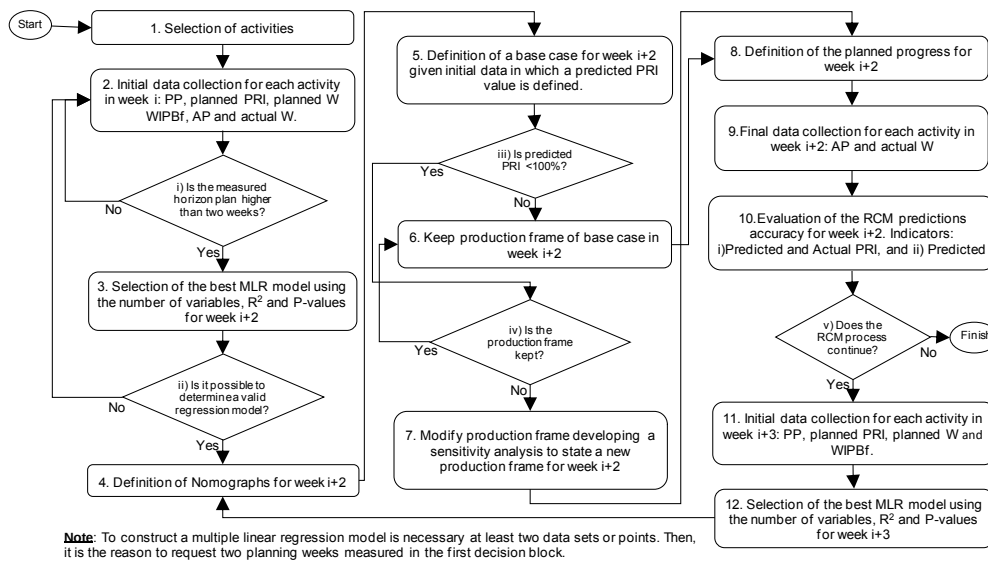


Figure 2: Methodology to implement the RCM (González et al, 2010)

4. A RCM computer prototype

The methodology described in Figure 2 has been implemented in a computer prototype called RCM-Plan that allows easy and quick application of the RCM framework to on site planning. RCM-Plan has allowed to remove barriers to adoption of RCM concepts in construction projects. The following

sections describe previous tools for improving planning reliability and production predictions in construction. Then, the RCM-Plan software architecture is introduced.

4.1 Computer approaches to improve planning reliability and production predictions in construction

LPSTM application has inspired the development of several computers applications, supporting several of its main functions, which allow improving planning reliability. Among others, can be mentioned: WorkPlan (Choo et al, 1998); WorkMovePlan (Choo and Tommelein, 2000); Integrated Production Scheduler (IPS) (Chua et al, 1999); Lean Enterprise Web-based System for Construction (LEWIS) (Sriprasert and Dawood, 2002); SPS Production Manager (SPS|PM) (SPS|PM, 2009); Project Plus Control (P+C) (P+C, 2009). In general, these approaches provide support to the planning process but do not solve the operational planning issue that emerges when contractors and subcontractors arrange work plans making predictions about their performance. In general, many contractors assign work to subcontractors based on their intuition and experience resulting in unreliable work plans.

On the other hand, there are several methods in construction that can improve production predictions such as *virtual prototyping* (Huang et al, 2007); or *discrete event simulation modeling* (Martínez, 1996). However, these predictive approaches can be complex to adopt among construction practitioners as an ordinary practice. RCM-Plan, described in the next section, provides a tool that is easy to use and implement to automate the procedures associated with RCM, providing prediction capabilities to support the adoption of reliable commitments in planning meetings.

4.2 RCM-plan framework

RCM-Plan was developed as part of a research effort from the Production Management Center (GEPUC) at Pontificia Universidad Católica de Chile, to improve the current planning practices in the Chilean construction industry. RCM-Plan architecture is based on Microsoft Visual Basic .Net, framework 2.0, developed with Visual Basic 2005. Microsoft Excel version 2000 is required for RCM-Plan operation on the client-machine user application. The matrix approach is used in RCM-Plan to calculate the different parameters of the MLR models, i.e. $\beta_0 \dots \beta_3$, which is implemented in Excel and in turn interacts with the .Net framework, showing the main MLR statistical results. By using Excel the system generates the necessary graphics such as nomographs, weekly progress, PRI evolution, labor resource evolution, etc. and several types of reports. RCM-Plan does not use data base provided by external suppliers, since its architecture uses .xml files to store historical data, making the information very portable. By summarizing RCM methodology shown in Fig. 2, RCM-Plan computer architecture and operation is briefly described as follows:

1) Selection /Creation of Activities: In this stage, project managers select activities to improve their planning reliability. Thus, activities are created within RCM-Plan and are individually analyzed to

get their different production outputs and statistical parameters. For one or more activities, RCM-Plan generates data base files termed as ‘.rcmpl’ that can be imported or exported to other computers.

2) MLR Models and Nomograph Construction: The RCM process collects on-site information and predicts work plans performance on a weekly basis, generating typically MLR models starting from the 3rd week. Figure 3 shows a general screen for tools and information that provides RCM-Plan, listing a specific activity (in this case, partition-joint tape). The main tools are related to *Enter Planning* (for actual week), *Modify Planning of Last Week*, *Modify Selected Week* (data of any week), *PRI and Progress Graphics* (PRI and Progress evolution) and *Average PRI* (summary of PRIs and CCLs). In this version, only the predicted CCL is regarded. Also, RCM-Plan considers a predicted PRI equal to 100% to develop nomographs (a common reliability level expected by planners). In Figure 3, 17 weeks of historical information are considered and the planning process of 18th week is illustrated.

Week	Actual Worker-Wi	Planned Worker-Wee	WIPBf (ML)	Planned Progress	Actual Progress	Predicted Progress	Actual PRI	Predicted PRI	Predicted CCL	R2	Selected Function	Validat Week
1	25	30	9467	3957	2029		51.276%					✓
2	30	30	9099	3957	5410		100.000%					✓
3	29	30	8672	3957	2899	5410.00	73.263%	100.000%	63.505%	1.00	Workers (W)	✓
9	0	30	3610	3957	0	3731.80	0.000%	94.309%	0%	0.53	Workers (W)	✓
10	15	30	1800	3957	2412	3731.8	60.955%	94.309%	45.281%	0.53	Workers (W)	✓

Figure 3: General screen of RCM-Plan

To plan 18th week, it is necessary to select a MLR model. RCM model automatically calculates all the possible combination of variables (W, WIPBf and PP) and its corresponding R^2 . In Figure 4, the *Adding Planning for Week 18* dialog box, *Selection of Function* tab, shows which variables are selected for a specific MLR model and the corresponding R^2 -value (decision-makers manually chose a MLR model using the heuristic mentioned earlier in section 3). This dialog box allows showing the full MLR model (*View Prediction Function* option) which is a function depending on W and WIPBf variables in this case and creating the corresponding nomographs (*Nomograph* option). The latter option allows showing graphically the interactions between PP and W given several WIPBf sizes. This is the most important feature of the RCM-Plan, to explicitly visualize in a multidimensional environment the interactions of several production parameters, allowing reliable prediction of activity progress, and thus, more reliable planning commitments and work plans.

3) RCM Planning Process: Once a decision-maker has selected PP, W and WIPBf levels, this information should be entered into the planning for next week (18th week in Figure 5), which is done in the *Adding Planning Week 18* dialog box, *Enter Planning Data* tab. Note that W is entered as a planned estimate. *Predict Progress* is automatically generated as RCM output, showing the PRP level

for week 18, i.e. predicted work plans for this week. At the end of the 18th week, AP and actual W levels are entered using the *Modifying Progress* dialog box.

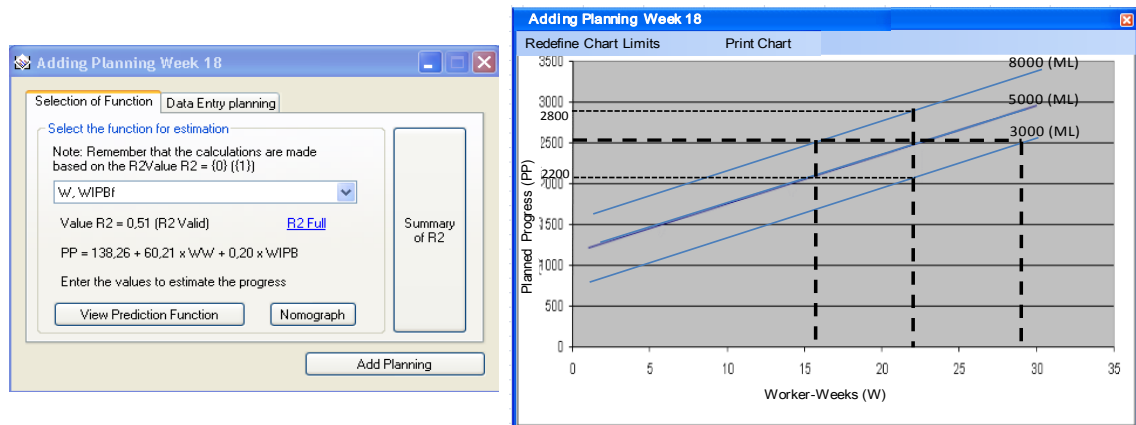


Figure 4: Adding planning by creating RCM prediction function and nomographs

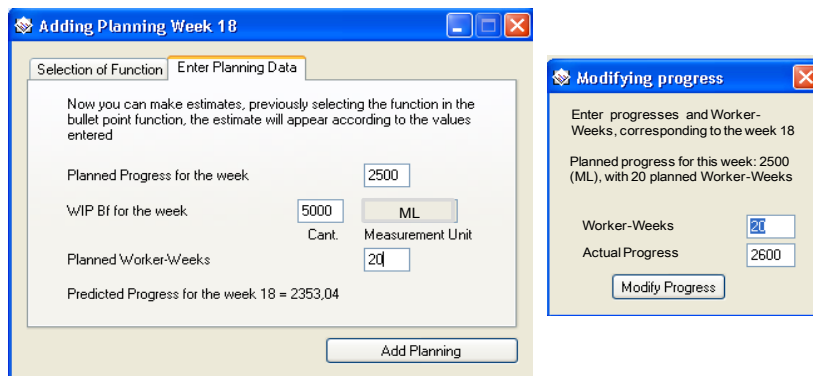


Figure 5: Adding planning by entering RCM inputs and actual progress

4) Evaluation and Feedback: At the end of every week, several reports are produced (see Figure 6).

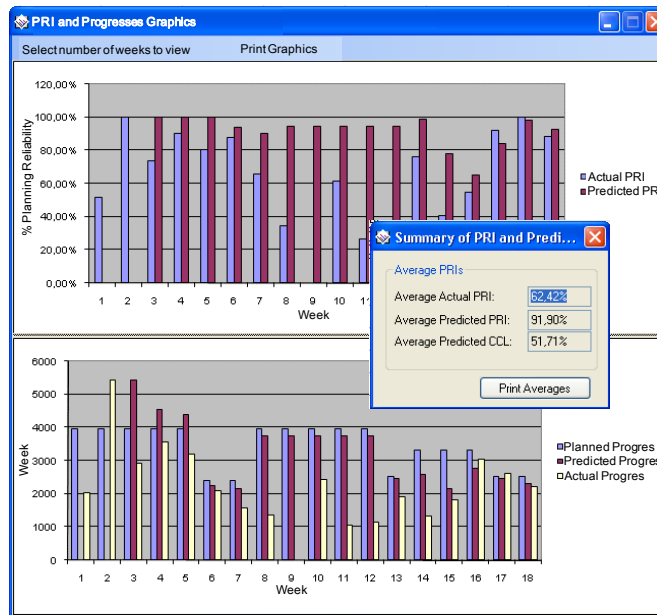


Figure 6: PRI and progress evolution reports

The *PRI and Progress Graphics* dialog box describes the Predicted/Actual PRI and Planned/Predicted/Actual Progress respectively for all weeks. Also the *Summary of PRI and Predicted CCL* dialog box described the average Predicted/Actual PRI and the average Predicted CCL for the analysis period. This information allows evaluating performance of planning process in terms of its reliability and accuracy using the RCM-Plan.

5. Case study

From the total cases studied with the RCM (section 3), RCM-Plan was actively implemented in 6 projects and 15 activities. The RCM-Plan architecture allows the automation of RCM calculations and procedures and a reliable visualization of its mains inputs. These features facilitate the on-site application of RCM concepts and reduce possible barriers of implementation. In this section, a case study where RCM-Plan was applied is used to illustrate its impacts on planning reliability and activity performance.

5.1 Case study A: Multi-family residential building

Plastering activity in a multi-family residential building was selected, analyzing how improving planning reliability through the RCM-Plan could increase labor productivity. Figure 7 summarizes the data evolution of RCM-Plan application.

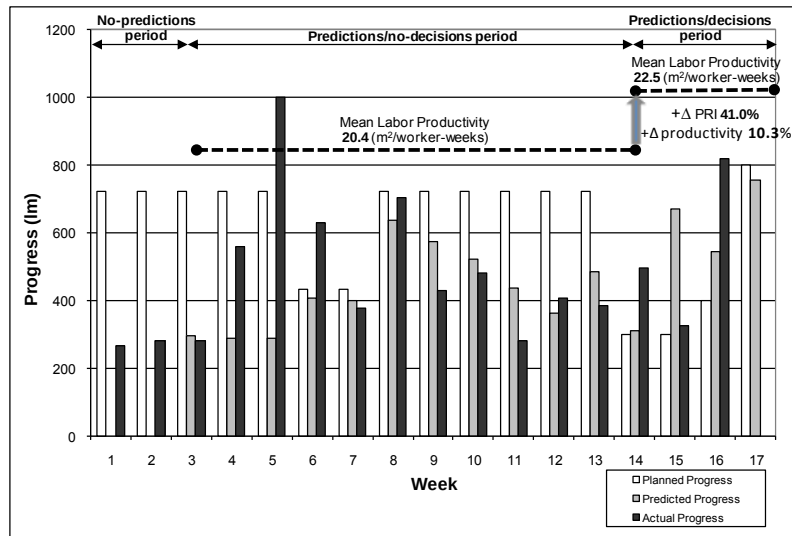


Figure 7: RCM application evolution case study A (González et al, 2009)

In this case, MLR models were mainly specified as a combination of W and/or WIPBf variables, with different model parameters, β_1 and β_2 , every week (note that RCM process is dynamic, changing parameters and even variables of MLR models week to week). Three different periods can be distinguished in Figure 7: the No-predictions period (1st – 2nd weeks), where data is collected for the RCM; the Predictions/no-decisions period (3rd – 13th weeks), where planning predictions were performed to test the RCM, but were not used by the manager to make decisions; and the Predictions/decisions period (14th -17th weeks), where the manager relied on the RCM outputs to make planning decisions.

RCM-Plan was used in the planning process of this case from the beginning, being the RCM-Plan impact analysis focuses on the last two periods. An active intervention on the W and WIPBf variables was decided on the 11th week, starting from the 14th week, when sensitivity analyses using the RCM-Plan were performed to study the effect of WIPBf over W. Based on these analyses, the manager decided to slow down the activity not involving a higher number of W during 14th and 15th weeks. During these weeks, a larger WIPBf was deliberately generated maintaining a low W level. It was determined that a WIPBf size closer to 2000 m² could maximize labor productivity in order to achieve PP levels of 800 m² with W levels closer to 31 worker-weeks. During the 16th and 17th weeks the numbers of W was increased to take advantage of a higher WIPBf size.

A rough analysis of the data from Figure 7 shows that the mean actual PRI for the Predictions/no-decisions period and the Predictions/decisions period is 70.55% and 100%, respectively. The effect over labor productivity for the same period was estimated as the ratio between actual progress and worker-weeks. Mean labor productivity for the Predictions/no-decisions period and Predictions/decisions period was 20.4 (m²/worker-weeks) and 22.5 (m²/worker-week), respectively. In other words, planning reliability was increased by 41.0% and productivity by 10.3% (see Figure 7). A larger WIPBf size during weeks 14th and 15th was produced, resulting in improved productivity for the following weeks. The mean actual PRI for the 3rd - 15th weeks is 72.49% and for the 16th - 17th weeks is 100%, improving planning reliability by 38.0%. Similarly, the mean labor productivity for

the 3rd - 15th weeks is 20.6 (m²/worker-weeks) and for the 16th - 17th weeks is 27.0 (m²/worker-weeks), with a productivity improvement of 31.0%. The improvement in labor productivity is explained by a better planning reliability and a direct action over production variables such as W and WIPBf using the RCM-Plan as a decision-making aid tool.

6. Conclusions

This paper addressed the theoretical and practical framework that supports a computer prototype called RCM-Plan based on Rational Commitment Model (RCM) principles, which allows to improve reliability of operational work plans in construction projects. By using site production data such as workers, buffers and plans, RCM-Plan automatically develops statistical models (multiple linear regressions) to predict activity progress, and thus, support reliable work plans. One of the most important features of the RCM-Plan is the explicit visualization in a multidimensional environment of the interaction of several production parameters (workers, buffers and plans) and its impact on planning predictions and labor capacity. This allows creating more reliable work plans, having in mind a more realistic and a rational characterization of the production environment in projects. The implementation of the RCM methodology can be complex but experimentation with RCM-Plan allowed reducing implementation barriers in the organization of the case projects. Further research to improve capabilities of RCM-Plan is necessary, which is part of the ongoing research of the authors.

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Building Information Modelling in the Netherlands: A Status Report

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Abstract

Building Information Modelling (BIM) is nowadays widely accepted as a key enabler for innovation in construction. In the Netherlands, people have been working on BIM for more than twenty years, although most activities have been research efforts. But since the leading CAD vendors have embraced BIM as a key development in CAD innovation, the implementation and use of BIM technologies in practice have increased significantly.

Apart from various “pseudo-BIM”- initiatives (BIM-solutions within a single commercial software platform, “closed” BIM-solutions that are not accessible by external parties, fancy CAD-solutions presented as BIM-solutions), there are a number of interesting BIM-related developments in the Netherlands.

The first development is the COINS project. This project aims for agreements for the storage and exchange of construction objects. The main results of COINS are currently specifications for these agreements and software tools for implementation of COINS-based systems. COINS uses the OWL format for object definitions; interfaces with the IFC-models have also been developed. The COINS project is initiated by the Dutch civil engineering industry, but the current focus is on products of the entire building industry. Several pilot projects are currently taking place both in civil engineering and in office and residential building.

The second development is somewhat different: it is the BIM Case Week, an initiative that brings together professionals in the construction industry for a week, and lets them work together on a design of a building project. The approach is fairly down-to-earth but it has provided very useful insights in how exchange and sharing of construction information takes place in practice.

The third development is the Dynamic BIM initiative; this is currently an academic initiative that aims at the support of project dynamics in a BIM context. The focus in this initiative is on innovative design and engineering processes enabled by BIM technologies.

Keywords: building information modelling, the Netherlands, status report

1. Introduction

One of the current keywords in building innovation is Building Information Modelling, or BIM. Since a few years, BIM is a buzzword. But Building Information Modelling is not a new activity or technology; in fact people have been working on BIM (using different terms) for decades, although mainly in research settings.

People in the Netherlands have been involved in BIM research since the early days of BIM, the eighties of last century. Over the years, Dutch researchers have been working on BIM in various projects. In recent years, a transition can be seen in the Netherlands from mainly research oriented activities towards dissemination and implementation in building practice. More and more people and companies become active with BIM. Articles on BIM appear in practice oriented journals, new courses for building professionals are set up, and new dedicated BIM websites are set up, and so on.

This paper gives an overview of some important BIM-related developments in the Netherlands. First a short historical overview of BIM in the Netherlands is given. Next the COINS project, the BIM Case week and the Dynamic BIM initiative are discussed, followed by a short discussion of other developments. But before all that, a short statement is made about the definition of BIM.

2. What is BIM?

There are a number of different definitions of BIM around. As more people are working with BIM, this number increases, and as a consequence more misunderstandings occur. As long as BIM is mainly a research topic, this is a little unpractical, but more or less unavoidable, just like with many other definitions in research. But with the transition from BIM as a research topic towards BIM as a commercial product or service, the need for a clear definition becomes really apparent. For example, many companies claim they are doing BIM while critics say they are only offering smart CAD solutions.

A useful definition for the term Building Information Modelling is the following by Lee et al (2006), which is also used on Wikipedia: **Building Information Modeling (BIM)** is the process of generating and managing building data during its life cycle. Typically it uses three-dimensional, real-time, dynamic building modeling software to increase productivity in building design and construction. The process produces the Building Information Model (also abbreviated BIM), which encompasses building geometry, spatial relationships, geographic information, and quantities and properties of building components

In addition, a useful definition for the term Building Information Model is the following by Van Nederveen et al (2009): a **Building Information Model** is an information model of a building (or building project) that comprises complete and sufficient information to support all lifecycle processes, and which can be interpreted directly by computer applications. It comprises information about the building itself as well as its components, and comprises information about properties such as function, shape, material and processes for the building life cycle.

The last definition is a little bit long term oriented, as life-cycle support by BIM is currently far from common practice.

But let us go back to the initial question: what is BIM? A key question in this respect is: how can we distinguish between “BIM” and “non-BIM”? For that purpose, the following characteristics of BIM can be highlighted:

- BIM aims at the exchange of semantic information. That is: the model that is developed does not only cover geometric information, but also material properties, functional information, etc. For example, many advanced CAD systems that use concept of parametric modelling can be very useful design aids. But if their internal model is solely based on geometric entities, you cannot call these BIM modellers.
- A prerequisite for BIM is the use of open standards. A Building Information Modeller may be a “closed” system, but the information that is exchanged or shared must be defined according to an open standard, such as IFC. Although closed systems can be very effective, in the long run they can lead to vendor-dependency and to outdated systems that are very difficult to upgrade.

Neither of the definitions stated above explicitly mention open standards as a prerequisite for proper BIM. Open standards are indeed often mentioned as a prerequisite. On the other hand, one can question whether it is absolutely necessary to use for example IFCs in a BIM environment. In our view this is an open issue.

3. History of BIM in the Netherlands

The Netherlands has quite a rich history in BIM research and development, which goes back to more than twenty years ago. In the nineteen eighties, several groups in the Netherlands were involved in research on CAD systems for architecture, and on the issue of data exchange between CAD systems. The Dutch architectural CAD system Arcos/Arkey CAD was launched with some “building intelligence” built in. A discussion started on the use of so-called reference models for CAD exchange.

A key reference model in this context was the General AEC Reference Model by Wim Gielingh of the Dutch research institute TNO (1988). This model was developed for the ISO STEP (ISO 10303) project, and it provided a number of concepts and principles that we can regard now as BIM concepts: as required and as designed information, generic-specific-occurrence information, life cycle data, views on building data, etc. The famous “Hamburger” notation and the associated ideas are still used in publications from all over the world.

Another interesting publication out of that period is the so-called IOP Bouw Informatie Model (Van Merendonk and Van Dissel 1989). This model was the main end result of a large Dutch research project aiming at the modelling of building information. Most of this publication consists of process

models in IDEF0, furthermore some data models have been presented in IDEFx. The models are nowadays rarely used or referenced, but the title of the model is definitely remarkable.

In the early nineties, some very interesting BIM-related work was carried out in EU-projects in which TNO was involved, such as ATLAS, PISA and COMBINE (Tolman 1999). In all of these projects, product modelling based on ISO STEP played a key role. Many key concepts and principles of IFC origin from these projects.

From the late nineties until today, a number of smaller scale national activities related to BIM took place. Participants involved include among others the building specification organization STABU, the organization for installation systems UNETO. Some of the initiatives have formed a platform called PAIS, see www.paisbouw.nl. A significant national development has been VISI, a standard for communication in building projects based on transactions and messages, see www.visi.nl. VISI uses protocols for common communication processes using transactions that consist of a sequence of messages between participants.

At the moment there are a number of interesting BIM developments going on in the Netherlands. Three developments will be discussed in the next three sections of this paper. The first development is the COINS project. This project is interesting because many key players from the Dutch construction industry are participating. The approach taken can be regarded as pragmatic, yet they do use an open standards approach based on IFC and OWL.

The second development is the BIM Case Week. This initiative brings together professionals in the construction industry for a week, and lets them work together on a design of a building project. The BIM Case Week is similar to the Build London Live events in the UK. Its biggest value is the great amount of public attention for BIM that it attracts.

The third development is the Dynamic BIM initiative. This is currently an academic initiative that aims at the support of project dynamics in a BIM context. This initiative is particularly interesting because it tries to bring BIM another step further through new research and innovation.

An important development in the Netherlands that is not directly about BIM, but that has a significant impact on BIM work, has been the growing interest in Systems Engineering. Since the late nineties, Systems Engineering was introduced at the large infrastructure principals ProRail and Rijkswaterstaat, when these organizations became involved in large scale projects such as the High Speed Link railway project between Amsterdam and Paris. With Systems Engineering, infrastructure projects became more formal, with explicit procedures for requirements management, verification & validation and risk management. Of course the companies that work for Rijkswaterstaat and ProRail had to follow the Systems Engineering process, which meant that almost the entire civil engineering sector had to deal with Systems Engineering. The impact of Systems Engineering on BIM work in the Netherlands can be seen in current developments that will be discussed below.

4. The COINS project

The first Dutch development to be discussed in this paper is the COINS project. This project aims for agreements for the storage and exchange of construction objects. The acronym COINS stands for ‘Construction Objects and the INtegration of processes and Systems (see www.coinsweb.nl and click on “Introduction COINS program”).

The COINS project was started in 2003 by a number of organizations from the construction industry most of which were already involved in the VISI project, see above. Similar to the VISI project, the COINS project has quite a strong support from industry: about 30 organizations (public principals, construction companies, engineering offices, research institutes, universities, colleges and software companies) are involved in the project. But while in VISI the focus is on the communication process, the focus in COINS is on the content of the communication between participants: the construction object information. This information deals with 3D geometry and other object characteristics such as material, planning data, cost data etc., in fact any BIM data that is needed for the project.

The COINS system architecture has two important components: the COINS Building Information Model (CBIM) and the COINS Engineering Method (CEM). The CBIM is as could be expected the building information model: the structure of objects and their associated data. For the definition of this the Ontology Web Language (OWL, see www.w3.org/2004/OWL) is used. Interfaces with IFC have also been developed. The COINS Engineering Method, or CEM, describes the methods and procedures that are followed in the engineering process. The CEM is especially used for the definition of systems engineering methods that have become popular in the Netherlands (see above), for example requirements specification procedures, or verification and validation procedures. The combination of a CEM and a CBIM for a specific application is called a COINS Framework, see Figure 2.

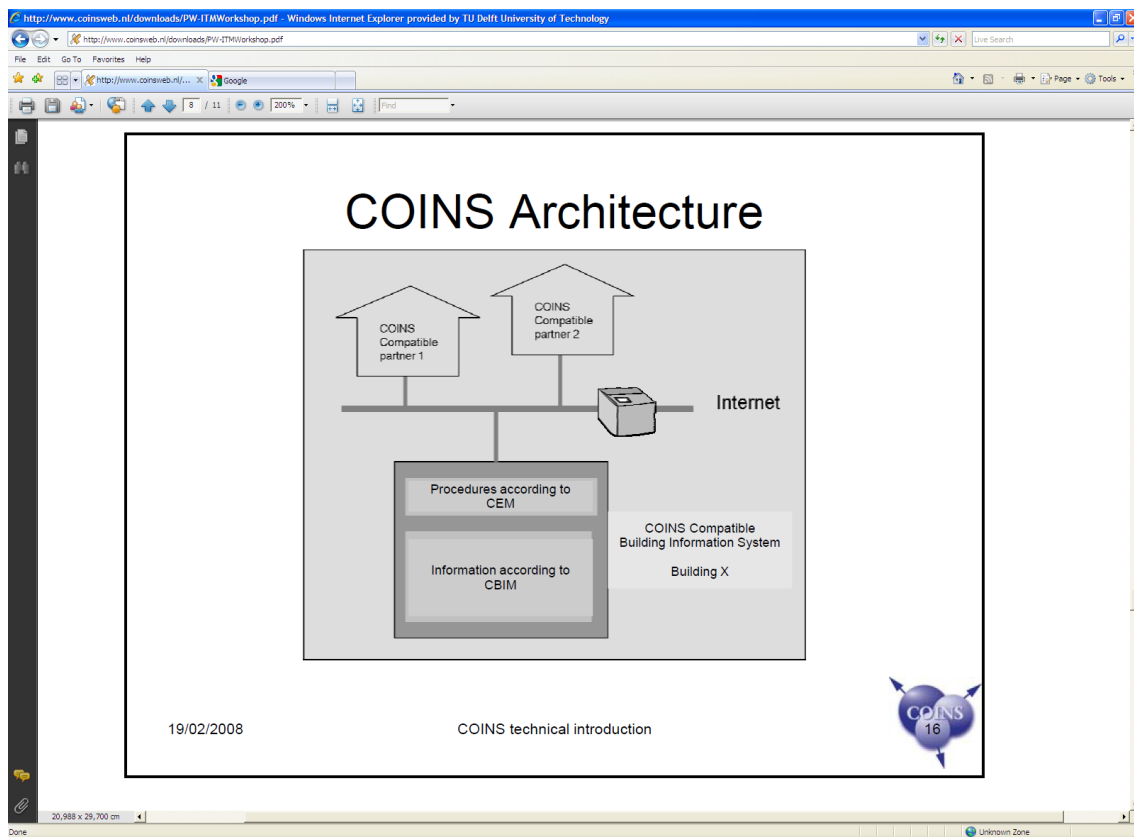


Figure 2: COINS architecture

A number of COINS pilot projects have been carried out to date. In each of these projects a COINS CEM/CBIM Framework has been elaborated for a specific scope. Examples are:

- RSS/Lunetten: functional specification/design of a railway station
- BAM: engineering, 3D-objects and quantity take-off
- IT-partners: engineering and interoperability
- IBU: functional specification/design of a waste water buffering facility
- Groningen: concurrent 3D-design of a small bridge
- Structon: 4D/BIM object management for a parking garage

(See www.coinsweb.nl).

Furthermore, a useful piece of software called the COINS Navigator has been developed. This software can be used to import, explore, query and export a COINS model (CBIM). This software is

freely available, but it has a prototyping status. The intention of COINS is that IT companies take over the concepts of this software and turn it into professional products.

5. BIM case week

The next development is somewhat different: it is the BIM Case Week, an initiative that brings together professionals in the construction industry for a week, and lets them work together on a design of a building project. The BIM Case Week has been organized in the Netherlands in 2007 and 2008, with approximately 100 participants each time, mainly from building and construction practice (architects, engineers, public authorities, etc). The next edition will be in March 2010. The main goals of the BIM Case Week are (1) to enlarge the awareness of the BIM concept and BIM technologies in the building and construction industry and (2) to disseminate knowledge and experience among building and construction professionals.

The general setup is as follows: the participants arrive on Monday morning, the assignment for a construction project is presented, and from Monday afternoon onwards, different teams work on the development of their design proposal, using BIM for the exchange of design and engineering information between the different disciplines in the team (architectural, structural, HVAC etc.). In fact this kind of event can be called a true “workshop” where the participants are really *working* on a project, instead of the numerous workshops that are in fact small-scale conferences with paper presentations of papers, where working mainly means listening to other presentations.



Figure 1: Participants at work in the Dutch BIM case week

The BIM Case Week formula has turned out to be very successful. There is no doubt that the participants of the BIM Case Week have learned a lot from each other and from the project that they have been carried out. Furthermore, the BIM Case Week has gained attention from key persons and organisations in the Dutch building sector, such as the public principals Rijkswaterstaat, ProRail and the large cities. One reason for the success is the pressure cooker effect: the participants are in the same room for a week and they are thus forced to solve problems right away. Furthermore, the degree of interaction between participants is very high. In a few days, the people at work share a lot of knowledge, experience, ideas and thoughts, and often become friends. In “normal life”, it could take at least months to reach this degree of sharing knowledge and ideas. Apart from that, the BIM Case Week proved to be a very useful test facility for all kinds of BIM technologies. With so many experts around, the shortcomings of the current state of BIM technologies became quite clear, both technical shortcomings and process-related and human-related shortcoming.

Of course not everything went perfect in the BIM Case Week. In 2007, the emphasis turned out to be on exchange of 3D geometry information, rather than on true semantic BIM information. Also very practical problems such as the network connections took too much attention. These aspects were significantly improved in 2008. Some issues that are still remaining are (1) a common understanding of the concept of BIM, (2) the need for arrangements for the exchange between participants, and (3) the need for process modelling and process management. These and other experiences and conclusions of the BIM Case Week have been well documented (Adriaanse et al 2007 and Baayen et al 2008), but unfortunately only in Dutch.

The Dutch BIM Case Week is very similar to the Build London Live event that has been organized in the UK in 2008 and 2009. The authors do not know all the details of the Build London Live events, but it is expected that much of what has been said on the BIM Case Week is also applicable to the Build London Live events.

6. Dynamic BIM

The next development discussed in this paper is the Dynamic BIM initiative. This is currently an academic initiative that aims at the support of project dynamics in a BIM context.

The motivation for Dynamic BIM starts from the observation that current building projects are carried out in a way that is ineffective and inefficient: construction projects are usually delivered too late, too expensive and not what the client wanted. The Living Building Concept (LBC) research at Delft University (De Ridder and Vrijhoef 2005) has learned that building processes can be improved by a shift from cost orientation to value orientation, and by a shift from a client-driven perspective to a supplier-driven perspective. The latter shift means that a building solution does not start with the clients’ requirements, but with a suppliers’ building system: a system of parametric building elements and components that can be utilized for fast, industrial development of building structures as a solution of the demand of a client.

When BIM projects are considered from an LBC perspective, it can be concluded that BIM projects are normally based on common building processes, that is: traditional client-driven and cost-driven building processes.

In contrast, Dynamic BIM aims at the support of a supplier-driven and value-driven building process. The key to Dynamic BIM is that the idea of the suppliers' building systems described above is implemented according to BIM principles. This means that the building system can be seen as a building box in which standardized building elements and components are described with their (parametric) dimensions, material properties, dynamic behaviour, cost data etc. Furthermore, information on relationships such as connections is stored in the building box. The elements, components and relationships together form the building system.

The advantage of this Dynamic BIM system is that a designer is able to make a design in a very short time, because the design comes down to the configuration of standardized building objects. And not only the design is developed in a short time, also the consequences of the design (on life cycle cost, energy use, environmental impact, waste production, etc.) can be assessed at short notice, using dedicated simulations on the proposed configuration of standardized objects.

The key point in this approach is that the main part of the design process has moved from the design for a specific project to the design of multi-purpose objects and connectors for the building box.

The Dynamic BIM approach described above is new and has not been applied before. But the needed technologies are available. The next step is to combine and use these technologies in order to develop the Dynamic BIM system as described.

7. Discussion

The discussed developments all have their strengths and weaknesses. The COINS project is probably the most important and also the most mature development. One of the strengths is the large number of key companies and organizations that take part in COINS. The somewhat pragmatic and practice/oriented approach of COINS seems necessary to keep the large number of participants interested. From a technical point of view, COINS can be regarded as state of the art. An open standards approach using IFCs and OWL is used. The only "weakness" of COINS is that it is not really a breakthrough development. But that cannot really be expected with this line-up of participants.

The biggest value of the BIM Case Week is the fact that it attracts so much public attention for BIM. This pressure cooker event with 50-100 participants trying to accomplish something in a week is really appealing. From a technical point of view it is less spectacular. Especially in the first edition, the emphasis was more on 3D modelling than on BIM, but this has significantly improved.

The Dynamic BIM development is most interesting from a research point of view as it aims for new, innovative additions to the concept of BIM. But until now it has been only an academic development and there are not yet any real results to show.

A remaining issue is the use of open standards for BIM. In the Netherlands the IFC standard is generally accepted as the main standard for BIM. Also it is generally accepted that open standards are preferable above closed solutions, although there are also Dutch examples of “closed BIM” solutions. But above all there is a general feeling that standardization is a slow and difficult and not very exciting process. Moreover we can see that even a small country such as the Netherlands has enough room for concurrent standards that are really difficult to integrate (i.e. the IFC and the IFD standards, both of which have strong supporters in the Netherlands).

8. Other developments

Apart from the developments above, there are a number of other interesting developments related to BIM in the Netherlands.

8.1 BIM servers

Since a number of years there is a growing need for a piece of software that can be used to import, explore and store IFC models that are produced by design or engineering software: a BIM server. In the Netherlands this has led to the development of the so-called Fidumo, the First Dutch Model server, launched in 2007. The Fidumo was developed by a consortium of two architectural offices, an engineering firm and two software companies under the lead of two the Dutch organisations CUR/PSIBouw and SBR. The Fidumo software was based on software by the Norwegian software company Jotne EPM Technologies.

Meanwhile, a small academic consortium of TNO and TU Eindhoven developed an alternative: the BIM Server. This is a rather simple piece of open source software with the same aim as the Fidumo server: to import, explore and store IFC models that are produced by design software. The software is partly based on prototype software that was earlier developed for EU research projects. More information can be found at www.bimserver.org.

8.2 BIM as a marketing brand

A development that is not really research-related but yet interesting, is the emergence of the use of the BIM acronym as a marketing brand. One example is a consultant who calls himself “de BIM-specialist”. Of course he can be found at www.debimspecialist.nl. A similar example is a company offering professional education in BIM called the BIM Academy, see www.bimacademy.nl. Both examples indicate that BIM is no longer a research acronym, but that it has become a buzzword in building and construction practice.

8.3 EU Research

Not as visible, but more interesting from a research point of view are the Dutch contributions to EU research on Building Information Modelling. Already for many years, the main Dutch contributor to BIM/related EU/research is TNO. They have been involved in three 6th Framework projects: Manubuild, SWOP and InPro, and they are now involved in the 7th Framework project IntUBE. IntUBE stands for Intelligent use of buildings' energy information, and aims at lower energy consumption of existing buildings through the use of advanced information technologies. One of the project activities is the development of an energy-oriented BIM-server. Of course the earlier described BIM Server by TNO will play a role in this activity.

An interesting aspect of the EU research by TNO is its follow-up. Sometimes it seems that EU research mainly results in more EU research. But in the case of TNO there are some nice examples of research results with a follow-up in practice – or in more practice-oriented research. For example, in the COINS project discussed earlier and in the VISI-project (see www.visi.nl) some results from EU-research play an important role, especially in the chosen software approach. Furthermore, the BIM Server by TNO can be seen as another spinoff of EU research that seems to be (or become) a valuable and welcome contribution for building and construction practice.

9. Conclusion

This paper has given an overview of BIM-related developments in the Netherlands. The discussed developments show a shift from middle-to-long term research activities towards dissemination, implementation and commercial activities. BIM has become a true buzzword in the Netherlands and it is exciting to see what is happening now and what will happen in the near future.

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Web sites

BIM Academy website www.bimacademy.nl

BIM Case Week website www.bimcaseweek.nl

BIM Server website: www.bimserver.org

Build London Live: www.buildlondonlive.com

COINS website www.coinsweb.nl

De BIM Specialist website: www.debimspecialist.nl

PAIS website www.paisbouw.nl

VISI website www.visi.nl

World Wide Web Consortium: www.w3c.org.

Radio Frequency Identification (RFID) and the Lean Construction Process

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Abstract

The demand for increasing efficiency in project delivery has stimulated the exploration of new technologies which may be implemented to improve productivity of construction work. One particular technology that has recently drawn the attention of the industry is Radio Frequency Identification (RFID) and its possible applications within the construction arena. RFID technology as applied to the construction industry is still in its infancy. While building on past successes, as revealed in the limited number of research studies, exploration of new uses continues. There are, obviously, many uses for RFID technology in the construction arena. Each of these uses is aimed at utilizing ones resources in a more efficient manner and streamlining the project management process. Some of the uses are (1) personnel tracking and safety, (2) material handling and yard management, (3) tool or equipment tracking, (4) theft deterrence, and (5) integration with BIM.

The purpose of this study is to explore the different uses of RFID technology in the construction industry and how these integrate with the Lean Construction Process. The case study methodology will be utilized to investigate how contractors are beginning to utilize the technology to increase efficiencies within the industry. By analyzing actual contractor's use of this technology through the case study method, the industry will become more and more aware of and familiar with the technology, its applications and projected benefits.

Keywords: radio frequency identification, RFID, lean construction, technology, construction technology

1. Introduction

Radio Frequency Identification (RFID) is not a new technology. Its use dates back as early as World War II when it was used for friend or foe recognition for anti-aircraft gunmen. RFID is a versatile technology and is put to a wide variety of uses, such as security for retail stores, tracking transfer bags at airports, managing inventory and theft in manufacturing plants, electronic cashless payment cards, and electronic car keys (ERA Build, 2006). Its use has become so prevalent that some speculate that RFID will universally replace barcodes in the not too distant future (Hock, 2009). The use of RFID technology is slowly creeping into the construction industry as an innovative tool in supply chain and inventory management. Its adoption and implementation into a historically obstinate American construction industry has been slow, but as prices on tags continue to fall (as low as 5 cents) it is reasonable to expect that the industry will begin to take advantage of all that Radio Frequency technology has to offer (ERA Build, 2006).

Lean construction or Lean Project Delivery (LPD) is an innovative planning, design, and operational philosophy. It has been championed by co-founders of the Lean Construction Institute, Gregory Howell and Glenn Ballard, since the early 1990s (Post, 2007; ENR, 2007). Lean construction was inspired by lean production methods developed by Japanese automotive manufacturer, Toyota. The lean production initiative was headed by engineer Taiichi Ohno whose pioneering methods were primarily concerned with the elimination of waste and inventories. He was a student of Henry Ford, but saw too much waste in his operations and focused on perfecting the design of the production system; thereby decreasing defects and the need for re-work. Ohno disagreed with the production at all costs mindset and empowered his workers to make decisions (even stopping the assembly line upon receipt of a defect) requiring less management personnel. Lean production consist of four basic principles which have been modified and applied to the construction industry: (1) identify and deliver value to the customer, eliminate anything that doesn't add value; (2) organize production as a continuous flow; (3) perfect the product and create reliable flow through stopping the line, pulling inventory, and distributing information and decision making; and (4) pursue perfection (Howell 1999).

2. Background of the problem

The construction industry is based on firms' ability to constantly improve efficiency and productivity in order to survive in a competitive environment. New techniques and methods are constantly crafted and applied to the industry, from better equipment and machinery to highly detailed scheduling software. Lean Construction principles and Radio Frequency Identification are two such innovations and can vastly improve operational efficiency and productivity (Park, 2005).

Radio Frequency Identification (RFID) technology is an automatic identification technology that utilizes radio frequencies to transmit data. RFID involves the use of tags, also called transponders, which contain a portable, modifiable database which is capable of receiving data from and transmitting data back to a reader. Radio Frequency Identification is a sister technology to bar code labels and scanners. Bar code labelling is often seen in use on construction sites as well, but RFID is

now performing some of the same tasks (Jaselskis & El-Misalami, 2003). Some predict that bar code technology will soon be obsolete (Mokhoff, 2008). RFID tags are able to withstand harsh treatment and environments and are now cheaper than ever with some priced as low as five cents (ERA Build, 2006; Atlas RFID, 2009). Due to their becoming more durable and cheaper over the last decade it is expected that RFID technology will quickly become more prevalent in the construction industry (Anderson, et al., 1995). RFID tags can be placed on any resource and track it throughout the entire construction process.

Lean construction is a production management-based approach to project delivery that focuses on maximizing value and minimizing waste through collaboration and teamwork in job planning, design, and management (Ballard & Howell 2007). The lean philosophy can be applied to any type of construction, but it is particularly useful on complex, uncertain and quick projects. It challenges the belief that there must always be a trade between time, cost, and quality (Howell, 1999). Lean construction encourages teamwork and a willingness to shift burdens along the supply chain. The problem with the current method of job design, planning, and management is that production systems do not operate well when every person tries to optimize their performance without understanding how their particular job affects the rest of the activities on-site. The current method focuses on speed of production at all costs. Lean construction focuses on managing dependencies and variation in production rates and supply of materials throughout the production system. Managers can minimize waste and maximize customer value through management of variation, dependencies, and backlogs; thereby increasing productivity and efficiency (Ballard & Howell 2007).

3. Purpose of the study

The purpose of this study is to examine what strategies involving lean construction principles and Radio Frequency Identification technology construction firms are employing to become more efficient and productive. All construction firms are interested in gaining a competitive advantage through efficiencies in cost and time. The findings of this study are meant to make the construction industry, academic and non-academic, aware of methods that are improving the way the industry operates (Coady, et al., 2008).

There is a general lack of academic literature incorporating both lean construction initiatives and RFID technology (Coady, et al., 2008). Some studies have been written solely on the lean construction principles and methods and some focus only on RFID technology. It would be beneficial to the construction field to expose a range of issues and situations in which RFID and lean construction philosophies can be applied to the industry. This study aims to combine the technological and philosophical aspects of RFID and Lean to provide general contractors with ways to increase productivity in their company operations.

4. Lean construction

Lean construction has been in existence since the early 1990s when Gregory Howell and Glenn Ballard became enamored with the lean philosophy that Toyota Motor Corporation used to gain a competitive advantage in the automotive industry under engineer Taiichi Ohno (Post, 2007; ENR Staff, 2007). Howell and Ballard converted Toyota's manufacturing practices into a philosophy that could be applied to the construction industry which they aptly dubbed lean construction (Howell, 1999).

Lean construction, in essence, is the process of minimizing waste through increased collaboration, predictability, innovation, and accountability (Post, 2007). It includes contractors in the design phase, which helps facilitate collaboration among the parties involved with the building process. Therefore, questions can be asked and conflicts can be resolved before construction begins (ENR Staff, 2007). Lean Production Design also focuses on the way the work itself is actually planned and managed. If the planning system is under control, managers can control inventories and excess capacities of labor and/or materials and avoid causing variation in work flow (Howell, 1999).

5. RFID

Radio Frequency Identification technology has been in use for over 70 years in a wide variety of ways, but it has not been in use in the construction industry for long (ERA Build 2006). The oldest literature found on RFID's possible influence on the construction industry is journal article by Anderson, Jahren, Rodriguez, and Njos titled Radio-Frequency Identification Applications in Construction Industry written in 1995.

Radio Frequency Identification (RFID) is an automatic identification technology that utilizes radio frequencies to transmit data. RFID involves the use of tags, also called transponders, which contain a portable, modifiable database which is capable of receiving data from and transmitting data back to a reader. The reader and the tag must be within a designed range of each other to operate properly (Anderson, et al, 1995).

There are two distinct types of tags; passive and active. A passive tag is one that lacks a battery supply and therefore must be activated by the emission of a specific frequency from a reader. Passive tags have an unlimited life and are usually smaller, lighter, and cheaper than active tags, but also have a shorter range or operable distance from the reader. Active tags are those which operate on a limited battery supply and intermittently emit a frequency to be interpreted by a reader. Active tags have longer reading ranges and can store more data, but are relatively large, heavy, and expensive compared to passive tags (Taylor et al., 2009). Passive tags have a shorter reading range than active ones because they operate on a lower frequency. As the operational frequency of the device increases, the distance at which the tag can be read increases and so does the speed with which the information will be exchanged between the tag and the reader. A low frequency tag operates at around 120-135 kHz and an extremely high frequency tag operates at about 2450 MHz (Taylor et al., 2009).

The applications of RFID in the construction industry continue to expand. Active tags have been cast in concrete to monitor the temperature of the mix and provide workers real-time temperature readings, which aids in monitoring the curing process (Gaudin, 2008). Some within the industry are tagging job-site equipment with high-frequency active tags in order to monitor its location, deter theft and locate equipment should it be stolen (Gaudin, 2008). Worker identification cards can be loaded with passive tags so that management can monitor an employee's location on site. There is also evidence to support the idea that an employee's productivity can be determined, to a degree, by their location on the jobsite throughout the workday (Jaselskis & El-Misalami, 2003). RFID technology can be implemented to record on-site inventory as it arrives, document where and when it was received, and locate specific items electronically as they are being installed (Taylor et al., 2009).

6. Case study

This specific case study pertaining to RFID applications within the construction industry was performed on a power plant expansion project constructed by Bechtel Corporation in the Northern United States. The expansion project consists of two coal-fired steam-turbine generating units, as well as supporting facilities, and related civil work. The contractor's scope of work consists of engineering, procurement, construction, and start up. The project will cost an estimated \$2.15 billion dollars, with construction scheduled from 2005 to 2010. Of the two units, one is scheduled to begin operation in 2009, and the second is scheduled to begin operation in 2010.

6.1 Materials management process without RFID

The materials management process for the project is comprised of a series of activities or processes that ultimately lead to the installation of a component into the facility. A majority of the steel and piping for the project was received on site via truck. Some components for the project were shipped by boat. Materials are delivered to the site along with a packing slip, which details the material item, where it came from, contact information, date of shipment, etc. Each material component comes with its own specific material identification code for the project that is written on the surface of the component. The entire receipt process and the entry of items into the materials management database was performed with a paper based manual method. The materials are accounted for and manually entered into the materials management database system, so that construction activities could be coordinated depending on the availability of materials.

As material components arrive at the job-site, they are taken to the lay-down yards and placed within a specific grid. Caldas et al. refer to this stage as "Sorting" (Caldas, et al, 2006). The components are grouped within grids according to characteristics and material identification code. Different groups of materials are assigned a color scheme. Specific colors and twisted combinations of colored flags are attached to the respective groups of materials for future identification and locating purposes.

Materials are stored in the lay-down yard until needed for installation. When a construction crew or trade is prepared to construct a certain portion of the facility, the necessary materials have to be retrieved from the lay-down yard. For this, a superintendent coordinates with a field engineer and

communicates the plans for assembling a certain area of the facility. The field engineer would generate a material withdrawal request (MWR), which listed all of the necessary materials that the superintendent's crew needed in order to complete the specified scope of work. The MWR is sent to the Materials Management staff, where they develop a "pick ticket". The pick ticket lists the materials needed, along with the respective lay-down yard and grid location of the component.

Workers would take the pick ticket to the lay-down yards and visually locate the materials that were needed for installation. Once located, the components were flagged, organized, and staged so that the pick-up process of those materials would be easier and more efficient. The materials would be loaded and taken to the construction area where they were turned over to the construction team. Once the materials had been turned over to the construction team, the receiving foremen would sign off on the materials to assure that they have received them.

6.1.1 Problems presented with the manual system heading

The issues presented for materials management on Bechtel's power plant expansion revolve around the ability of personnel to locate and flag specific material items (flagging) so they can be organized for convenient pick-up and transporting. When materials required for installation are not ready at the time they are needed, installation crews become idle and non-productive, which can increase craft labor hours up to 16 - 18% (Torrent and Caldas, 2009).

The sheer volume of materials required on the construction site presented the materials management team with several problems. The \$2.15 billion power-plant project is comprised of an incredibly large number of intricate components of steel, piping, and other structural and functional components. Individual piping pieces can become very difficult to identify when they are closely stacked together in areas of what can be thousands of square meters per lay-down grid.

The arrangement of the material yards is also a factor which can contribute to decreased efficiency in the flagging process, as well as the rest of the material management process. The farthest lay-down yard was almost three miles from the construction site. Therefore, minimal time spent at the storage yard was desired since it took a significant amount of travel time to get there and back.

Another factor affecting the material management process was the weather conditions. Extremely cold temperatures, combined with rain and snowfall, were the main areas of concern regarding severe weather that could affect construction productivity. The flagging process was made much more difficult after heavy snowfalls for the obvious reason that the materials would get covered in snow and the material ID codes must be uncovered, with shovels or by hand, in order to be properly identified.

6.2 Experience with automated systems and lean construction

Due to the problems associated with the manual tracking system, the decision was made by management to implement a full scale RFID/GPS based system for the entire on-site materials management process. ERA Build noted that long implementation time and difficulty in obtaining the

skills and knowledge on the technology can be key operational and technical barriers that face companies in adopting the technology (ERA Build, 2006). This was the company's first full scale application of the technology. The decision to invest and employ the technology on a large scale was made less difficult, in large part, due to the company's previous participation and involvement in pilot tests. Bechtel hosted an academic study pertaining to RFID technology on one of its construction sites in 2005.

Bechtel's field test was performed over approximately three months on a twin-boiler project in Rockdale, Texas. Chief sponsors of the pilot were the Construction Industry Institute (CII) and FIATECH, and the research team was comprised of about two dozen individuals representing universities, construction firms, institutes, and technology vendors (Saywer, 2008). The field tests compared the times of the typical paper based manual method of locating steel items, to the RFID/GPS based automated method for tracking down components in the lay down yards. The trial results found that the average time taken to locate a specific component with the manual process was 36.8 minutes. The average time taken to locate materials with the automated method was 4.6 minutes. Also, when using the manual method, 9.52% of material components "were not immediately found," compared to the 0.54% of the automated method. The research team regarded the success rate of the automated system to be quite significant considering the fact that the failure to locate critical items can lead to costly slowdowns, and sometimes even re-procurement (Saywer, 2008).

6.2.1 Lean strategies

Bechtel utilizes Lean management strategies throughout their business processes and construction projects. Lean aims to decrease the amount of defects, or errors, or failures that a company might encounter throughout its business processes. Lean aims to develop quantifiable business improvements via statistical analysis of data. The experience gained through the field study proved to be valuable for Bechtel, in regards to developing future applications. Not only did the field studies produce valuable data for statistical analyses, but the relationship that was gained with the technology vendor during the field tests, was able to be continued, and developed into a business relationship for their full scale implementation.

RFID technology fits well with the Lean production philosophy fulfilling all four of the goals previously mentioned. Utilization of the RFID material tracking system allowed the integration of the delivery, storage, stocking and supply processes through a single automated system thereby providing the client with a more productive and efficient materials management system.

6.2.2 Technological specifications: Tags and readers

The tags utilized in this full scale implementation were active RFID tags. These active tags continually "wake up" and send out their ID information at pre-configured intervals (i.e. every 1 second, every 2 seconds, every 10 seconds, etc.). The active tags are Ultra High Frequency (UHF), and they operate on a 915MHz frequency level. The lifespan of the tags is generally five years. The physical dimensions of the tags measure about 5 x 1 x .85 inches and weigh about 50 grams. Tags with these characteristics and reading ranges cost approximately \$25(US) each.

The reading units utilized in this application were a combination of RFID reader and Global Positioning System (GPS) receiver. The readers were mobile, handheld computers, or personal digital assistants (PDA), suitable for field readings. The readers' operate with Microsoft Windows. Approximately six handheld readers were utilized on the entire project; usually a team (i.e. iron-workers) would have its own reader which was designated for them each day. RFID/GPS readers such as those utilized in this study currently cost approximately \$5,000(US).

The automated materials management process also used barcode scanners for association purposes. The scanners were mobile, handheld devices that utilize Bluetooth technology. The scanners operate on High Frequency (HF) radio waves at a 13.56 MHz frequency level. The scanners are rechargeable. The physical dimension of the barcode scanner is about 4.8 x 2 x 1.3 inches and weighs 132 grams (about 0.3 pounds). These barcode scanners currently cost around \$450-\$500(US). Server software is also required for the system and it cost approximately \$35,000 - \$50,000(US) depending on the software and the vendor.

6.3 Implementing the RFID/GPS based system

The RFID/GPS based materials management process was not implemented from the beginning of the project. It was only after the problems mentioned above arose, that the decision to implement the automated tracking system was made. At that time, around 65-75% of the materials for construction had already been delivered to the site. Having the majority of the materials on site meant that the materials management process would have to be retro-fitted with the technology. Roughly 6-10 employees were assigned the task of attaching tags to materials in the lay down yards, and associating those tags to the specific material piece in the management system. This project tagged 20,000+ unique material components with RFID tags. Approximately 12,000 tags were utilized for this project, as tags are reusable.

6.3.1 Attaching and associating RFID tags to materials

RFID tags were attached to the material components with plastic zip ties. Once the tags are attached, they must be associated with the respective material to which they are attached, for future tracking purposes. Some materials arrived on site with a barcode label that indicated the component's material ID. Others did not have barcodes attached, and their material ID would be written on the exterior of the component.

If the material component had been delivered with a barcode label, then the association process becomes very simple and almost instant. The barcode label on the material component is simply scanned along with the barcode label on the RFID tag attached to it. The barcode scanner is able to instantly transmit the material ID and RFID tag's ID into the RFID reading device wirelessly via Bluetooth technology. Once the material ID and tag ID had been input into the RFID reader, the worker could hit "associate" on the RFID reader to initiate communication with the tag while next to it, and that specific RFID tag's ID would then be linked to the material component on which it was attached. Once the tag was associated, the workers would hit the "locate" button on the RFID/GPS reader, and the component's latitude and longitude is stored in the reader. The tag had been

associated to the specific material component and now that specific material component was ready to be tracked. When items arrived with barcode labels, the association process, after the tag had been attached, was very simple, and completely automated. The association process takes approximately 10 seconds.

6.3.2 GPS mapping and RFID tag locations

Before the system was implemented, the lay-down yards throughout the site were geo-coded, mapped and entered into a geographic information system (GIS), which divides the yards into their respective coordinated grids. As Torrent and Caldas explained, GPS receivers can be set to transform collected systems into a coordinate system. The default latitude and longitude degrees for a global system can be transformed into a “local projected system” so that it “simplifies the implementation of the localization mechanisms by providing coordinates in fundamental units of length, such as meters (Torrent and Caldas, 2009). An image of the digital lay down yard on an office desktop easily identifies the material and its location in the lay-down yard.

6.3.3 Tag item location with RFID/GPS system

When there are a large number of material items, attaching individual GPS receivers to each piece of material has been deemed an infeasible option for the purposes of locating construction materials (Torrent and Caldas, 2009). Therefore, the project in this study utilized six RFID reading devices that were equipped with GPS receivers, and the material components were tagged with RFID tags. The GPS receivers are able to determine their own location at any given time. The active RFID portion of the reader could then be utilized with localization methods, which are algorithmic based location projections based on strength of signal and reader location, as described by Torrent and Caldas, for the projected locations of the RFID tagged components that were within reading range of the reader. Periodic updates are made in order to update the projected locations of materials.

6.3.4 Automated locating process

With the RFID/GPS system in place, the goal is to make the material locating (flagging) process much easier and faster. With the automated system in place, after the Engineer has developed a material withdrawal request (MWR), the materials management office staff generates a pick ticket packet which included a list of the required materials and each item’s specific yard and grid, as well as a supplemental image, which would give the workers the approximate location of each component within their respective grid, assigned by the GPS/RFID localization methods. The workers go to the correct lay down yard and grid, and go approximately to where the printed map had indicated the material’s location to be within that grid.

Once in the area, the workers utilize the RFID/GPS reader to narrow in and find the component. The reader could pull up two different modes for finding the items. The map view utilizes the GPS portion of the reader. The digital map of the yard can be displayed on the handheld screen and the GPS receiver will show where the employee is standing, and the projected location of the material. The employee’s positioning on the screen is represented by a blue dot, and the material component is

represented by a red dot. Another method was to set the reader into what was referred to as the Geiger counter mode. A Geiger counter is an instrument that can detect and measure radioactivity (Iovine, 2000). The Geiger counter mode of the reader allows the worker to communicate only with the specific tag that is desired. The Geiger counter can be utilized within 150ft proximity from the tagged components. As the worker moves with the reader, the GPS receiver determines and gathers information on the location of the reader. The RFID portion communicates with the desired tag, and the reader utilizes localization methods based on the positions of the reader (gathered by GPS), and the received strength of signal from the desired tag at those positions (gathered by RFID). A compass pointed the employee in the direction of the tag with which the reader was communicating. When the reader is within a couple of meters from the tag, the compass would change to a cross-hair and display the words “WITHIN RANGE”.

6.3.5 Performance of the system

The performance of the technology was satisfactory and it was noted that there were very few malfunctions. One issue of concern was whether or not the technology would perform in very cold temperatures. They found that the system worked down to -26 degrees Fahrenheit. Also, it was mentioned that at extreme temperatures below that mark, the readers were affected by the cold before the tags, so workers would warm the readers by means such as holding the readers inside their coats. Tags could easily be read through a couple of feet of snow.

Although the tags were durable, moving materials or placing heavy materials on top of each other can sometimes damage the tags. It was proven that if the outer shell of the tag has been damaged, but the internal battery and antenna device had not been affected, the tag maintained its readability function.

6.3.6 Results and future plans

Jim Rogers commented on the current standing of the automated system and the effects that RFID/GPS have had on the project: “We used all the (RFID) tools, and the application of LEAN to eliminate a wasteful flagging step. We now send the loading crew straight to the material rather than having another pair of people go ahead to make sure they can find the material, flag or identify it with colored ribbon, in order to optimize the loading crew’s time, and that of the crane. The quantified savings were centered on eliminating the flaggers, although many other benefits are known, e.g. schedule, supply chain risk, staging space savings.”

The RFID/GPS based system utilized on the project described in this case study will continue to be used by the company for upcoming projects of similar type. Two new projects will utilize the same technology are recently getting underway in Ohio and Illinois. In this case study, the automated system was retrofitted to the existing materials already on site and in the lay down yards, however, future applications will aspire to implement the system so that the materials will be tagged with RFID before they arrive on the project site. When commenting on further developments of RFID based solutions, and the processes that will be impacted and changed, Rogers noted: “The whole supply chain, from engineering through procurement, field material management, construction, and some selected components (that need maintenance) by the customer. We started with the greatest need,

with a compelling business case, and we will build from there.” The future goals will be to track different components throughout the entire supply chain, as well as while on site, and selected components that will need maintenance in the future, could also remain tagged with RFID after installation to facilitate easier identification for maintenance. To do this, it will require increased cooperation and coordination with suppliers, customers, and others involved in the supply chain process.

7. Conclusions

Although RFID technology solutions for the construction industry are still in the early stages of development, case studies are showing that custom solutions can be proven beneficial for some construction companies’ processes. Solid business cases for RFID based solutions that can be uniformly applied across the construction industry remain to be seen. This may be in large part due to the fact that each construction project will be unique to a certain degree, whether it is by size, complexity, life-cycle, geographic location, etc. Also, depending on the size and structure of a construction company, it may or may not be able to accommodate, and assign overseers for the adoption of a new technological system. Those companies that remain curious and open minded towards the technology will be more likely to realize potential benefits.

Materials management systems utilizing RFID technology may be further refined in the future if manufacturers are encouraged to place the tags on the materials during the manufacturing process. Materials ordered with RFID tags in place will truly be in line with the Lean construction process.

Another technology that may facilitate the transition from tracking field materials to in-place materials is in the area of building information modelling (BIM). As more and more projects are becoming BIM based, a natural progression will be to link the RFID solution to the BIM solution. This would mitigate the problems currently encountered with reading tags of in-place materials and the loss of data once a battery ceases to operate. If the owner receives an as-built model, the facilities management process can eventually be streamlined. This is truly in line with the lean construction philosophy.

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The Last Mile: A Pilot Study of Best Practices for Successful Implementation of Mobile Communication Technologies at the Construction Site

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Abstract

It seems that every year construction project schedules become more and more compressed to meet the demands of developers, building owners and construction company shareholders. This compression of time, combined with decreasing profit margins due to increased competition, creates a situation where there is little room for error managing the site. Site superintendents have numerous daily responsibilities to keep the job running efficiently. In order to manage effectively, project superintendents need access to all project information data all of the time. While most construction office trailers have computers and high speed internet connections, the majority of actual construction sites do not. Construction companies are not utilizing the available technologies to effectively and efficiently manage their projects. This paper offers best practices for implementing simple mobile communication solutions for the “last mile” on the construction site. In part, this paper has discovered the needs through a survey sent out to randomly selected large general contractors to establish the types of communication technology companies are currently using and to get feedback regarding what does/does not work for said companies. When implementing new technologies, each company should consider trying each hardware tool on a trial basis and then create a plan of execution that includes education and training. At this point, the company can develop or revise any standard operating procedures manual and evaluate the future cost-effectiveness of said technology over the “last mile.”

Key Words: construction project schedules, time compression, mobile communication industry

1. Introduction

Industries such as healthcare, gaming, trucking and energy have seen significant productivity improvements through the use of mobile communication technology (Gayeski, 2004). Skilled workers in these industries are able to use the internet and other cutting edge systems to communicate, plan, collaborate and complete complex tasks in varied locations with remote colleagues in record time. But the construction industry is notoriously slow to embrace new technology (Stewart, Mohamed & Daet, 2002).

Construction sites, due to their remote nature, are less efficient and productive than their counterparts in the corporate office. Many of these inefficiencies could be eliminated or reduced through the use of readily available mobile communication technologies. If the project superintendent could instead enter the data gathered during a site walkabout into a tablet PC or PDA, then that information could be sent to the project specific website (PSWS) or home office file system and the duplicate data entry would be eliminated. If an architect issues a response to a Request for Information (RFI), that response is typically sent to the contractor's home office. Once the home office receives the answer, the information is forwarded along to the job site, either via fax or e-mail. If the response is time critical and the project supervisor is on the jobsite instead of in the project trailer, he or she might not receive the information in a timely manner. Give the project superintendents a handheld, portable, internet connected device, however, and he or she could know instantaneously about the response and direct site workers accordingly.

There are a number of obstacles faced by contractors considering an upgrade to newer technologies. While many large contractors might have the resources, both financial and human, to incorporate the latest technologies and workflow procedures to improve project communications within their organizations, many small and mid-size contractors do not (Williams, Bernold & Lu, 2007). These contractors, who often have very slim profit margins, are loathe to add any additional operating costs for computers, internet access and project management software for fear of reducing their bottom lines even further. In addition to the cost component, small and midsize contractors often feel they don't have the time to train their employees in new technologies and practices (Williams et al, 2007). While these obstacles are real, they can be overcome, and contractors would be wise to investigate and potentially implement the various time and cost saving measures utilized in other industries to help maintain a competitive advantage and to improve their project superintendent's workflow.

Inefficiencies at the job site can result in slower growth, or no growth for companies, which leads to stagnant wages and lower profit margins. In addition, inefficient workflows can result in missed details requiring expensive rework, delayed schedules resulting in liquidated damages and increased stress for employees. Through streamlined project communications and workflow processes at the jobsite, contractors could realize significant productivity improvements, improving their bottom line and growth prospects. Therefore, the purpose of this paper is to provide best practices for contractors wishing to implement mobile communication technologies, both cellular and land based Wi-Fi systems, to improve their workflow processes at the job site. This paper reviews:

1. Currently available mobile communication technologies with questions to ponder before making a purchasing decision that is right for the reader.
2. Potential application of these technologies to the project superintendent's workflow on a construction site and suggested improvements to current workflow processes.
3. Potential obstacles to implementation of these technologies and workflow changes.
4. Best practices for final implementation.

The intent of this paper is to provide all contractors, regardless of size, with some best practices for improving project coordination, project superintendent workflow and jobsite communication through the use of these tools. The best practices will also address perceived obstacles so that smaller contractors will feel confident implementing them, without placing significant burdens on company profits as well as training or operating expenses.

2. Literature Review

Construction sites are heavily paper-dependent work locations and are inefficient when it comes to workflow. Project plans are printed and bound in large, heavy rolls of paper, which are not easily carried around the jobsite. Handwritten sketches are faxed from the site to the office for clarification and notes are written on site and transcribed into digital format back in the trailer. Allowing the site supervisors and managers to instantaneously access all project documents in a small hand held device and input data as necessary will improve productivity, reduce duplication efforts and reduce errors and delays (Chen & Kamara 2007; Kimoto, Endo, Iwashita & Fujiwara, 2005; Lofgren, 2005; Reinhardt, Akinci & Garrett, 2004).

Rebolj, Magdic and Cus-Babic (2000) created one of the earliest case studies of utilizing mobile computing on a construction site. Although the study is now dated due to significant technologic advancements in the past nine years it still holds relevance for research on this topic. Some of the questions raised and left unanswered in the report, closely match this author's questions: How does mobile computing work on site? What organizational changes are required? Are the common commercial phone network services sufficient for mobile computing in construction? How complex is the problem of integrating mobile computing into existing information system? What educational efforts will be necessary?

2.1 Return on investment

Companies should not make changes just for the sake of making changes. There should be a valid business reason for making adjustments to their operations. Before any well run organization makes adjustments, however, an ROI (return on investment) analysis is completed to verify if the changes make sense. In a detailed 2004 study, Thomas, Lee, Spencer, Tucker and Chapman found that increasing IT usage on construction projects resulted in a 4% drop in construction costs (2004). They

also found a direct correlation between increased IT use and increased project performance. Furthermore, they found that “the use of these technologies also contributes to schedule compression.” The business case for implementing these changes in an organization can make sense, provided the planning is done properly and executed accordingly. Unfortunately, this study was based on projects that occurred in 1997 and 1998, before widespread utilization of technology tools occurred and the findings may be slightly dated. However, the findings should still be applicable for today’s owners and contractors.

2.2 Site management hardware

Kimoto et al (2005) show how companies can improve their workflows by incorporating a PDA into their operating procedures. The paper suggests that inspection, checklist, progress monitoring and drawing/specification reference systems can be added to a PDA, giving a construction worker on site access to the latest project data at almost any given time. This allows the worker to construct his or her portion of the work per the latest drawings including revisions. In addition, the worker can input schedule updates, punchlist information and other checklist and report information into the PDA. This data can then be synchronized with the site trailer PC periodically so that information can be analyzed and acted upon appropriately by the supervisors and managers. Kimoto et al (2005) do not include wireless syncing via Wi-Fi or mobile connections, but do discuss this as a future potential workflow to eliminate the time-gap between getting the data at the site and entering it into the central project database.

In an early study on this subject, Cox and Issa (1996) discuss utilizing an IBM Thinkpad 710T for acquiring quality control data on the jobsite. This data is then uploaded to a central database for reporting purposes. The 710T was a precursor to the modern day tablet PC utilizing an electromagnetic pen for entering data. This paper provided good ideas for collecting quality control data at the jobsite, but does not discuss using the Thinkpad as a tool to access information already located on the central database server. Modern tools allow for instantaneous two-way access to information data.

2.3 Implementation of new processes

In 2005, Lofgren noted that in order to effectively implement mobile computing tools on a construction site, one must consider the end user’s behavior and requirements. As construction sites are typically staffed with blue-collar workers who might not be well versed in using computers as part of their work, care must be taken to incorporate their needs and workflow processes to ensure successful implementation of any such system. If the needs of the end users are not met by these tools, any attempt at implementing such a system is bound to fail. Since each company has different workflow processes and workforce demographics, planning the implementation is crucial and successful planning can lead to satisfied workers and higher productivity. What Lofgren (2005) did not note, however, is that the younger, blue collar workforce entering the construction trades is probably more adept at using computers than their older colleagues. Implementation of such a system might need to look at the training needs of the workforce, based on their comfort level with technology. Strong management and leadership skills will be required to seamlessly roll out new

systems to ensure successful implementation. History is littered with case studies of poorly implemented operational changes that resulted in negative ROIs.

Chen and Kamara (2007) provide a model for selecting the appropriate mobile computing applications and tools, based on a user's specific project needs and characteristics. Their model takes into consideration the types of construction information that will need to be exchanged between the various team members. Based on the selected criteria, users can select a mobile application and mobile computer system that works best with that specific project's requirements. After selecting a mobile computer system, companies can select a wireless network type. All construction projects are not the same and the needs of each company and site will differ. The results of Chen and Kamara's study show that by preplanning the workflow of a specific project, companies can select a best approach based on their specific project requirements, eliminating guesswork and money spent unwisely. Using this model, in conjunction with Lofgren's look at the makeup of the team's dynamics, would help ensure successful implementation. The downside to using Chen and Kamara's model, however, is that if a construction company's projects vary in requirements, it does not make sense to change mobile communications systems each time a new project is started.

2.4 Available communication technologies

Nuntasunti and Bernold (2006) provide a case study for the implementation of a Wi-Fi connected construction site. The study discusses the methods employed for implementing such a system on a large construction site in North Carolina, which would appear to require significant IT support to implement and maintain. According to the follow-up survey of the project participants, the most valuable benefit for this type of system was the real-time image capturing and video systems. In order for these types of systems to work, however, numerous pieces of equipment must be placed throughout the site, which result in high implementation and maintenance costs. In addition, the video and still images consume large amounts of bandwidth to process and require significant storage capacities on their back-end servers. With the extensive availability of mobile broadband systems, such as 3G networks, site specific Wi-Fi system will probably not be widely emulated in the future.

Reinhardt et al (2004) discuss the requirement for creating an appropriate framework for information to be passed back and forth. While the scope of their study is beyond the limits of this paper, their hypothesis is that the backend software that holds all this database information needs to be set up correctly to create an efficient and effective communication system between team members. Without a good system in place, they argue, the productivity improvements that could be achieved with mobile computing applications will not be as good as they could be. Web-based project management systems, or PSWS (project specific web sites), such as e-Builder™, Autodesk's ConstructWare and Meridian's Project Talk provide centralized online databases that can hold the necessary project information and allow team members to collaborate as needed in real-time. Some PSWS now offer wireless integration with their websites (Cox, 2006). This allows site workers using wireless handheld devices such as Blackberries or iPhones to update information in real time to the PSWS while walking around a jobsite utilizing a mobile cellular internet connection. This capability allows workers to have access to the latest project information and provide updates to the team instantaneously, thereby improving productivity and reducing the potential for errors and costly rework.

2.5 Technology limitations

There is, however, a drawback to assuming that all contractors have access to a PSWS for this study. According to a 2007 survey, Williams, Bernold and Lu found that the companies they surveyed showed a large interest in web based document management systems as a potential beneficial tool for their operations. Even though commercially available PSWS currently exist, 51% of the surveyed US construction companies had never used a web portal, compared to just 13% of Korean firms. This shows that while US contractors are interested in the benefits that PSWS might provide, they are not as interested in implementing these tools for one reason or another. Williams et al (2007) suggest that barriers to implementation, such as perceived high cost, training and IT support requirements have hindered widespread adoption of these technologies to date. This study was in-depth and provided valuable insight showing how construction managers in both the US and Korea see opportunities and challenges when assessing implementation of these tools. It would have been helpful, however, if the authors had compared and contrasted construction management methods and practices in both countries to make a more in depth comparison between the two countries. It is quite possible that differences in contracting methods, organizational workflows, and work culture might have affected the results of the survey.

3. Methodology

The primary research methods for this topic involved review of similar studies and papers, combined with the author's own site management experience, research via the internet, Purdue's online libraries, technology company websites and newspaper and magazine articles. In addition, a survey was produced and sent out to randomly selected large general contractors. These contractors were part of the 2007 Top 400 Contractors list of the Engineering News Record publication. The intent of the survey was to find out what types of communication technologies companies are currently using in the field and to get feedback from them on what works for them and what doesn't work for them. This meta-analysis, combined with the survey data, compiles the latest communication technology information with traditional construction workflow processes to create new proposed hybrid systems which contractors can utilize to change their standard operating procedures as may be deemed appropriate for their organizations.

3.1 Survey development and IRB approval

A 29 question survey was developed covering a range of topics. Topics included company demographic information, hardware tools utilized by the project manager and project superintendent, PSWS usage, internet connection information, training programs and cost data. Once the survey was developed, it was submitted to the Purdue University Office of the Vice President for Research for review by the independent Institutional Review Board (IRB). The IRB reviewed the survey and the Research Exemption Request submitted and they confirmed that the survey was exempt from the full requirements of 45 CFR 46 or 21 CFR 56. Once the exemption notice was received, an online survey was created on Survey Monkey's website (www.surveymonkey.com). Survey Monkey was chosen for its ease of use and ability to compile and collate the individual responses, while maintaining each

respondent's privacy. In addition, the use of a website allowed the survey link to be sent via an e-mail and the survey to be taken online at any location.

4. Results: Data analysis and discussion

As part of this research, a 29 question survey was successfully sent out to 74 large general contractors and construction managers operating in the United States. The survey recipients were all listed in the Top 400 Contractors list of 2007 from the Engineering-News Record publication. A random number sequence generator was used from the website www.random.org to pick numbers between 1 and 400 with no duplicates. The first 100 numbers selected were then matched to the Top 400 list to create the recipient list. Once the recipient list was made, company contact information was gleaned from the company's public website where available. Of the first 100 companies selected, only 83 had company websites which listed their public contact information. Survey invitations were sent to all 83 of those companies. Of the 83 invitations that were sent out, 9 came back as undeliverable, resulting in a total of 74 invitations successfully being sent out. Out of those 74 invitations, 16 responses were received resulting in a response rate of 21.6%. Thirteen respondents answered all questions. Since the response rate was low and the sample size was small, the results of this survey should be viewed with this limitation in mind.

4.1 Company demographics

Overall, 6 out of 16 respondents work for companies which operate in all regions of the United States. Of the remaining companies, the majority of them do business in the Midwest or the Mid-Atlantic regions. All regions were represented by at least two firms in the survey. Respondent's company revenues ranged from \$150 million per year to over \$1 billion per year with all ranges being somewhat equally represented. Companies with revenues less than \$150 million per year did not respond to this survey even though they were included in the original survey invitation.

4.2 IT Hardware tools, internet connections, & software

All respondents agreed that IT hardware tools were critical to the success of their operations. According to data collected, 12 out of 13 respondents reported that their project managers utilized a PDA with internet access for their job responsibilities but only 4 out of 13 said that their project superintendents had the same tools. Similarly, 12 out of 13 also reported that their PMs had a laptop or tablet style computer, while 10 out of 13 noted their project superintendents had one. Interestingly, 12 out of 13 believed that their project superintendents were more productive and efficient when using IT hardware tools. It appears that companies have been slow to integrate technology tools into the day-to-day responsibilities of their project superintendents, though they believe it to be beneficial.

Overall, 14 out of 13 respondents reported that their project superintendents could connect to the internet in the traditional manner via a wired or wireless local area network (LAN) set up within the project trailer. In addition, 5 out of 13 respondents noted that their project superintendent had the capability to connect to the internet via mobile cellular systems or wide area networks (WAN) outside the trailer. Companies are using mobile broadband capabilities in increasing numbers, but

implementation of these newer technologies is slow going. In order to fully integrate onsite project data access capabilities into their standard operating procedures, companies will need to adopt mobile cellular or WAN internet connection technologies to make workflow processes for the project superintendent more efficient at the site.

In all, 4 out of 13 respondents reported that their project superintendents can access the internet through PDAs and 10 out of 13 reported that their project superintendents can access the internet through a laptop or tablet PC. At this time, it appears the preference for internet access is through laptops and tablet PCs and not through PDAs, although some companies allow for both. Regarding available software, 5 out of 13 believed that PSWS were critical to the success of their operations. As these technologies mature and companies get acclimated to using PSWS on projects, the adoption rates will increase. In 2007, Williams, Bernold and Lu reported that only 51% of US companies had used a PSWS for their projects. In this survey, 12 out of 13 respondents reported that their companies used a PSWS at least some of the time. Furthermore, 6 out of 13 reported using PSWS “always” or “frequently” on their projects.

Even though PSWS usage rates appear to be increasing only 4 out of 13 respondents reported requiring their project superintendents to use a PSWS as part of their day-to-day responsibilities. Interestingly, 3 out of 13 said they “always” or “frequently” utilize PSWS for their projects but do not require their project superintendents to use them. This would seem to suggest that some companies are not utilizing the PSWS to its full potential by incorporating project superintendent’s workflow into the process.

The top 3 reasons cited for using the PSWS include RFIs, daily reports, and meeting minutes as noted data collected. Currently companies appear to use PSWS primarily for basic document management and not as often for more computing intense tasks such as tracking cost data or managing contracts. If companies are only interested in this basic type of PSWS setup, then utilizing a PDA on site would seem to make a lot of sense, in lieu of utilizing a laptop or tablet PC. PDAs can handle simple tasks such as filling out daily reports or RFIs as they do not require intense computing and bandwidth requirements and do not require large screens to accomplish the task.

4.3 Training and costs

As has been demonstrated, 8 out of 13 respondents reported having some sort of formal training program covering the use of IT tools, while 10 out of 13 said they had formalized standard operating procedures in place for their project superintendents to follow. Ten respondents believed that their project superintendents were well trained on the use of the IT tools their companies use. Overall, 9 out of 16 respondents said their project superintendents used their IT hardware tools effectively to follow standard operating procedures. Companies appear to be doing a good job of training their project superintendents on their standard operating procedures. More work could be done to formalize training on IT related matters and to help project superintendents effectively use their hardware tools.

According to statistics gathered, 7 out of 13 reported that their companies spent under \$500,000 on IT hardware tools in the past two years. Four were unsure and the remaining 2 noted that more than

\$500,000 was spent. All of the companies who spent more than \$500,000 had gross revenues over \$1 billion last year.

5. Discussion and conclusions

It is important that a company not try to reinvent their operations to fit the mobile computing technology available. Instead, the company should try to incorporate the new technology into their current workflow processes to improve their operations or find technologies that can “mirror” or be customized to match and / or adapt to existing processes. In addition, companies should not try to do too much at once. It makes sense to start off by making incremental changes to their workflow processes, rather than making wholesale changes to their entire operational system. Before planning a large scale implementation, perhaps an individual or a small project can act as the “guinea pig” to work out the pros and cons of a selected system. The selected mobile computing system for each company also will vary based on the type of PSWS used, the demographics of the workforce, the type of information exchanged with team members and the type of construction work being done. In addition, there may be forces outside of the contractor’s control that might affect the type of system they use.

Previous research has covered: (1) the various technologies available to all contractors, both large and small (Kimoto et al, 2005, Cox et al, 1996), (2) what to consider when selecting available technology for a specific company (Lofgren, 2005, Chen, 2007) and (3) how construction site communication workflow might be upgraded to become more efficient and effective using PSWS and other available software systems (Reinhardt et al, 2004, Cox, 2006, Cox 2007). This paper attempts to distill this research into usable information for all contractors and to create best practices for implementation.

5.1 Potential obstacles to implementation

Changes in workflow processes can be stressful and difficult to overcome. Many employees will be resistant to change. Resistance to change can be overcome, but management must properly plan for it and execute the plan. Successful implementation will require strong leadership skills on the part of management.

Perceived high costs of implementing IT changes are another potential obstacle. According to Gomolski & Tracy (2008), construction companies with revenues larger than \$500M annually were expected to spend approximately 2.2% of their revenues on IT in 2008. According to Zurier (2006), large homebuilders (more than 300 homes) spent only 0.4% of their revenues on IT in 2005, significantly less than the manufacturing and construction industry average of 2.1% that year. Small builders (less than 300 homes) spent less than 0.2% of their revenues on IT. Clearly, many companies are unwilling to spend money on IT tools, even though the evidence suggests that this spending will generate an increased return on their investment.

Perceived costs and time involved for training is another perceived obstacle. Continued training should be a part of every company’s plans for their employees, so that they may work as productively and effectively as possible. Training is an investment in the employees and keeps their skills up to

date. You may ask yourself “what if I train my employees and they leave?” Well, what happens if you don’t train them and they stay?

5.2 Implementation and training

Without an education and training plan in place, implementation of new technology procedures will not work effectively. Employees will resist the changes and try to obstruct or ignore the plan. Kotter and Schlesinger (2008) suggest there are six different methods for dealing with resistance to change in organizations. Of those six methods, three methods warrant discussion on this topic: (1) education and communication, (2) participation and involvement and (3) facilitation and support.

The education and communication method starts by providing an explanation of the need and reasoning behind the change to employees. Once they can understand why the change is necessary, they will be more likely to accept the change. The participation and involvement method takes place by including some employees in the decision making process. This can be accomplished by creating a committee or task force that reviews the proposed changes and provides their input based on how their departments might be affected. Not every employee will be well versed on IT usage or be willing to accept it. Since many project superintendents have come up through the construction ranks, they might have a particularly difficult time adapting to newer technologies if they have not encountered it before. Training and support can help alleviate any fears or concerns they may have about implementing technology in their day-to-day routines.

5.3 Implementation costs and summary

There is no correct amount to spend on IT for the company operations. It will depend on what the organization needs to meet its operational requirements. Even if firms do not wish to spend 2% of their revenues on IT, which is the large company industry average, an increase in current spending, if properly implemented, will provide a benefit. Thomas et al (2004) noted that increasing IT use on a project will decrease project costs and compress schedules if implemented correctly. Companies should look to the long term for the benefits that can be achieved.

Once these tools have been implemented, it is important for companies to assess how well the changes are working. These follow ups are necessary so that modifications or adjustments can be made to the processes. In addition, it may highlight the need for additional employee training or education. Typically evaluations take place via interviews or surveys with employees who are utilizing these tools.

The company should decide if it wants to utilize a larger, more powerful and flexible piece of hardware, such as a tablet PC, with the understanding that these devices will be slightly heavier and bulkier than a PDA or Smartphone. The advantage to this approach is that a tablet PC can also eliminate the need for a separate laptop. Once a decision has been made on the type of hardware, the next step is to make sure that the selected hardware has the following attributes: (1) it is lightweight, portable or mobile; (2) it is ruggedized to the necessary level required by the company; (3) it can be read in all lighting conditions; (4) it has various internet connection capabilities (i.e. ability to connect

via cellular or Wi-Fi connections); and (5) it has a battery capable of operating long times between charges.

Once a hardware tool has been selected, the next step would be to implement these tools on a trial run on a typical company project to see whether the selected approach makes sense and what changes, if any, need to be made to the implemented processes before expanding them to the entire company.

Once a successful trial run is accomplished, a plan for execution should be created, if it hasn't been already. The plan, at a minimum, should include education and training for employees and revisions to the standard operating procedures manual based on the new processes. If a standard operating procedures manual does not exist, then this would be a good time to create one. The execution of the plan will probably be the most difficult aspect of these changes and will require the greatest amount of pre-planning by management to make sure the implementation succeeds.

5.5 Recommendations for contractors

It is assumed that most project superintendents these days have a laptop or desktop computer in their project trailer. It is also assumed that most of them carry cell phones, with or without internet and e-mail access. Adding a PDA or tablet PC to the project superintendent's arsenal would replace their current IT tools, not add to it.

If the project superintendent requires read only access for project documents such as RFIs, meeting minutes, daily reports, change orders and other small size documents, then the smaller and more portable PDA or Smartphone may be the best solution for the company. These tools can also double as their standard cell phone and digital camera and have the ability to access the internet and e-mail.

However, if the project superintendent needs read only access similar to PDAs *and* is expected to provide data input, such as QA reviews, punch-list reviews, safety audits and schedule updates, and they also need to access project drawings and other large format documents, then the tablet PC would be the better option. The tablet PC can replace their current laptop or desktop computer and is also lightweight and portable enough to be brought onto the project site for site walks. In addition, the tablet PC can be mounted in a cradle in the trailer and connected to a keyboard to act like a desktop computer. Further, many new tablet PCs have built in digital cameras and mobile broadband accessibility, making this a great solution for many project superintendents. Finally, tablet PCs can run sophisticated project management software, unlike most PDAs and Smart phones.

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Real-Time Management in a BIM Model with RFID and Wireless Tags

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Abstract

Radio Frequency Identification (RFID) tags and wireless tags can be used to track objects or people within a defined physical space. A BIM model on the other hand is the digital definition of a physical space. The possibility of these two technologies emerging together for real-time management during construction is exciting. The hybrid model can be used to monitor the procurement of construction materials to the jobsite. The same model can also be used to manage the movement of materials and equipment once they arrive on the construction jobsite. This method of tracking can be used for monitoring the progress of construction as it happens and can ultimately have an impact on the schedule of the overall project. This technology can also be used to track construction personnel on a job-site. Such tracking can significantly change the way security on construction job-site is monitored. The technology required for merging RFID and wireless tags with a BIM model are explored. Existing technology for the creation of the hybrid model and past case studies are examined. Future uses of this technology and its impact on construction management are speculated.

Keywords: building information modelling, radio frequency identification technology, job-site monitoring

1. Introduction

The use of information technology applications in the architecture, engineering and construction (AEC) sector has been on the upswing for the past decade. The latest technology that is rapidly changing the landscape within the AEC sector is Building Information Modeling (BIM). This paper explores the possibility of combining radio frequency identification (RFID) technology with BIM and a few associated applications that might result due this combination. It is argued that the use of this combination of technologies can provide a safer work environment for the construction worker and also enable project managers to monitor the productivity of construction workers.

2. RFID technology

This section of the paper addresses the technologies available for implementing RFID in a business environment including a brief introduction to RFID technology is presented. An overview of BIM is also provided as this paper deals with combining BIM and RFID technologies.

2.1 Radio frequency identification Technology

RFID technology is employed to track objects, animals and people. The technology consists of an RFID tag that is attached to the object being tracked and a RFID reader that identifies the tag when it is within the range of the reader. An RFID tag transmits a signal through radio waves that in turn are received by an RFID reader. It is widely accepted that this technology will replace the use of Bar Codes for tracking purposes. Two types of RFID tags are available commercially. An active RFID tag shown in Figure 1 contains a battery and transmits a signal autonomously and may be tracked when it is within range of the reader. A passive tag does not have a battery but is activated when it is within range of the reader. The information collected by the reader in both cases may be kept in a database. This technology provides real-time information about the presence of an RFID tag within range of a reader and therefore any object or person it is attached to.



Figure 1: Active RFID tags (Cisco.com)

Academicians have explored the role of RFID tags in construction for some time now (E.J Jaselskis, T. El-Misalami, 2003). Studies done by D. Grau et. al (2009) have demonstrated the effectiveness of using RFID tags in tracking materials to improve productivity in construction. J. Song et. al (2006) have shown that the delivery of construction materials to the jobsite can be automated by the use of RFID tags. RFID tags have also been used to track tools on a construction site (A. Sattineni, G. Garrett, 2006). The case for real-time monitoring and its benefits to construction productivity have been made (R. Navon, 2005). RFID tags were used in Brisbane Tunnel construction project to monitor the safety of workers underground (D. Friedlos, 2008). RFID tags are also being proposed by C.H Ko (2009) to develop a building maintenance system.

2.2 Wi-Fi RFID tags

Another new technology that will play an important role in the use of RFID tags in the future is the Wi-Fi RFID tag. Active RFID tag requires the use of RFID specific infrastructure to read the signal transmitted called the RFID reader. The Wi-Fi RFID tag can be read by any 802.11b or 802.11g wireless access point device instead of a RFID reader. The Wi-Fi RFID tag connects to the wireless access point similar to a laptop computer. There exist two advantages of Wi-Fi RFID tags over active RFID tags. The first one is the range of distance a tag may be located to be picked-up by the reader is much higher with a wireless access point device. One disadvantage however is that technology will require additional methods such as checkpoint triggers for locating the tag within a confined space since wireless access devices have a much wider range than RFID tag. Checkpoint triggers are essentially the devices that can read a tag with a much smaller range. Another advantage is that expensive RFID tag readers are not required. This Wi-Fi tag shown in Figure 2 has been used in the healthcare industry for tracking patient movement within a hospital.



Figure 2: Wristband Wi-Fi RFID tag (ekahau.com)

2.3 Building information modeling

The National Building Information Model Standard (NBIMS) defines (Facility Information Council, 2007) a building information model as “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.” BIM technology improves the overall quality of design, provides better performing buildings requires fewer change orders during construction, allows the contractor to optimize the schedule and cost of the project and provides for efficient handover of the buildings to the operations and maintenance. In the United States BIMs are becoming more prevalent on the jobsite and being used to improve the overall process of construction (McGraw Hill Construction, 2008).

All indications from the AEC industries are that the use of BIM in construction will continue to increase and significantly modify the practice of designing, constructing and maintaining future buildings. An industry survey report published by McGraw Hill Construction (2008) indicates that the use of BIM among contractors alone in the US would increase by 18% in just one year. The report also indicates that over 50% of all responders were using BIM, evidence that the likelihood of future projects using BIM is very high.

3. Using RFID tags in a BIM model

RFID tags are tracked electronically and the information can be stored in a database to be used later. A typical RFID tag may be setup to be tracked at regular pre-set intervals such as 10 seconds or 1 second. Each RFID tag may be located by assessing the position of the last reader to track it. Regardless of the type of RFID reader and tag combination used some computing will be required to accurately assess the location of the tag within a pre-defined physical space. Once this information is obtained it may be translated into a CAD file or similar format so that it may imported into the BIM model.



Figure 3: Location Beacon to determine precise co-ordinates for a Wi-Fi Tag (ekahau.com)

In order to monitor the movement of people on a construction site, it would be more important to find the general location of a person rather than the precise co-ordinates. Hence the location of the tag readers can be pre-decided at the specific control points such as site entrance, elevators, stairwell entrances or any location deemed hazardous within the construction site. In the case of Wi-Fi RFID tags, additional location beacons shown in Figure 3 may be used to locate tags within a room or a pre-determined zone of the construction site.

A BIM model that is compliant with the Industry Foundation Classes (IFCs) inherently adheres to a common data model. Most BIM software allows an external file to be imported and overlaid on the BIM model as shown by the red symbols in Figure 4. The RFID data described above can be imported into the BIM model and displayed. The resulting model can be monitored by the construction project manager or superintendent to ascertain that construction workers are at the proper location. Some additional modules within the BIM model may be needed to set up automatic triggers to highlight workers that are in a restricted area.

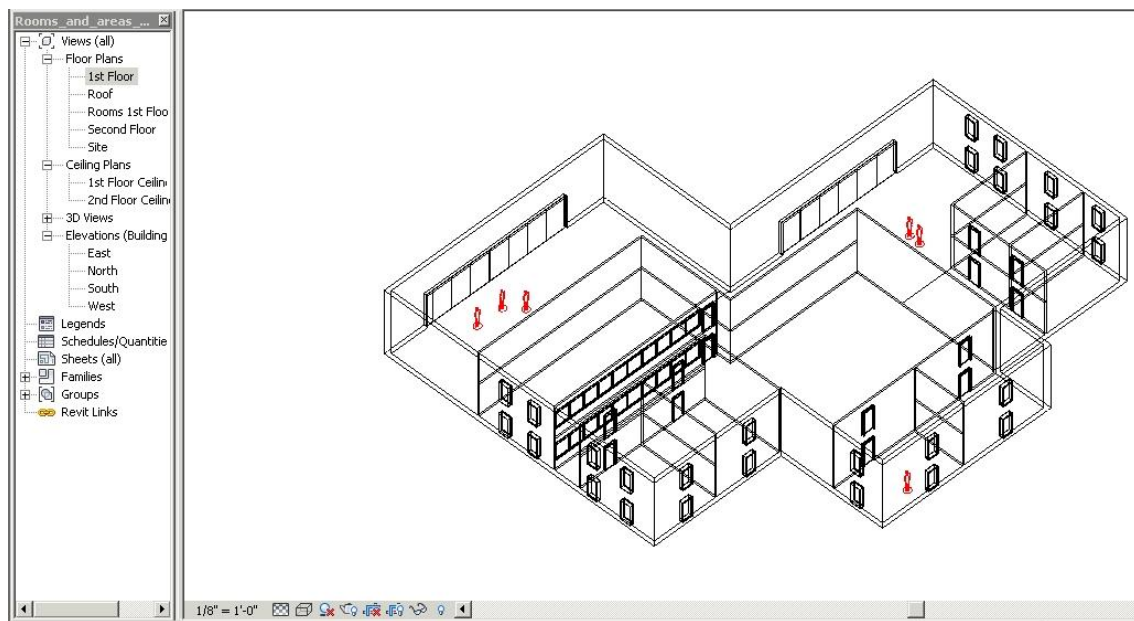


Figure 4: A possible screenshot of construction workers being tracked using RFID tags in 3-D view within a BIM model

3.1 Materials tracking in BIM model using RFID tags

RFID tags may be attached to building materials either by the manufacturer or upon arrival on the jobsite. RFID readers may be located on the job site near the material storage areas. By using this technology a project manager or site supervisor may keep track of the security of building materials stored. A simple spreadsheet may be setup to locate all the materials and send alert if any materials that are missing. This information could also be used to track the progress of work on the construction site. As an example if an RFID tagged steel beam is read by a reader in a location other than the material storage area then it might be deduced that the steel beam is being placed in its proper or perhaps even improper place. This method may be used from a remote location enabling a senior manager at the home-office to keep track of construction progress on the jobsite.

3.2 Construction worker safety supervision

It is globally accepted that safety risk to construction workers is very high. Over 2800 deaths have occurred in the U.K, over the past 25 years, as a result of construction activities (Health and Safety in Construction Industry, N.D). Accidents on construction sites are commonplace and tend to cause major havoc for the schedules and budgets of projects. Minimizing safety risk is an important concern for a construction company, regardless of its size. Studies done by S. Chae and T. Yoshida (2010) have shown that RFID tags may be used in preventing collisions between workers and heavy equipment in a construction environment. Another study done by W. Wu et al (2010) has demonstrated that near miss accidents can be studied in a construction environment using RFID technology.

Productivity of construction workers is directly related to the profitability of a construction project (Motwani et al, 1995). Supervision is an important aspect of measuring construction productivity. Incorporating RFID technology in a BIM model on construction site could alert the supervisor when a construction worker ventures outside the area where the work is being performed. The site supervisor may also use this information to direct construction workers to appropriate locations within a jobsite further improving productivity. As an example, the supervisor might ask the nearest construction workers at a specific location to tend to a material delivery truck that has just arrived on the construction site to minimize wait time. Studies done by Z. Riaz et. al (2006) demonstrate the lack of decline in safety accidents in construction and discuss how information and communication technology (ICT) may be used to reduce the accident rates. The technology proposed in this paper will use ICT to potentially minimize accidents in the construction industry. A proposed workflow for tracking construction workers through RFID technology in a BIM model is presented in Figure 5 below.

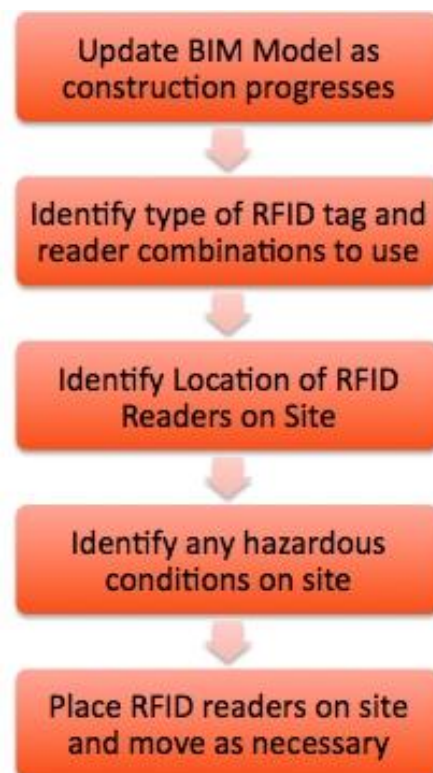


Figure 5: Proposed workflow to track construction workers in a BIM model using RFID Tags

Under extreme circumstances a construction site may have to be evacuated. This may occur during a fire drill, actual fire, controlled explosion and time of the day when the construction site is shut down after all workers are supposed to have left for the day. The approximate location of workers on the site in such circumstances may be detected by these RFID tags and appropriate action may be taken.

3.3 Privacy concerns for tracking construction workers

Anytime the movement of people is tracked, privacy concerns for the use of that information exist. These concerns must be addressed before the technology can be implemented. The tracking information must be used solely to monitor construction safety and productivity. The storage of the information must be limited to a few days only so that the data is not misused at a later time. It must be communicated to the construction workers that the proposed technology will enhance their safety provide for a better work environment.

4. Conclusions

Construction worker safety is an important issue on any jobsite. Accidents in the construction industry are both costly and dangerous to the workers. Also productivity of the construction workforce has a direct relationship to the profitability of the construction company. This paper has presented scenarios in which RFID technology can be used in a BIM to improve safety and productivity on a construction site. The use of RFID technology and BIM technology is gaining popularity. The application of each technology has been separately verified by its use in the industry and academicians. Indications are that these two technologies will continue to gain popularity in the industry. The accurate and real time combination of these two technologies would result in a 3-D model of a construction site that shows location of workers. Construction project managers and site superintendents may use this model to identify workers that are not at the proper location, which might result in either a loss of productivity or a potential safety hazard if not handled in a timely fashion. Construction materials may also be tracked on a jobsite in real-time using this combination of technologies. Several other applications of this combination of technologies may well exist but have not been addressed in this paper.

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Empirical Application of GPS Fleet Tracking Technology to a Soil Excavation Process

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Abstract

The unpredictable traffic condition around the construction site and individual operator's uneven productivity often make it difficult to identify an optimum number of hauling units. for a soil excavation process at once. The balance between hauling units for a soil excavation process, for example, has to be updated repetitively until it reaches an optimum stage. Speeding up this process is therefore expected to increase productivity especially at the beginning of the soil excavation process. One of the challenges in figuring out the optimum balance between hauling units, however, is to monitor the hauling units' operation accurately. This paper presents our investigation to figure out whether the real-time fleet tracking technology integrated with a stochastic construction simulation could facilitate the process of identifying the optimum number of hauling units for a soil excavation process.

Keywords: soil excavation, hauling unit, fleet tracking technology

1. Introduction

Developing the optimum combination of hauling units for a new construction project has never been easy because the unpredictable traffic condition around the job site and uneven individual operator's productivity make it difficult to reasonably presume the productivity of a certain combination of hauling units.

1.1 Difficulty in predicting the time for the hauling unit's round trip

The time required for a hauling unit to make a round trip is critical information in fleet planning for removing soils excavated from the job site. However, the speed of a hauling unit such as dump truck can be easily changed by the traffic condition on the route, and it has never been easy to predict how long it would take for a hauling unit to make a round trip. Developing a fleet combination for the soil-removing project in a foreign country is even harder because of more uncertain situation one has to bring in to consideration. For example, more international projects demand to use the local labours and it is not easy to figure out the productivity of the local operators at the early stage of project planning.

1.2 Difficulty in following up the hauling unit's operation in real time

Identification of the actual productivity of the fleet assigned to the project is critical for evaluating the goodness of the current fleet combination and making an adjustment. However, in many cases it has not been easy to figure out the hauling unit's operational pattern in real time and discover what is decreasing the productivity of the fleet.

1.3 Difficulty in planning an optimized hauling unit

It has never been clearly determined at the early stage of project planning how a certain construction fleet combination would produce in a foreign country. Construction professionals often have to increase the number of vehicles in a fleet by about 30% to manage unpredictable risk, which obviously would end up increasing the project cost.

2. Problem solving opportunity using Kaizen theory

Kaizen refers to a Japanese management strategy that demands constant and repetitive improvement in a process. It is a daily activity whose purpose goes beyond simple productivity improvement. It suggests professionals how to perform experiments to detect and eliminate waste in business processes. A PDCA (Plan-Do-Check-Act) cycle is one of the tools suggested to apply Kaizen to actual business processes. It is an iterative problem-solving process typically used in the auto industry. Activities implemented at each step are:

- **PLAN:** Establish the objectives and processes necessary to deliver results in accordance with the specifications.
- **DO:** Implement the processes.
- **CHECK:** Monitor and evaluate the processes and results against objectives and specifications and report the outcome.
- **ACT:** Apply actions to the outcome for necessary improvement. This means reviewing all steps (Plan, Do, Check, Act) and modifying the process to improve it before its next implementation.

Gray Construction in the U.S. demonstrated that the Kaizen strategy could also be applied to construction management (ENR March 5th, 2007). The Gray Construction's revenue was ranked 294th in the U.S. when the Kaizen strategy was applied to its management for the first time in 1986. Since then, Gray Construction has been growing to 126th among the U.S. construction firms with the revenue of \$350 million in 20 years to some extent due to its utilization of the Kaizen strategy. Jim Gray, CEO of Gray Construction, emphasized that the construction process is somewhat similar to the automobile assembly process and therefore the application of the Kaizen strategy could increase the productivity in the construction industry as it had done in the auto industry.

It is known that the Kaizen is more effective 1) when it is applied to a new project that no one has ever experienced, and 2) when there are repetitive components in the process. The process of removing soils from the excavation job site in a foreign country has these conditions and therefore it is reasonable to speculate that the Kaizen strategy might be working effectively for an overseas excavation project.

3. Tools for implementing the Kaizen strategy in construction

3.1 Stochastic simulation for optimizing the construction fleet combination

Stochastic simulation is a technology utilized to predict the productivity of a network of activities while handling uncertain conditions reasonably. The Construction Industry Institute (CII), a research consortium funded by major construction companies in the U.S., expected that 3D construction simulation technology based on stochastic probability would enable to develop a reasonable construction plan that minimizes the impact of unforeseen variables (CII 2001). FIATECH, another research consortium in the U.S. leading the efforts to best utilize emerging technologies for improving construction quality, presented lately that the construction simulation is one of the top 10 future technologies sought by many construction companies (Wood and Alvarez 2005). Texas A&M

University and other universities in the U.S. have reported the advantages of the stochastic simulation in construction planning (Kang, Ahn, and Nam 2007, Kang, Chae, and Park 2007).

3.2 GPS-based Real-Time fleet location identification technology

The city of New York expected that they might have to use about 250 dump trucks to remove the debris of the World Trade Centre attack. The city manager also expected that the removal of the debris from the WTC site would take well over a year, and cost nearly \$2 billion. At the early stage of the debris removal project, the city of New York figured out that the project was not moving as fast as expected because of the traffic jam in Manhattan. The project manager then suggested getting the GPS-based fleet tracking device mounted on trucks and monitoring their operation in real time in order to avoid the traffic jams and make sure the truck drivers were running on the right track. The outcome of this suggestion was exceeding their expectation (Becker 2007):

- The frequency of the truck's round trip increased from 5 to 10 times per shift.
- The total number of trucks used was reduced from 250 down to 50.
- The project was finished earlier than scheduled. They saved 4 month of time.
- The project cost was reduced from \$2 billion down to \$750 million.

4. Objective

The objective of the paper is to investigate whether the Kaizen strategy could facilitate construction professionals to better plan and control the soil excavation project in a foreign country.

5. Methods

5.1 Transportation network of soil excavation process

The first step was to develop a transportation network of the on-going soil excavation process. The research team decided to apply the Kaizen Theory to the excavation project that went on for the Sejong Special Autonomous City construction project in South Korea. The name of the city is a tribute to Sejong the Great, who commissioned Korean scholars to create the Korean alphabet (Hangul) that is used today. This city is located 160 km south of Seoul, the capital of South Korea.

The research team visited the job site and collected basic information such as traffic condition of the designated routes, capacity of various hauling units and excavators, variation of elapsed time required for the hauling unit's round trip, and so on. Figure 1 shows a typical job site configuration.



Figure 1: A typical job site configuration

With the data collected, the research team developed the transportation network shown in Figure 2.

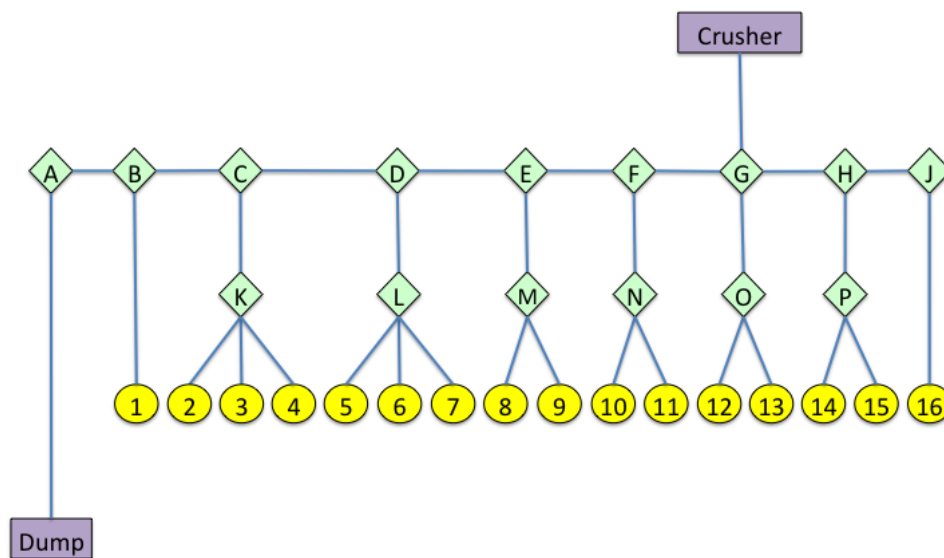


Figure 2: Transportation Network of Soil Excavation Process

5.2 Stochastic simulation model

The research team then developed a stochastic simulation model of the transportation network, which is presented in Figure 3. Arena Simulator, which is an off-the-shelf computer application specialized in stochastic simulation modelling, was used for this process. By implementing a series of sensitivity

analysis, the research team identified the optimum balance between different hauling units, loaders, and excavators.

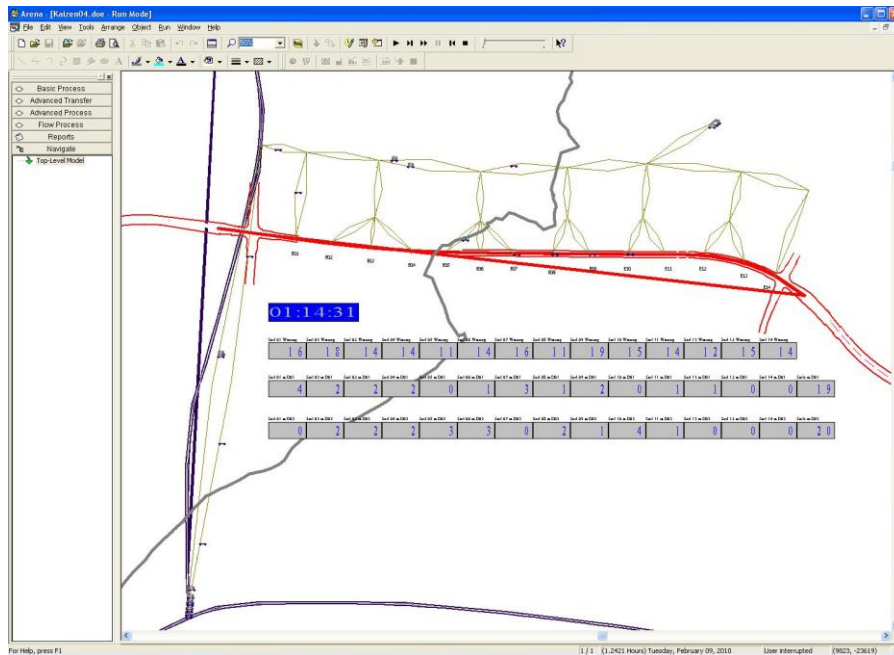


Figure 3: Snapshot of an ARENA simulation model

5.3 GPS fleet tracking system

As a next step, the research team developed a GPS fleet tracking system that can track down the locations of hauling units and display them on the Web browser in real time. The figure 4 shows the concept of our GPS fleet tracking system. The system is designed to identify the location of a truck using GPS, and transmit it to the Web-server over the wireless telephone communication. Figure 5 shows the snapshot of the Web-based Fleet Tracking system.

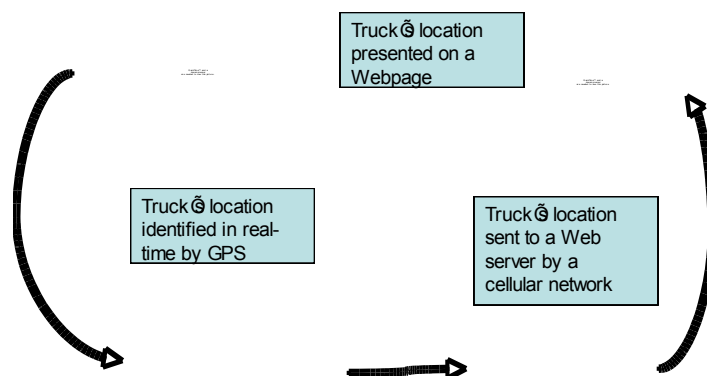


Figure 4: Concept of the fleet tracking system

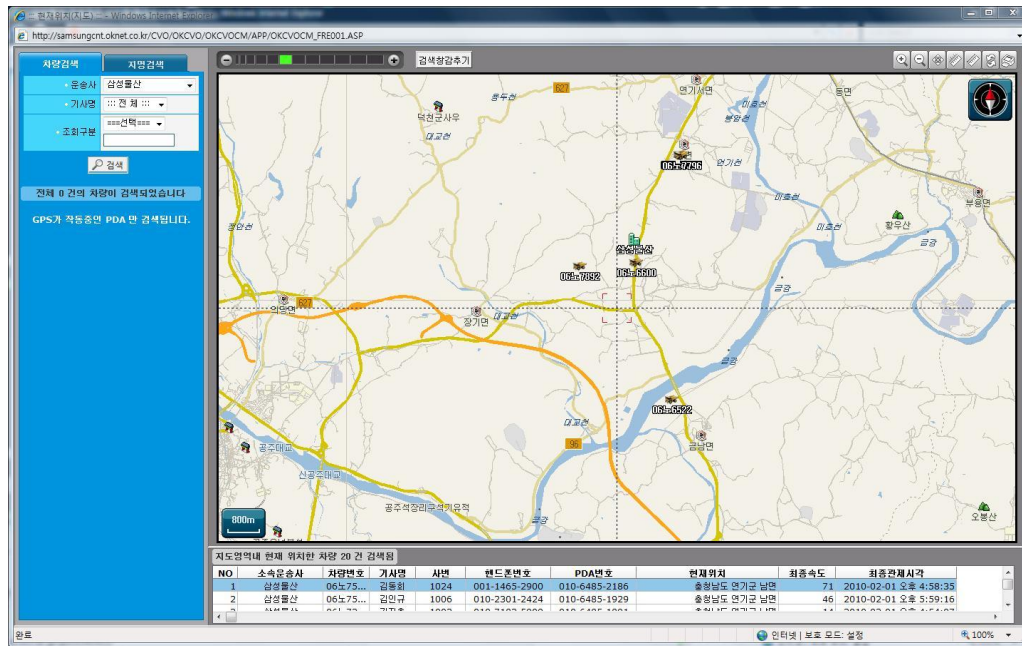


Figure 4: Web-based fleet tracking system showing the location of dump trucks

5.4 Application of Kaizen theory

The research team monitored the location of the hauling units in real time using the GPS fleet tracking system. The data collected here were compared with the outcome of the stochastic simulation model. The difference between the simulation model and actual hauling units' operation was used to come up with modified parameters for the stochastic simulation model. By running the updated simulation model, the research team determined a new combination of hauling units. This process iterated until the gap between the simulation model and fleet's actual performance was minimized.

6. Conclusion

The GPS location identification system presented in this paper demonstrated its potential in speeding up the process of getting the optimum balance between excavation equipments and hauling units identified. However, some equipment operators refused to get this system installed on their dump trucks because of the privacy issue. They did not want to get their location identified automatically in real time. Unless we demonstrate a tangible benefit of using the GPS location tracking system, it would not be easy to apply this technology to actual practices. The project contract type was an another challenge. Since the earth excavation and transportation work was outsourced to the subcontractors, the project team failed to find the dramatic benefit to the general contractors for applying the GPS system to their project. The research team learned that our system would work more effectively if it were applied to an overseas project, for which the general contractors need to purchase and operate construction equipments by themselves. This is an on-going project, and project participants are currently interviewed to figure out pros and cons of the GPS fleet tracking system.

Acknowledgement

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A Synopsis of the Handbook of Research on Building Information Modelling

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Abstract

Today, Building Information Modelling (BIM) is promising to be the facilitator of integration, interoperability and collaboration for the future of the AEC industry. The mission of the recent Handbook of Research in Building Information Modelling is determined as providing an up-to-date comprehensive and collective perspective of both the latest leading-edge research along with the current understanding and practice in the area of Building Information Modelling within the global construction industry. The *Handbook* consists 28 chapters authored by 50 leading experts in the area and was published in December 2009 by IGI Global. This paper aims to provide a synopsis of the *Handbook*, and discuss the emerging research and industry-related issues for Building Information Modeling from the perspective of the contributors to the *Handbook*.

Keywords: BIM, building information modelling, handbook

1. Introduction

The AEC industry has in many ways changed very little over the last 100 years. The contracts or rules by which the industry engages have their roots firmly in Victorian processes. The traditional nature of the industry involves bringing together multi-disciplines/practitioners to deliver, in many instances, complex one-off products requiring a tremendous amount of coordination. In addition, high levels of competition and low levels/barriers to market entry exist. The tools to manage and develop the design process have until the last decade been very much focused on automating 2 dimensional drawing board techniques. Recent developments have seen emerging technologies focused on web based collaboration systems and 3D object based tools. In fact, the barriers to efficient collaboration and exchange of information still exist in the industry. More recently Building Information Modelling (BIM) has become a very active research area in order to address the problems related to the inefficient sharing of information and collaboration throughout the lifecycle of a building (i.e. from feasibility and conceptual design through to demolition and re-cycling stages). When the term Building Information Modelling (BIM) was coined in the late 1990s a path of destiny for users of digital building models in the AEC industry began to emerge, leaving the AEC industry with many questions to be answered such as:

- Were we not actually Modelling the ‘Building Information’ in the 2D CAD era, before the term ‘Building Information Modelling/BIM’ was brought to our attention?
- When working on BIM, are we trying to establish a standard shared digital building model, a new collaborative methodology for managing projects, or are we chasing to achieve a paradigm shift for the traditional processes of the industry?
- Will BIM help us to transform the production processes in a form that is leaner, greener, and where industrial functions can be digitally managed or will it only cause us (the users/stakeholders of BIM) becoming ‘LOST’ between the complexity of real life industry processes and modelling phenomena of the AEC universe?

Such questions have motivated both the academic community and industry in a hopeful search to understand BIM, from its roots to its functions, from its capabilities to its possibilities. In the late 1990s, BIM was prescribed as a remedy for the illness of ‘Data Interoperability’ in AEC industry. However, it is now apparent that this ‘*magic remedy*’ has evolved to cure much more ‘*illnesses*’ than it was originally prescribed for.

Today an implementation of the BIM paradigm is achieved by using several applications supporting BIM and the use of agreed schema standards such as IFC. Most well known AEC applications are capable of importing and exporting their internal models as IFCs, and few of them are also capable of acquiring information from an IFC model through the use of a shared resource such as a model server database. BIM is applied in many different areas and on different levels, e.g. either BIMs used as a resource to enable interoperability or Building Information Modelling has been realised as a process of managing a project through a single shared information backbone. Recent research in the area demonstrated how 4 to N dimensional simulation applications can be facilitated using BIMs (Rebolj

et al., 2010; Spearpoint, 2010). Countries such as Singapore use BIMs to validate that building models are compliant with code and regulations. Research has also demonstrated that Building Information Modelling can facilitate the design of energy efficient buildings towards addressing sustainability and reduction in CO2 emissions issues (Solis and Mutis, 2010; Bee Hua, 2010).

2. Building information modelling and integrated project delivery

As mentioned earlier, the AEC industry is highly fragmented and thus integrated ways of working has always been an apparent need for the industry. The Integrated Project Delivery (IPD) approach, which recently emerged in the US, reflects the perspective on the future of project life-cycle management and project delivery (IPD Working Definition, 2007). IPD encourages early contribution of knowledge and experience and requires proactive involvement of key participants in the earlier stages of the projects. BIM is regarded as essential in efficiently achieving the collaboration required for IPD. Input from the broader integrated team coupled with BIM tools to model and simulate the project enable the design to be brought to a higher level of completion before the documentation phase commences. Thus, the project is defined and coordinated to a much higher level prior to the start of construction, enabling more efficient construction and a shorter construction period. From an Integrated Project perspective BIM can be defined as:

“the information management process throughout the lifecycle of a building (from conception to demolition) which mainly focuses on enabling and facilitating the integrated way of project flow and delivery, by the collaborative use of semantically rich 3D digital building models in all stages of the project and building lifecycle”

The BIM process is unique as it is based on digital, shared, integrated and interoperable Building Information Models. From that perspective, BIM can be defined as the process and facility that enables information management throughout the lifecycle of a building, while a Building Information Model is:

“the (set of) semantically rich shared 3D digital building model(s) that form(s) the backbone of the Building Information Modelling process”

Although BIM is the key enabler of the IPD process, BIM goes beyond the management of information in the IPD process in that the process concludes with the closeout stage following construction, while the BIM process continues even beyond the demolition (disposition) stage, i.e. as a process of knowledge management providing input to future projects.

3. Handbook of research on building information modelling and construction informatics

The *Handbook of Research on Building Information Modelling and Construction Informatics: Concepts and Technologies* was recently published to focus on providing an up-to-date comprehensive and collective perspective of both the latest leading-edge research along with the

current understanding and practice in the area of BIM and Construction Informatics within the global construction industry. The overall objectives of the handbook were to:

- Provide a unique comprehensive and collective perspective of BIM to-date along with the opportunity to initiate the debate towards an agreed definition.
- Bring together the current collective body of knowledge of academic research with that of industry understanding and practice in order to provide a holistic picture of Building Information Modelling within the industry.
- Provide contrasting and comparative perspectives on the latest leading-edge research from academia with the understanding and practice of both the AEC and other related knowledge domains.
- Provide a future reflection of the direction for BIM in identifying the barriers and addressing their resolve.

In order to meet these objectives the editors chose to select as many diverse perspectives as possible. The *Handbook* brought together a broad field of experts from a variety of domains of the AEC and ICT industries including civil and mechanical engineering, architecture, computer science, software engineering, geographical information science, urban planning and management, and surveying.

4. BIM research compass

In addition to its well recognised role in facilitating the design phase of the project life-cycle, we propose that depending on the environment in which they are used, Building Information Models can have different functions such as being a *Space Linker* that links macro and micro urban spaces, an *Interoperability Enabler* which facilitates information sharing between various stakeholders and the software applications they use, a *Data Store* which stores the building information throughout the lifecycle of a building, a *Procurement Facilitator* that facilitates several procurement related tasks in the building lifecycle, a *Collaboration Supporter* through enabling the use and management of shared building information in real-time, a *Process Simulator* by facilitating the simulation of construction processes (i.e. nD), a *System Integrator* which enables the integration of several information systems across the industry, a *Building Information Service* which can serve real-time on-demand building information over the Internet, a *Green Builder* that enables advanced analysis supporting the design and construction of environment friendly/energy efficient buildings, and a *Life Saver* which facilitates emergency response operations.

The 28 chapters of *The Handbook of Research on Building Information Modelling and Construction Informatics: Concepts and Technologies* have motivated the authors in defining a research compass for BIM (Figure 1). The research compass provides the current research directions for BIM derived from the perspective of the chapters in the Handbook.

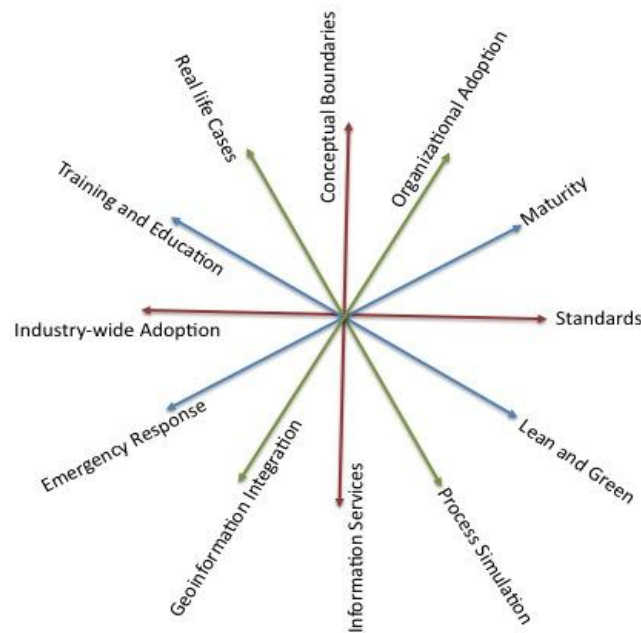


Figure 1: BIM Research Compass

4.1 Direction 1: Conceptual boundaries

The first research direction for BIM appeared as determining the conceptual boundaries of BIM mainly from the information modelling perspective. BIMs have mainly emerged in the form of schema standards for information exchange, i.e. as enablers of data level interoperability. In fact, there are numerous questions to be addressed while drawing the conceptual boundaries of BIMs. As mentioned in Van Nederveen (2010), the key questions to begin with are “What is Building Information Modelling? and What is a Building Information Model?”, while at the same time we need to have clear objectives for BIM. A clarification between (a) what is being modelled such as requirements, function, boundary conditions, building configuration, connectivity, shape, processes lifecycle aspects and discipline views, and (b) how these can be modelled, such as through parametric models, part libraries, nD models, various representations and presentations, including visualisations is a functional requirement for justification of the models and the modelling process. The research in the area should also focus on enhancing the methods and languages for information modelling and reasoning based approaches to BIM.

4.2 Direction 2: Adoption

The implementation of product modelling approaches and Building Information Models has been a subject of research for nearly 20 years in the AEC industry. In fact, the low interest and investment

on ICT and the lack of strategic perspective on the use and implementation of ICT has prevented the successful adoption of collaborative systems and interoperable information models within the industry. Furthermore, the move from CAD based thinking to the vision of BIM is much more difficult as it involves the shift in fundamental data management philosophy. As indicated by Bew and Underwood (2010), in a similar manner to the move from old accounting packages to Enterprise Resource Planning (ERP), this transformation includes the formal management of processes on a consistent, repeatable basis. Like the ERP implementation, this too is a very difficult transition to make. The lack of mature process management tools and methodologies for the projects has made this transition more confusing. The construction industry's approach to contracts, training and education also need attention if it is to deliver this operating model and approach. BIM adoption most likely occurs in phases (i.e. in an almost Darwinian evolutionary way), but serious effort should be taken to move from one phase into another. As indicated by the authors, in the evolutionary approach to implementing BIM, organisations must be realistic as to their current capability and progress through the evolution.

4.3 Direction 3: Maturity

A key area in BIM is organisational readiness which plays a significant role in the absorption and diffusion of ICT within enterprises. The level of absorption and diffusion affects the rate of success in ICT implementations and their industrial uptake. If BIM is considered as a set of new technology and methodologies supporting information management in the AEC industry, then maturity in terms of implementing and using BIM (technology and methodologies) is critical to the success of a BIM implementation. Frameworks for measuring BIM maturity can greatly facilitate organisations in positioning themselves against their competitors in terms of technological, methodological, and process maturity. Such a maturity framework is explained in Succar (2010) where a five-level BIM-specific maturity index is developed to measure the BIM maturity of organisations.

4.4 Direction 4: Standardisation

The information modelling dimension of BIM is heavily dependent on standards. Early building product models made use of native ISO 10303 tools and methods to represent building information. Similarly, the BIM standard of today, IFC, is still making use of the geometric model (Part-42) of ISO 10303 in representing building elements, and methods of information sharing and exchange as defined in ISO 10303. As standardisation is a key enabler and facilitator of data level interoperability, this area will continue to be a focus of BIM research. For example, Dado et al. (2010) provides an extensive review of the historical background of the product modelling in AEC industry. After this historical overview, an overview of the characteristics of interesting conceptual product approaches such as Standardisation, Minimal Model, Core Model, NOT, Vocabulary and Ontology Product Modelling is presented. In recent years the US has taken the initiative for developing nationwide BIM standards which covers more than representation and exchange of information (Suermann and Issa, 2010). This can be regarded as a comprehensive approach to developing BIM standardisation, and such approaches can help in formalising the information exchanges, the processes and workflows.

4.5 Direction 5: Lean and green

In recent years the construction industry has begun to adopt lean production principles that have been applied in the manufacturing industries. This approach to construction management is known as Lean Construction. As also overviewed by Solis and Muits (2010), the aim of Lean Construction is to enable continuous improvement of all construction processes in the building lifecycle (starting from design through the demolition of the building). Process improvement is carried out in order to maximise the value in construction (i.e. building production) and minimise the cost of the production. On the other hand, to address global concerns on environmental issues, the construction industry now has to take the initiative to build more 'environment-friendly' buildings, along with reducing its own carbon footprint such as during the construction stage. The use of shared building models together with collaborative environments (i.e. BIM methods) during design and construction process can naturally contribute to leaner and greener construction through eliminating the need for travelling to project meetings and site controls, while the use of intelligent BIMs for design optimisation (i.e. in CO2 emission analysis, etc.) would play a role in the design and operation of environmentally-friendly buildings. Finally, in terms of leaner construction the IPD approach covers a lot of process changes/improvements and information management over shared digital models which in turn will help in the process changes required by IPD.

4.6 Direction 6: Process simulation and monitoring

Construction process simulation has been facilitated through visualisation for over 10 years. The approach that involves the visual simulation of construction processes is known as 4D CAD. The efforts in the area of 4D CAD are making much use of 3D CAD models, and in recent years BIMs have been superseding 3D CAD models in the visual simulation of construction processes. Analysis such as clash detection can now be completed using BIM software. BIMs are also used in monitoring the construction progress and as Rebolj et al. (2010) describes, activity progress can be monitored directly by using a combination of data collection methods, which are based on the BIM, especially on the 4D model of the building.

4.7 Direction 7: Building Information Services (BIS)

A current trend in the software industry is towards enabling interoperability over web services. In fact the AEC industry is still not fully benefiting from the service oriented approaches as the focus of our industry is still very data integration-oriented. As indicated in the recent Construction Informatics roadmaps (e.g. ROADCON, 2003; Strat-CON, 2007), BIM-based web services will be the catalysts of information integration and interoperability in the foreseeable future. The use of BIM Servers is now increasing with open-source implementations such as BIMServer (BIMServer, 2010). In the *Handbook*, London et al. (2010) explain a framework developed to facilitate multi disciplinary collaborative BIM adoption through the informed selection of a project specific BIM approach and model servers. The framework consists of four inter related key elements including a strategic purpose and scoping matrix, work process mapping, technical requirements for BIM tools and model servers, and framework implementation guide. The authors concluded that the future BIM approaches

would require the shared models in model servers to be linked with external systems in a heterogeneous environment.

4.8 Direction 8: Building and Geo-information integration

As mentioned by Peters (2010), there is significant value in integrating BIM and Geospatial Information Systems into a single system. The differences between CAD applications and Geo-information systems have generated barriers of integration of different representations of buildings in AEC and urban models. Van Oosterom et al. (2006) and Isikdag and Zlatanova (2008) draws attention to the need of integrated geometric models and harmonised semantics between two domains in order to tackle the interoperability problems between the AEC and Geo-information domains. In the *Handbook* Song et al. (2010) reviews the benefit of integrating BIM with the urban scale contextual data. Moreover, it is also explained that a range of stakeholders such as building contractors, estate agents, city management, and public sector etc. will benefit from the integration of BIM and (3D) GIS. Wang and Hamilton (2010) provide information on the design and development of the integration framework of BIM and geospatial information by – Building Feature Service (BFS) - a service defined to retrieve building information similar to OGC web services (used for retrieving geospatial information). As mentioned by Borrmann and Rank (2010), support for semantic queries in BIMs enables the users to extract partial spatial models from a full building model. This type of queries will also facilitate the integration of BIM and Geo-information models. As indicated by Paul (2010), connectivity relations in BIMs also have significant importance in terms of correct mathematical representation of the building. If these relations can be structured correctly the transformation of information between BIMs to Geo-information models can easily be validated.

4.9 Direction 9: Emergency response

Following on from the theme of the last section, emergency response operations indoors, require a high amount of geometric, semantic and state information related to the building elements. Until very recently Egress Models used in building evacuation has mainly been based on 2D floor plans. This situation is now about to change as the required level and amount of information can now be transferred from BIMs. In addition, BIMs are now used in fire simulations. In the *Handbook* Spearpoint (2010) considers how the IFC building information model can be used to transfer building geometry and property data to fire simulation models and suggests improvements to the IFC model with respect the needs of fire engineering.

4.10 Direction 10: Industry-wide adoption

In addition to the adoption research direction, Industry-wide Adoption takes the bigger industry wide picture into account considering BIM adoption. In terms of the focus of studies on industry-wide adoption then this is very much towards the positioning of BIM adoption across disciplines in relation to their current status and future expectations and based on such factors as the tools, people and processes. These studies (e.g. Gerrard et al., 2010) provide a bird's eye view of the industrial

adoption picture. The efforts on measuring the extent to which BIM has been implemented nationwide provides an indication of the industrial uptake of BIM, which can be used to position the BIM maturity of organisations in the context of their national BIM adoption level. This positioning is important as the adoption level is affected from the environment that the organisations operate in. As covered in the *Handbook* barriers impeding the implementation of BIM widely across the industry are also identified by these studies.

4.11 Direction 11: Education and training

As most of the readers of the *Handbook* would agree Education and Training is *sine qua non* for the successful BIM implementation and adoption in addressing such issues/barriers as culture, etc. As mentioned in Tanyer (2010) and is apparent in the IPD efforts in US, AEC professionals are beginning to move away from the traditional way of design and project delivery towards a more integrated one. The academic efforts in support of IPD are clustered around the development of undergraduate/postgraduate courses on the theoretical and practical principles of integrated design, where students deliver a design project collaboratively by exchanging information between various applications. Project-based collaborative learning environments such as in Stanford University (PBLLab, 2007), and e-learning environments such as ITC-Euromaster (2009) will also facilitate (and be facilitated by) the use of BIM and collaborative design approaches.

4.12 Direction 12: Real-life cases

BIM is not a subject of a pure (laboratory type) research anymore. This has significantly evolved over the last few years with the implementation of BIM methods and shared digital models in real-life projects increasing exponentially. The final chapters in the *Handbook* provide a sampling of the many ongoing BIM facilitated projects around the globe. For example, as explained by Lostuvali et al.. (2010) the principles of Lean Production and BIM technologies offer new opportunities to improve the quality, cost, schedule, and productivity in a highly fragmented multi-disciplinary sector. The case study presented by the authors in Underwood and Isikdag (2010) provides an overview of the synergy between the principles and tools of Lean Project Delivery Systems with BIM technologies in a large-scale hospital project. Although we have observed more implementations of BIM in North America and Australia in recent years, the efforts on the implementation of BIM in Asia (e.g. Hong Kong, Singapore, etc.) are also noteworthy. As noted by Riese (2010) in the implementations of BIM tools and methods in design and construction of large facilities in Hong Kong, it is observed that complex three dimensional design and construction information databases can be aggregated and managed collaboratively over the Internet by large project teams working remotely from each other. The improved quality of design and construction information that is being produced is making it possible to deliver better quality buildings. By reducing abortive works on site, buildings can be delivered on time and with reduced post construction claims and penalties.

5. Conclusion

BIM aims to resolve the problems related to sharing of information and collaboration throughout the whole lifecycle of a building. In fact, the current implementations of BIM contribute to the automation of various processes mainly during the pre-construction stages of the building lifecycle. However, it is also being used in monitoring and validating the processes during the construction stage and its potential in facilitating the post-construction stages, which offers a great opportunity, is slowly being discovered. Today, the optimistic view of BIM argues that BIM will change the construction processes in a way that will cause a paradigm shift in the overall construction process. In fact, as editors of the *Handbook* we approach this optimistic view deliberately as the paradigm shift in the overall construction process can not only be achieved by i) more efficient information management, ii) process automation (i.e. functionalities promised by BIM) and iii) better collaboration.

The industry can only move towards a real paradigm shift as off-site manufacturing becomes more common and production processes become leaner and more value-oriented. By off-site manufacturing and design processes becoming leaner and value-oriented as much as other key production industries (with support by IPD and BIM approaches), this might eventually force a real paradigm shift in the construction sector, which in turn would be the move from design-produce/build to produce-design-assemble type of construction. During this paradigm transformation the role of BIM will be increasing the level of seamlessness in automation of processes and augmenting the value of shared information.

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A Comparative Analysis of the Strategic Role of ICT in the UK and Turkish Construction Industries

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Abstract

ICT has now become a strategic asset for any organisation and the importance of IT-based innovation is recognised in bringing productivity improvements and sustainable competitive advantage to industry. The construction industry is one of the largest contributors of wealth creation to Europe's business economy. However, ICT investment has been inward looking with predominantly pockets of improvements, mainly focused on technical operations, that have failed to bring about sustainable competitive advantage to organisations despite of the significant investments over the past decade. A recent effort into the strategic positioning of ICT in construction in the UK aimed to assess the state of strategic thinking towards ICT investment for continuous improvement and sustained competitive advantage. The objective included understanding the evolving use and uptake of IT, identifying the shift in executives thinking, determining the disparities in IT awareness throughout the supply chain and identifying future patterns in creating business core capabilities based on IT. A similarly concurrent study conducted in Turkey investigated whether the Turkish construction industry views ICT as a strategic resource. The study investigated a number of areas including the role of ICT strategy within the organisation, drivers for investments in ICT, and the barriers to the successful implementation of ICT within the organisation. This paper aims to provide a comparative analysis of the results from these two studies conducted concurrently in different countries, both of which have well developed construction sectors, in relation to exploring the similarities and disparities along with the reasoning in the current strategic focus of ICT of organisations conducting business in the UK and Turkish construction sectors.

Keywords: ICT, strategic value, construction industry, strategy, investment

1. Introduction

In the 21st century ICT has now become a strategic asset for any organisation to deliver business improvement/value and achieve sustainable competitive advantage. Moreover, ICT innovations are increasingly having important implications beyond business to socioeconomic development due to their role in introducing and diffusing the concepts of knowledge sharing, community development and through the promotion of equality. The importance of ICT based innovation in bringing productivity improvements and competitive advantage to industry is highlighted in a recent European task force study on ICT sector competitiveness and uptake (European Commission, 2006). While a constant decline in labour productivity since the mid-90s (partly attributed to the lack of ICT related investment), it is evident that the higher productivity growth rates observed in the US and Europe's other world trade partners result from greater use/integration of ICT by all segments of the economy. However, it should also be acknowledged that industries have not been in a position to capitalise on the investment in terms of productivity growth (OECD, 2003).

From the perspective of the construction industry, it is one of the largest contributors of wealth creation to Europe's business economy, accounting for 9.7% of gross domestic product (GDP) and almost 60% of gross fixed capital formation (European Commission, 2006). The industry is an extremely information-intensive and knowledge-based industry, and therefore construction organisations need to fully embrace ICT if they are to remain competitive (BERR, 2008). Despite the industry having embraced ICT, particularly over last decade, investment is still inward looking with predominantly pockets of improvements that have failed to bring about sustainable competitive advantage to organisations in spite of the significant investments over the past decade. For example, Salah (2003) showed that 75% of ICT investments in construction did not meet their business objectives. Furthermore, evidence shows projects are abandoned, significantly redirected or kept alive despite business integration failure. According to Sessions (2009), the annual cost of ICT failure Worldwide is around USD 6.18 trillion when taking into account not only the direct costs of the investment itself but also the indirect costs associated with lost opportunities. Moreover, this is continuing to get worse as identified by the 2009 US Budget (2009) where the failure rate within the US is increasing at the rate of around 15% per year. These significant failures and missed opportunities directly cost businesses and have led to the dissolution in the strategic benefits of ICT resulting in decreasing levels of future investment in ICT (Goulding & Alshawi, 2004; Peppard & Ward, 2004; Zuhairi & Alshawi, 2004). This is further fuelled by a misalignment in the understanding of the strategic value of ICT to the organisation that exists between business executives and ICT personnel. On the one hand, business executives do not fully recognise the functionality and full value of ICT to the business, while on the other ICT personnel do not possess an understanding of the business and its strategic objectives (Basu and Jarnagin, 2008). In many cases, ICT is still considered by the management of organisations as purely a cost cutting tool or a utility that is owned and managed by their ICT departments. This technology push approach alone, which to some extent is still dominating many industries like construction and engineering, is not harnessing the full business potential of ICT and therefore is unable to lead to sustainable competitive advantage. While the implementation of a few

advanced IT applications (mainly technology-driven solutions) have brought about ‘first comer’ advantage to an organisation, this approach has not led to strategic benefit for the organisation towards achieving sustainable competitive advantage. Historically, the development and implementation of ICT has either not formed part of an overall ICT strategy or where an ICT strategy exists, this has not aligned to the strategic objectives of the business. Therefore, to facilitate sustainable competitive advantage, in the first instance emphasis has to be on establishing strategic policies for ICT investment that are formulated to align with the business strategy thereby leading to more business-driven ICT strategies.

Two separate studies were recently conducted concurrently in the UK (Alshawhi, et al. 2008) and Turkey (Isikdag, et al. 2009), both of which have well developed construction sectors, which focused on exploring the strategic thinking towards ICT within their respective sectors. This paper aims to provide a comparative analysis of the results from these studies in relation to exploring the similarities, disparities and the reasoning in the strategic focus of ICT of organisations conducting business in the UK and Turkish construction sectors.

2. Research designs and approaches

Within the UK the study was focused on identifying the current gaps in the industry’s core decision makers’ understanding of the needs for change and successful implementation of IT in organisations, i.e. the study aimed to “Assess the state of executive thinking towards IT investment for continuous improvement and competitive advantage”. The objectives were to:

1. Understand the evolving use and uptake of IT in relation to the industry’s past and current understanding of the value of IT to innovation and continuous improvement.
2. Identify the shift in executives’ thinking in terms of:
 - understanding the role of IT for improving performance;
 - the impact of continuous innovation in technology on their enterprises;
 - their awareness on the relationship between IT, process management and people;
 - identify the difference in understanding of IT priorities between business executives and IT/innovation directors.
3. Determine disparities in IT awareness between contractors and consultants.
4. Identify future patterns in creating IT-based business core capabilities.

The study was conducted through a survey questionnaire consisting of 11 questions that was designed to assess the awareness and understanding of key industry investment decision makers on the strategic benefits that IT could bring to their organisation. In this respect, the questionnaire construct was based on the relationship of decisions to critical elements (IS/IT Strategies; Business Process Management and Reengineering, and IS/IT Skills), and drivers (E-Readiness of organisations; Advanced Technology, and Financial Impact) which were considered important issues for further investigation. Each question was designed to have five options that described the evolution through maturity levels using maturity concepts (Salah and Alshawi, 2005; Alshawi, 2007) and portrayed in a “scenario like” style to make it relevant to Chief Executives and IT Directors. Furthermore, each question referred to three scenarios of how respondents saw the answer to the question in 1995 (based on their experience) and under their current practices (2007 practice), and how they wished to see the best answer (potentially indicative of future trends). This design construct was used to help assess the progressive development of organisations, while at the same time being able to identify the gaps between the thinking of executives (awareness level), moreover, what was actually being practiced.

The survey was sent to the top 100 most influential contracting organisations and top 100 consultant organisations in the UK, targeting both Chief Executives and IT (or Innovation) Directors. A total of 109 responses were received (57 Contractors, 52 Consultants) which included 37% from Chief Executives and 63% from IT/Innovation Directors. Further disaggregation identified that around 20% were from Contractor Chief Executives, 32% by Contractor IT/Innovation Directors, 31% by Consultant IT/Innovation Directors and the remaining 17% were Consultant Chief Executives.

In terms of the Turkish study, the overarching aim of the study was to explore the perceptions of the Turkish construction industry in relation to the strategic importance of ICT. The approach adopted for this study was semi-structured interviews which were conducted with 21 major contracting and consulting organisations in the Turkish AEC industry in light of a questionnaire. The questionnaire was formulated consisting of 19 questions based on a literature review in the area of the role of ICT in the AEC industry and the studies on evaluating the usage and benefits of ICT for AEC organisations.

The first group of questions was concerned with investigating the role of ICT strategy in the organisation, while the following set explored the drivers behind their ICT investments. Further questions focused on the role of ICT in recruitment, structure of ICT departments, barriers and facilitating factors for the successful implementation and management of ICT in the organisation. Finally, the role of ICT through the various phases of the construction lifecycle was explored.

The semi-structured interviews were conducted generally with ICT managers by visiting each of the organisations. Each interview started with an informal introduction to the research before exploring the aspects based on the questionnaire by two interviewers. The interview results were cross-checked by the interviewers and a copy of a completed questionnaire was reviewed by the interviewers and the interviewee in order to validate the answers given by the interviewee.

The following sections provide a comparative analysis of the main findings from these studies by exploring both the similarities and disparities between the two country's construction sectors in relation to the keys aspects of the strategic value of ICT, ICT strategy, ICT investment, and the drivers and inhibitors to delivering strategic value through ICT investment (Table 1). A cognitive analysis approach was adopted in order to map the key findings of the two studies and identify the relationships between them.

3. Strategic value of ICT

The key findings from both studies provide a positive picture in terms of a clear recognition in both industries towards the strategic value of ICT to deliver competitive advantage. In terms of the UK evidence indicates that the industry is fully aware of the strategic benefits of ICT across the organisation rather than to individual department or project which is reflected in the Turkish industry where ICT is viewed as both value adding and critical to the business. However, what is also evident is that this has not yet been attained in either of the industries which will be further explored through the following sections. Both sectors seem to take a rather conservative approach to their investments which are potentially a result of not being in a position to take risks.

4. ICT strategy

When looking into ICT strategy then the importance of aligning ICT and business strategies is well acknowledged by both industries towards delivering value from ICT and this is further evident in that the findings from both studies identify that ICT strategy should significantly contribute towards achieving the (strategic) business objectives. However, although both industries are aware of the importance of aligning ICT and business strategies on delivering competitive advantage, these are not currently well-practiced in either industry. Within the UK industry there has been a shift towards ICT strategies slowly beginning to be integrated into business strategies, while in contrast, ICT strategies within the Turkish sector are being formulated with a focus on the corporate business objectives albeit not integrated. Furthermore, well formulated and documented ICT strategies do not appear to be widespread across the Turkish industry.

In terms of strategy setting and the role of ICT departments in the process, it is evident that the role of IT departments has been transformed from providing technical support to engaging in business improvement and strategy within the UK industry. Furthermore, ICT Directors within the UK appear to be driving for Board representation although there is still some perception (although minor) that ICT departments have no role to play within their organisation in relation to strategy setting. From the Turkish industry's perspective, the situation would appear worse in that there is almost a split between those ICT departments still only responsible for the provision of technical support and those also involved in strategy development. Those ICT departments responsible for strategy setting are in the main central/core ICT departments engaged in formulating ICT strategy to align with operational needs informed through input from the various departments within the organisation.

Table 1: Comparison of the Strategic Role of ICT in the UK and Turkish Construction Sectors

	Commonalities to Both Sectors	UK Sector Specific	Turkish Sector Specific
Strategic Value of ICT	- Recognise strategic value of ICT to deliver competitive advantage. - Not yet attained.	Aware of strategic benefits of ICT across the organisation rather than to individual department or project.	ICT is viewed as both value adding and critical to the business.
ICT Strategy			
<i>Aligning ICT and business strategies</i>	- Acknowledge importance. - Recognition in ICT strategy significantly contributing towards achieving business objectives. - Currently not well-practiced.	- Shift towards ICT strategies slowly beginning to be integrated into business strategies. - Conservative approach to investments.	- ICT strategies are being formulated with a focus on the corporate business objectives albeit not integrated. - Well formulated and documented ICT strategies not widespread. - Conservative approach to investments.
<i>Strategy setting</i>		- IT departments transformed from providing technical support to engaging in business improvement and strategy. - ICT Directors driving for Board representation.	- Almost split between ICT departments still only responsible for the provision of technical support and those also involved in strategy development. - ICT departments responsible for strategy setting are central/core departments engaged in formulating ICT strategy to align with operational needs.
ICT Investment			
<i>Investment</i>		- Moved away from investing to reduce costs at an operational level towards the organisation. - Focus moved to products and services from both an internal and external perspective.	- Focus on the cost reduction of and adding value to processes. - Emphasis is still much more internally targeted towards winning work. - ROI an important factor in

			<i>determining ICT investment strategy.</i>
<i>Organisational Maturity</i>		▪ <i>Recognise importance of aligning IT with business process management/re-engineering although not yet practiced.</i>	▪ <i>Mainly concerned around reducing the cost of and adding value to processes.</i> ▪ <i>Redesign of processes identified as significant for the more effective implementation and management of ICT.</i> ▪ <i>Ill-defined processes are still a current challenge.</i>
<i>ICT knowledge and skills</i>	▪ <i>ICT knowledge and skills of employees recognised important towards achieving business improvement.</i> ▪ <i>Not yet being fully utilised for innovation to deliver strategic value from ICT.</i>	▪ <i>Clear understanding for the need of ICT skills across the organisation rather than for individual departments or projects.</i>	▪ <i>ICT training forms an important part of their investment.</i> ▪ <i>ICT training in the main is currently business process focused.</i>
<i>New/advanced technologies</i>	▪ <i>Recognise importance to investigate impact to facilitate delivering future competitive advantage.</i> ▪ <i>Yet to take advantage of this.</i> ▪ <i>Shift from technology push/driven approach towards on-going investigation into new technologies.</i>		
<i>Influence of previous implementations on future investments</i>		▪ <i>Previous implementations (internal or external) have no influence.</i>	▪ <i>Experience gained from previous ICT implementations plays an important role.</i>

<i>Drivers/Success Factors</i>		▪ <i>Main driver is on internal business improvement.</i> ▪ <i>Moved away from winning work (internally focused) to improving communication and with partners and amongst their supply chains (externally focused).</i> ▪ <i>Emphasis on ensuring ICT aligns with process (process management/re-engineering).</i> ▪ <i>Training and developing both the necessary ICT skills along with competencies in order to deliver value from ICT is recognised as significant.</i>	▪ <i>Still much more inwardly focused such as on winning work.</i> ▪ <i>ICT strategies/investments are not heavily dependent on external factors.</i> ▪ <i>Activities such as benchmarking are not recognised as being important.</i> ▪ <i>Focused on better understanding and defining of process within their organisations.</i> ▪ <i>ICT training is identified as one of the key factors to achieving successful ICT implementations.</i>
<i>Inhibitors</i>		▪ <i>Broader and all encompassing perspective.</i> ▪ <i>Mainly evolve around the issue of organisational “readiness” (e-readiness) which is perceived will be the main concern in the future.</i>	▪ <i>Very much technological related such as lack of an efficient and effective network/communications infrastructure.</i> ▪ <i>Process also recognised as a key inhibiting factor in relation to the challenges faced by ill-defined processes.</i>

5. ICT investment

In terms of ICT investment, interestingly, while the UK industry has moved away from investing in ICT to reduce costs at an operational level towards the organisation, significant ICT investment in the Turkish industry is being driven through the alignment of ICT strategy with operational needs with a focus on the cost reduction of and adding value to processes. Investment in ICT is recognised by both industries as value adding, although this is more prevalent in the UK where the focus has moved to products and services from both an internal and external perspective compared to the Turkish industry where the emphasis is still much more internally targeted towards winning work.

As previously mentioned, although there is a clear recognition by both industries in the strategic value of ICT and the importance of ICT strategy on delivering corporate strategic goals, this has not yet been attained. It is evident that both industries appear to be at a stage in their 'level of organisational maturity and capability' towards strategically benefiting from their ICT investment where the current focus is on process and process improvement. ICT investment within the Turkish industry is mainly concerned around reducing the cost of and adding value to processes. In the UK the importance of aligning IT with business process management/re-engineering is recognised although this has yet to be practiced. This also correlates with the Turkish sector where the redesign of processes is identified as significant for the more effective implementation and management of ICT, while at the same time ill-defined processes is still a current challenge. This would indicate that both industries are currently faced with the challenge of beginning to fully understand their processes and improving them to facilitate delivering strategic value from ICT.

It is evident that the basis for ICT investment in both the UK and Turkish industries is still very much driven by 'cost effectiveness' and clear financial benefits rather than towards delivering the strategic corporate goals and ultimately achieving competitive advantage. This is particularly evident in the Turkish industry where only a small minority do not consider ROI as an important factor in determining their ICT investment strategy.

From the perspective of people, the ICT knowledge and skills of employees are also recognised by both industries as important towards achieving business improvement, but this is not yet being fully utilised for innovation to deliver strategic value from ICT. In the UK there is a clear understanding for the need of ICT skills across the organisation rather than for individual departments or projects. Within the Turkish sector the provision of ICT training forms an important part of their investment and the emphasis placed on the importance of training is further evident in that where a separate budget has not been dedicated then ICT training is still provided. The provision of ICT training within the Turkish industry in the main is currently business process focused.

In relation to investing in new/advanced technologies both industries are very much aligned in recognising the importance to investigate their impact to facilitate delivering competitive advantage

within their organisations in the future. While the UK and Turkish industries are yet to take advantage of this, it is further evident that thinking has clearly shifted in both industries from a technology push/driven approach which has been traditionally adopted towards an on-going investigation into new technologies that inform ICT strategy and deliver business improvement.

An area where there is clear difference between the two industries in relation to ICT investment is in the influence of previous implementations on future investment. It is evident within the UK that previous implementations, whether internal or external, have no influence on future ICT investment. In contrast, the experience gained from previous ICT implementations within the Turkish industry is identified as playing an important role on the success of future ICT investment.

6. Drivers, success factors and inhibitors

In terms of the drivers/success factors and inhibitors identified through both studies it is evident that there is significant recognition by both industries of the ‘softer’ issues of process and people in addition to technological aspects towards delivering strategic value from their ICT investments.

While the focus within the UK in terms of the main driver/success factor is on internal business improvement, this has moved away from winning work (internally focused) to improving communication and with partners and amongst their supply chains (externally focused). In contrast, the Turkish sector tends to still be much more inwardly focused (such as on winning work) whereby ICT strategies/investments are not heavily dependent on external factors, while activities such as benchmarking are not recognised as being important in influencing the success of their ICT implementations. The aspect of process improvement is recognised as a critical driver in both the UK and Turkish sectors. Within the UK the emphasis is placed on ensuring that ICT aligns with process (process management/re-engineering) whereas in Turkey the sector is specifically focused on a better understanding and defining of process within their organisations. Along with process people issues are very much evident in both sectors, in particular around the significance of training and developing both the necessary ICT skills along with competencies in order to deliver value from ICT within their organisations. This is particularly prevalent within the Turkish industry where ICT training is identified as one of the key factors to achieving successful ICT implementations.

When focusing on the inhibitors identified by the two industries then the key issue in terms of the Turkish sector is very much technological in terms of the lack of an efficient and effective network/communications infrastructure. Process is also recognised as a key inhibiting factor to the successful implementation of ICT in relation to the challenges faced by their organisations due to ill-defined processes. The UK study focuses a broader and all encompassing perspective in relation to the key inhibitors that mainly evolve around the issue of organisational “readiness” (e-readiness). “e-readiness” is coined to measure how “ready” organisations are to adopt and use the available ICT to improve their business performance and services to customers. It reflects the organisational soft issues

such as business processes, management structure, change management, people and culture. The major factors to incorporating e-readiness in organisations are the people, process and technology, from all levels (i.e. Executives, Managers and Operational levels). Organisational e-readiness is the “measure of the degree to which an organisation may be ready, prepared or willing to obtain benefits which arise from the digital economy” (Alshawi, 2007). The UK industry believes organisational e-readiness will be the main concern in the future.

7. Conclusion

In the 21st Century ICT has evolved to become a strategic asset for any organisation, regardless of sector, to deliver strategic value and achieve sustainable competitive advantage. However, while significant investment has been made in ICT, there is substantial evidence that this has not resulted in delivering strategic value. Overall the results of the comparative study has identified similarities in relation to the perceptions of the importance placed on the strategic value of ICT and the various aspects associated with people, process and technology. However, it is further evident that there are distinct aspects of differences that potentially relate to the level of maturity in practice of each sector. A promising picture has emerged from the comparative study in that the strategic value of ICT towards delivering competitive advantage is clearly recognised in both industries. However, a conservative approach to ICT investment is still evident and achieving strategic value from ICT investment towards delivering competitive advantage is yet to be attained in either sector.

Both the UK and Turkish construction industries are focused on aligning ICT and business strategies although this process appears to be much more integrated in UK practice. In terms of ICT strategy setting, the role of ICT departments has been more transformed within the UK industry from just providing technical support to engaging in business improvement and strategy compared to Turkey where the provision of only technical support is still equally widespread. While ICT investment in both industries is currently being driven by cost-reduction and value-adding, there is a shift in focus of the UK sector from an operational to an organisational level, which is product and service-oriented considering both internal and external factors. The emphasis within the Turkish industry still remains much more internally targeted towards winning work. Furthermore, ‘cost effectiveness’ and clear financial benefits are still the main basis for ICT investment in both the UK and Turkish industries rather than taking a more strategic perspective as is clearly recognised. It appears that both industries are at a level of maturity where organisations are facing the challenge of beginning to better understand their processes while having the capability to redefine/redesign them such that they can maximise the benefits from their investment towards achieving strategic value from ICT. This is more prevalent in Turkey whereas the UK sector is predominantly more focused on aligning ICT with process. In addition to process, people are also recognised as being an important aspect in terms of developing the required ICT knowledge/skills and competencies of employees which is recognised as a key factor within the Turkish industry. However, this aspect is not currently being fully utilised for innovation by either industry. From a technological aspect, both industries are very much aligned in recognising the importance of investigating the impact of

new technologies to facilitate delivering competitive advantage within their organisations in the future. Again, this is not current practice of either industry although the thinking (maturity) of both industries appears to have shifted from one of a traditional technology push/driven approach to that of an on-going investigation into new technologies that inform ICT strategy and deliver business improvement. Furthermore, the influence of previous implementations on future ICT investments has no significance within the UK compared to the Turkish industry where it plays an important role.

The Turkish industry, in the main, is still being inhibited by technological (infrastructure) along with process-related issues, while in the UK ICT infrastructure appears to no longer be a major issue. In line with the shift in focus towards the organisational level, a broader and all encompassing perspective in relation to the key inhibitors is evident in the UK sector. These mainly evolve around the issue of organisational “readiness” (incorporating the major factors of people, process and technology at all levels in the organisation) which the UK industry considers will be the main concern in the future to achieve strategic value/benefit from ICT.

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Digital Image Processing for Evaluating Defect Level in Visual Quality Inspection

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Abstract

The traditional construction industry dilemma concerns the definition of an overall quality standard and acceptable level especially in aesthetic issue because some work items in visual inspection are difficult to measure the absolute defect quantity. These are limited by using human vision inspection. In current practice, the visual quality inspection is still relied on individual subjective judgment. It causes several problems such as multiple-standards and unreliability. Thus, this research paper presents an innovative visual inspection system that uses the digital image processing (DIP). It attempts to reduce the human subjective measure and enhance the reliability for evaluating the defect level. The digital image processing helps to interpret from image data to features of inspected object. It helps to solve the human vision limitation in unknown of absolute defect quantity. Moreover, this paper presents the allow representation of long-gathered knowledge, and its use to solve the decision problems.

Keywords: digital image processing, visual quality inspection, defect detection

1. Introduction

Due to the fact that a high quality is one of criteria influencing customer satisfaction with regard to the performance of construction projects beside cost and time. Therefore, quality is a key element of survival and success in a high competitive environment of construction business. The inspection is essential processes in quality control for protecting defection to assure that the quality of final products fulfilled specifications and customer requirements (Pesante-Santana ,1997).

The traditional construction industry dilemma concerns the definition of an overall quality standard and acceptable level. By its nature, quality evaluation in a construction work can be divided into two attributes that consist of measurable and subjective attributes. The measurable attributes are related to material types, construction techniques and functional requirements. These attributes including the standard, sampling and specification of construction works are defined in contract document. As these can be measured, they frequently use the mechanical instruments to enhance the sensory input for the human judgments. Instruments such as gages are used to determine thread sizes, gap thicknesses, angles between parts, hole depths, and weld features. Thus, the judgment on quality of work can be evaluated by comparing between measurement result and specification. In contrast, subjective attribute of work items are related to aesthetic issue especially in architectural works. The content in the contract document uncovers about this issue. Because inspectors use only visual inspection which is difficult to measure the absolute defect quantity, these are human vision limitation.

In current practice, the visual quality inspection is dependent on individual subjective judgment. The problems of confliction about the satisfaction of aesthetic level have arisen as a result of different customer perception. Moreover, several project participants who are involved in evaluating quality inspection have different experience. It has multiple-standards and unreliability on quality judgement. Therefore, the quality evaluation of subjective attribute needs the method to minimize these problems.

2. Previous related work

The construction industry illustrates many previous research works which are studied to overcome the limitations of subjective evaluation in visual quality inspection by human inspector (Georgopoulos et al., 1995; Lee, 2004; Lee et al., 2006). They developed an automatic procedure replacement by using computer vision and image processing technologies to automate the process. These attempts are to determine the defects of road infrastructure by using digital image processing. The result of the process can help to optimize infrastructure maintenance strategies in operation stage. The digital image processing (DIP) is a popular information technology in infrastructure field. Lee, Chang & Skibniewski (2006) studied the inspection of the deterioration of steel bridge coating. Georgopoulos, Loizos & Flouda (1995), and Lee (2004) proposed the information technology for inspecting the pavement crack. Therefore, the use of image processing can support human judgments in quantifying and evaluating construction defects.

Although previous researches aim to support human subjective judgments by using image processing to detect and quantify construction defects, few researches focus on evaluating the intensive defect level in subjective attribute of aesthetic issue during the construction stage. The acceptable level of defect about aesthetic issue in architectural work is difficult to judgment because it depends on each personal perception. These causes lead to confliction. Therefore, we envision challenge to evaluate the intensive defect levels about aesthetic issues using in each organization.

3. Research objectives

This research paper aims to present the conceptual framework of an innovative visual inspection system that uses the digital image processing (DIP). It attempts to reduce the human subjective measure and enhance the reliability for evaluating the defect level. The digital image processing helps to interpret from image data to features of inspected object. It helps to solve the human vision limitation in unknown of absolute defect quantity.

4. Principle of digital image processing

Digital Image processing means the computerized processes which help to enhance the quality of image into suitable form with objective such as reduce noise, contrast enhancement, image sharpening or high level process etc (Yodrayub, 2007). Interest in digital image processing methods stems from two principal application areas. These are the improvement of pictorial information for human interpretation and the processing of scene data for autonomous machine perception (Gonzalez and Woods, 1992). The digital image processing in computer vision can be grouped into three levels of computerized processes in the continuum (Gonzalez, Woods and et al., 2004).

(1) Low-level involves primitive operations such as image processing to reduce noise, contrast enhancement, and image sharpening. A low-level process is characterized by the fact that both its inputs and outputs are images.

(2) Mid-level involves tasks such as segmentation (partitioning an image into regions or objects), description of those objects to reduce them to a form suitable for computer processing, and classification (recognition) of individual objects. A mid-level process is characterized by the fact that inputs generally are images, but its outputs are attributes extracted from those images (e.g., edges, contours, and the identity of individual objects).

(3) High-level involves “making sense” of an ensemble of recognized objects, as in image analysis, and at the far end of the continuum, performing the cognitive functions normally associated with human vision.

This research applies all levels. Before image processing in high-level which uses algorithms of logical and mathematical model to analyze the defect feature of interesting object in image, the quality of image should be improved by pre-processing in low-and mid-levels for easier analysis. The

algorithms in image processing are used to replace making sense and to overcome the subject judgment of human vision.

5. Conceptual framework of defect level evaluation system

The proposed conceptual framework is shown in Figure 1. It shows the whole methodology steps of defect level evaluation system that are sequentially linked together. The digital image processing is applied to quantify the defect value by analyzing image features of interesting object which humans solve unwittingly. Thus, the defect value is quantitative form which can compare with requirement standard. Knowledge management is applied to set own standard in visual quality inspection about aesthetic issue.

The system can be divided into seven modules which are spread in five main stages: (1) input stage (image acquisition module), (2) pre-processing stage (image quality enhancement and image scale adjustment module), (3) data analysis stage (image feature analysis module, defect value calculation module), (4) output stage (evaluation and translation module), and (5) capturing stage (knowledge base module). The case study of tiling inspection is chosen to present implementation of this concept. The detailed description of each stage is given as follows.

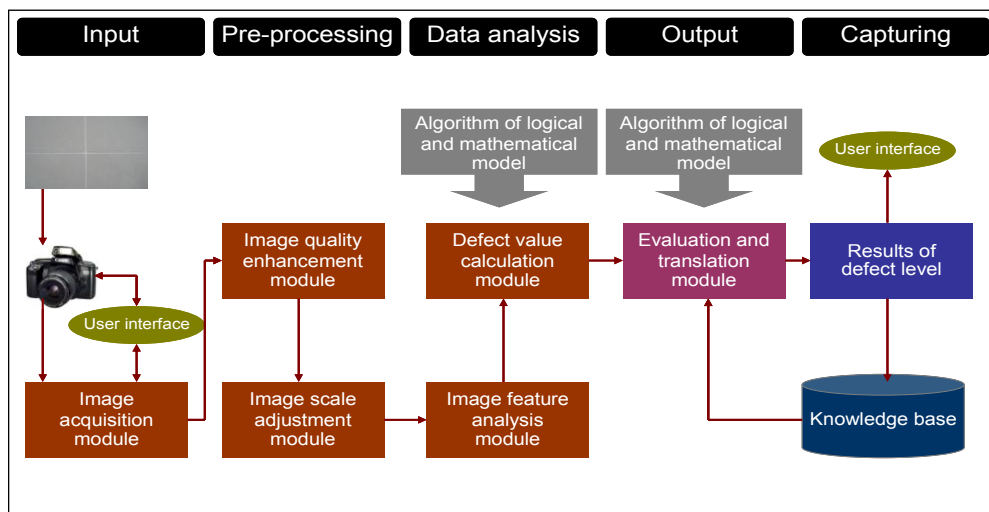


Figure 1: System architecture of defect level evaluation (modified from Laofor and Peansupap, 2009)

5.1 Input stage

The data flow starts from the data input stage that includes image acquisition module by connecting the digital camera with laptop pc. The image acquisition module captures and transfers image into computer for processing. The image contains the specific defect group for inspecting in each quality requirement. Under tiling inspection, the tile must be set in straight parallel lines. The distances between neighbouring tiles must be uniform. The neighbouring tiles have to be on the same level.

The glue has to be spread uniformly over the entire back of the tile. The tile must be pressed evenly against the floor (Navon, 2000). Our system does not intend to evaluate all quality requirements by using only image processing technique. But we focus on supporting visual quality evaluation in some quality requirements. Thus, the case study of tiling inspection can be inspected the straight parallel lines, uniform of distance between neighbouring tiles. The image acquisition must show the line, joint and level. The images should be taken in the same environment condition such as camera specification, pixels size (640x480), camera distance and others.

5.2 Pre-processing stage

The pre-processing stage aims to improve the quality of image into suitable form and easier analysis. It includes image quality enhancement module and image scale adjustment module.

- Image quality enhancement module

The image quality enhancement module uses the digital image processing to improve the quality of image for easier analysis. The case study of tiling inspection needs to reduce noise and convert colour image in Figure 2(a) to binary image (black and white) in Figure 2(b) by threshold techniques. The edge of tiles can be seen clearly for analysis in next module.

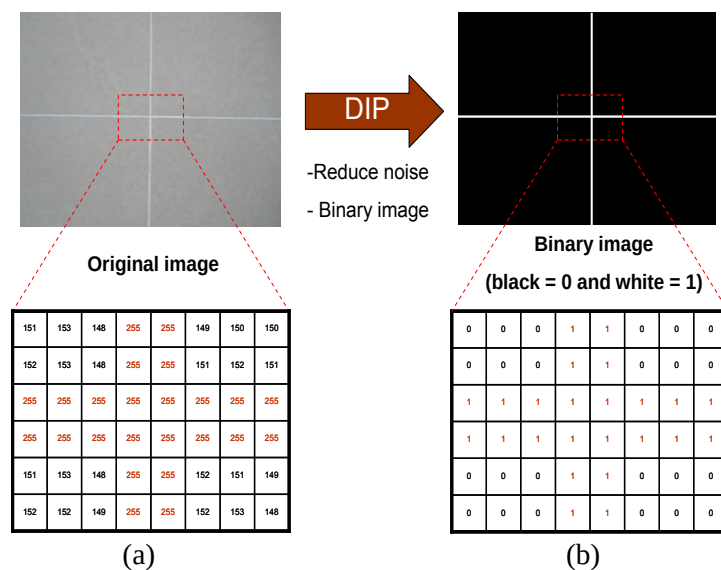


Figure 2: Image quality enhancement

- Image scale adjustment module

The image scale adjustment module helps to adjust the scale ratio of image to the same unit with real object. Usually, the virtual image is pixel unit which is different from real object. Thus, it can not compare scale with requirement standard. The scale ratio (pixel per mm.) depends on photography conditions such as camera specification, camera distance and angle, and others.

5.3 Data analysis stage

The data analysis stage aims to interpret defect feature on image into quantity form that includes image feature analysis module and defect value calculation module.

- Image feature analysis module

The image feature analysis module uses the digital image processing to analyze image features in Figure 3 such as regions, edges, scale, interesting points and texture. This case study uses the difference of image pixels value between black (0) and white (1) for finding the coordinate of tile edges in both vertical line ($V_1, V_2, \dots, V_m$), horizontal line ($H_1, H_2, \dots, H_n$). The slope (m) for finding angle of intersecting straight line in each point ($PV_1H_1, PV_1H_2, PV_2H_1, PV_2H_2, \dots, PV_mH_n$) can be calculated by using the linear regression equation. These are shown in Figure 4 after that it can be used to calculate the defect value in the next module.

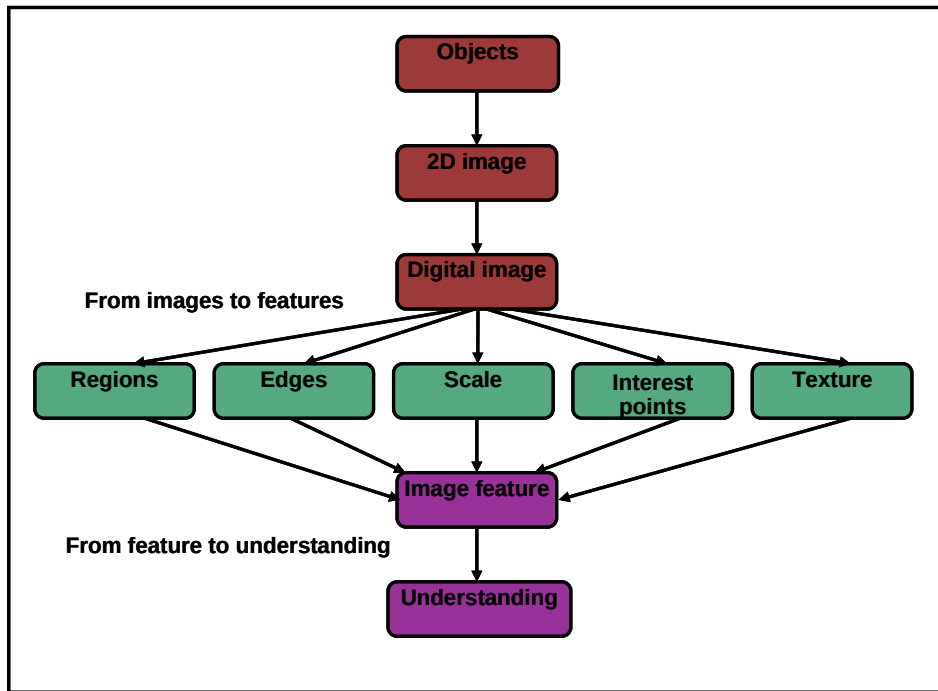


Figure 3: Digital image processing

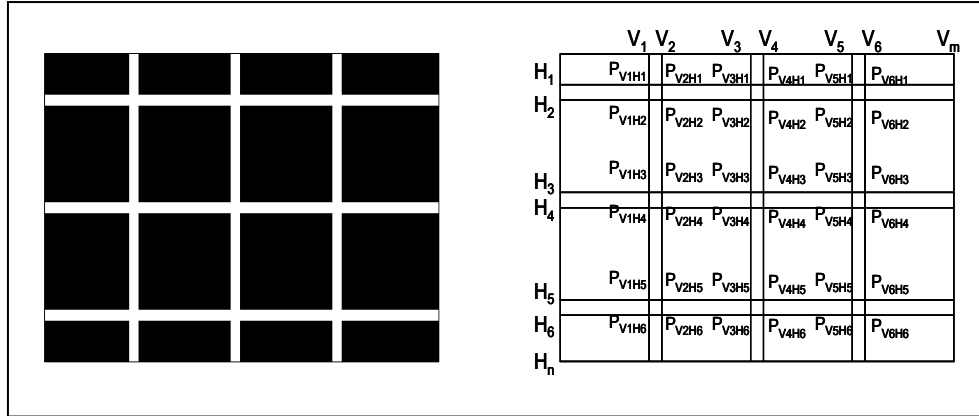


Figure 4: Image feature analysis

- Defect value calculation module

The defect value calculation module uses the algorithms of logical and mathematical model to quantify the defect value. It shows the intensive defect level from requirement standard. The case study of tiling inspection uses two algorithms to check the completion of tiling. First, the algorithm of distance inspection between neighbouring tiles (gap) must be uniform in Figure 5(a). Second, the algorithm of angle inspection of intersecting straight line must be right angle in Figure 5(b).

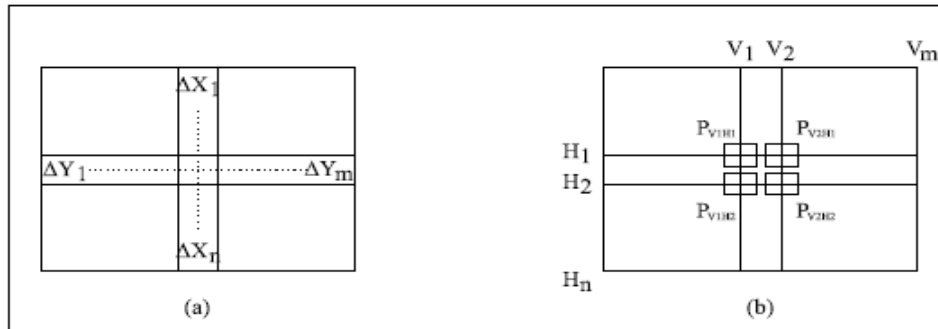


Figure 5: Algorithms of tiling inspection

5.4 Output stage

Output stage consists of evaluation and translation modules that can be translated into defect level by using the algorithm of logical and mathematical model. The algorithm is used to compare result of measurement from calculation with requirement standard from defect classification in knowledge base.

5.5 Capturing stage

In the capturing stage, the main purpose is to store defect value of quality criteria from representative images for developing quality standard. It is contained in the knowledge base module to support the evaluation and translation module. The representative images should be selected and classified by all project participants who involve in quality inspection process. This process helps the system by retrieving the inspectors' perception on quality standard and then can be used to capture the acceptable defect of work from project participants. Next, the representative images are evaluated by the defect value measurement. Thus, the criterion of defect level classification is developed to algorithm logical and mathematical model for evaluating the defect level of new image. This defect classification was stored as the knowledge base of representative quality standard. This acceptable defect in representative image can be used to compare with defect of the following works. The data flow of quality knowledge base is shown in Figure 1. This part can be used to create own standard in visual quality inspection about aesthetic issue for improving quality control continuously.

6. Results and discussion

This section aims to present results of testing and calculation of defect value from several tile cases. Due to the fact that tile manufacturing has several specifications such as material types, sizes, shapes, colours and patterns. Thus, our proposed system should cover these attributes. This research paper presents testing of different tile sizes, several colours and patterns of tile. From results of testing, our proposed system can be used to inspect in several tile sizes. However, the key problem is the converting of original image to binary image in several colours and patterns of tile which are shown in Figure 6.

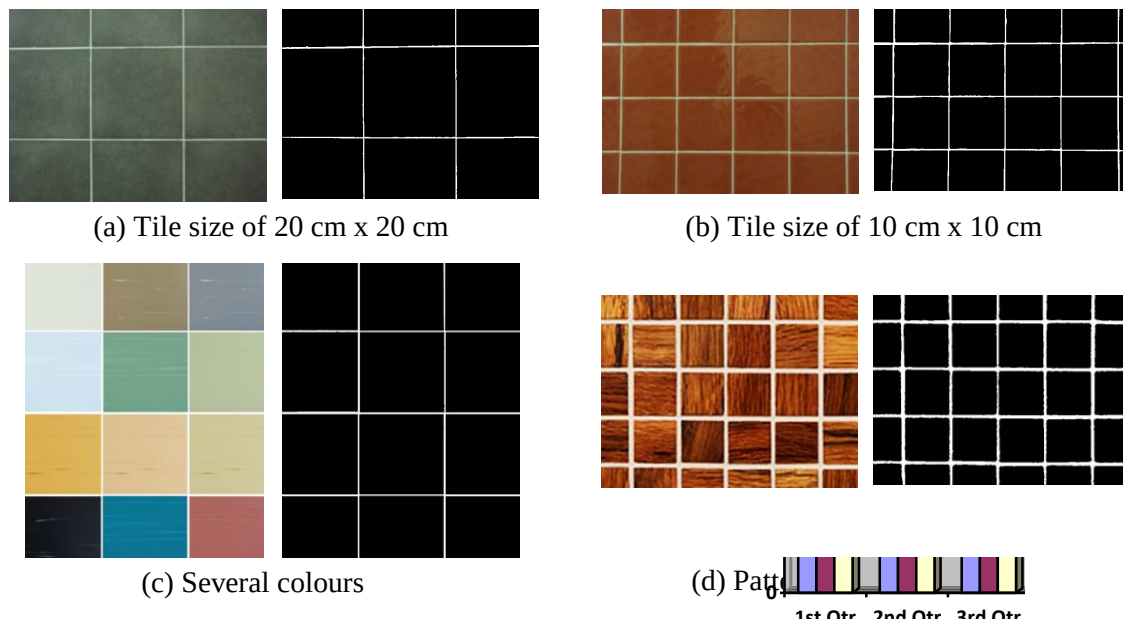


Figure 6: Tile cases

Each image has different threshold value for analyzing edge of gap line. The calculation results of defect value are shown in Table 1 and 2. The defect value from representative images can be set as criteria to evaluate the intensive and acceptable defect levels. These are used as a future quality standard of each construction project or organization.

Table 1: Results of distance inspection between neighbouring tiles (gap)

Lines	Gaps	Defect value	Line	Gaps	Defect value
(a) Tile size of 20 cm x 20 cm					
Vertical	Ev1	0.480	Horizontal	Eh1	1.268
	Ev2	0.412		Eh2	0.648
(b) Tile size of 10 cm x 10 cm					
Vertical	Ev1	1.224	Horizontal	Eh1	2.256
	Ev2	0.505		Eh2	1.334
	Ev3	0.577		Eh3	1.275
	Ev4	0.483			-
	Ev5	0.892			-
(c) Several colours					
Vertical	Ev1	0.710	Horizontal	Eh1	0.763
	Ev2	1.205		Eh2	1.376
	-			Eh3	1.464
(d) Pattern of tile					
Vertical	Ev1	2.648	Horizontal	Eh1	4.344
	Ev2	2.619		Eh2	2.283
	Ev3	3.332		Eh3	2.134
	Ev4	2.909		Eh4	2.302
	Ev5	1.770			-

Table 2: Results of angle inspection of intersecting straight line

Points	Defect value	Points	Defect value
(a) Tile size of 20 cm x 20 cm			
PV1H1	0.178	PV2H1	0.115
PV1H2	0.075	PV2H2	0.012
PV1H3	0.156	PV2H3	0.219
(b) Tile size of 10 cm x 10 cm			
PV1H1	0.096	PV2H1	0.048
PV1H2	0.131	PV2H2	0.366
PV1H3	0.040	PV2H3	0.104
(c) Several colours			
PV1H1	0.032	PV2H1	0.037
PV1H2	0.120	PV2H2	0.124
PV1H3	0.115	PV2H3	0.120
(d) Pattern of tile			
PV1H1	0.044	PV2H1	0.182
PV1H2	0.003	PV2H2	0.141
PV1H3	0.081	PV2H3	0.035

* These are just samples of all points on image.

7. Verification

A preliminary verification of proposed method is necessary in order to estimate the accuracy of interpretation from developed program before these are used to create own standard in project or organization. The procedure of field verification included image acquisition, implementation of algorithms for binary image production and determination of defect value, and the comparative analysis of coincidence value between the visual rating by human inspector and developed program. Usually, the results of verification should have coincidence value in the range of 80-100%.

8. Conclusions

The current construction inspection process always encounters the confliction of acceptable defect level about the aesthetic issue in architectural work. This research paper aims to present the conceptual framework of the innovative visual quality inspection system that uses digital image processing. The system helps to enhance the reliability and overcome the limitation of human vision in an analysis of defect features and actual quantity calculation for identifying the evaluated criteria of each defect level. These are used to improve the standard of quality evaluation in each organization to ensure a quality standard corresponding with the customer requirement and reduce conflict between involved persons in evaluating defects of work. The case study of tiling inspection is

chosen to present the implementation of this concept. Moreover, this paper presents the results of testing in several tile cases that there are different attributes such size, several colour and pattern of tile. However, the future work needs to test in other attributes of tile cases. In addition, we need to study and develop the algorithm in other case studies.

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Towards a Smart, Energy-Efficient ICT-Empowered Built Environment: the REEB Strategic Research Agenda

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Abstract

The REEB project is a Co-ordination action addressing the Strategic Objective: *ICT for Environmental Management & Energy Efficiency* for the construction sector. The project aims at providing a vision and a roadmap for co-ordinating and rationalising current and future RTD in the fields of ICT support to energy-efficiency in the built environment of tomorrow. The main outcome is a strategic research agenda that has been elaborated with the support from a European-led community dedicated to the innovative use of ICT supporting EE in Construction, bringing together the ICT community and key actors of the (Construction) Environment and Energy business sectors.

Keywords: energy-efficient buildings, ICT, vision and SRA (strategic research agenda), projects REEB and REViSITE.

1. Introduction

Growing concerns priorities today, especially in Europe, are environment protection and energy conservation, moreover in a context where “systems” (should they be transportation systems, industrial systems, systems empowering the built environment, etc.) are more and more complex and demanding in terms of information management: it is nowadays acknowledged that ICT (Information and Communication Technologies) is the key for a 2-way flow of both energy and information in the Energy sector as a whole (production, distribution, consumption and management). Due to its impact and the opportunities it offers, ICT is considered too as the key for a liberalised market, leading to changes in business practices in the Energy sector (in a similar way this has been the case with ICT strongly impacting the Telecom sector and market). ICT is the key for empowering people in the (built) universe in which they live, with smart e-metering and new smart e-devices, A high potential is also foreseen for ICT becoming fully pervasive in the future optimization of energy in the built environment - where “Energy-efficient smart buildings” are buildings which contain systems that manage information for an optimal operation of building energy flows over the whole building lifecycle.

In this context, REEB (the European strategic research roadmap to ICT enabled Energy-Efficiency in Buildings and construction) is an ongoing European R&D technology roadmap initiative (achieved in the context of an EC-funded Coordination Action - <http://www.ict-reeb.eu>) for IT to support Energy Efficiency (EE) in the built environment. REEB has been launched as a response to the need for coordinating and rationalizing current and future RTD in Europe in the area of ICT support to EE in constructions: it has been set to develop a European-wide agreed vision and roadmap providing pathways to accelerate the adoption, take-up, development, and research of emerging and new technologies that may radically transform building constructions and their associated services in terms of enhanced energy consumption.

This paper aims at introducing to the Vision and the Roadmap developed in REEB, after feedback and validation from many stakeholders at the crossing of ICT, Construction and Energy. REEB is a key milestone in identifying, synthesising, and prioritising a comprehensive set of agreed main problems, challenges and prescribed RTD for new ICT-based solutions related to the future delivery and use of EE facilities and buildings, in Europe and world-wide.

2. The REEB vision

The elaboration of the vision has resulted from the crossing of inputs provided by the REEB partners, and many stakeholders having joined the International REEB Community, bringing together the ICT community and key actors of the (Construction) Environment and Energy business sectors. A key finding is that, while there is an emerging consensus about the key RTD issues in ICT-enabled EE of buildings, the potential impact of various technologies is not sufficiently well known. Thereby it is difficult to assess the relative importance of specific technologies, applications and systems, and it is necessary to develop a more holistic understanding of the potential effects of ICT on the EE of

buildings. The vision in REEB is that the high level impacts of ICT to energy-efficient buildings are envisaged to evolve as follows:

- Buildings meet the EE requirements of regulations and users – *short term*.
- The energy performance of buildings is optimised considering the whole life cycle – *medium term*.
- New business models are driven by energy efficient “prosumer” buildings at district level – *long term*.

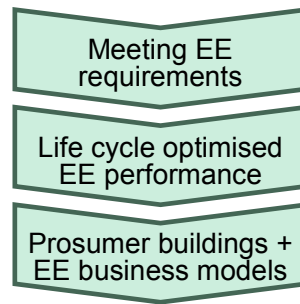


Figure 1: Envisioned evolution of energy efficient buildings

ICT contributions to the EE of buildings are largely via integrated design tools, automation & control systems, and decision support to stakeholders throughout the whole life of buildings. Full exploitation of the opportunities offered by ICT for EE requires adjustments of the processes and contractual practices of the construction sector, with a transformation of focus from the initial construction cost to whole life performance i.e. value to owners (**Figure 2: Industrial priorities**).

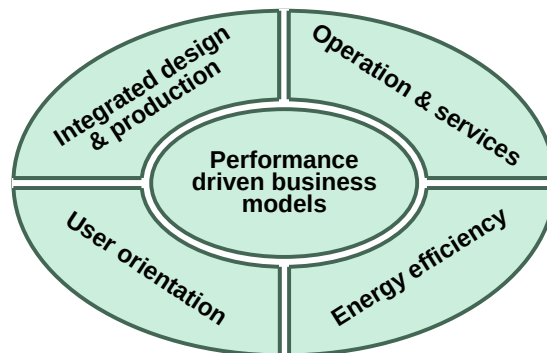


Figure 2: Industrial priorities

In order to align with the industry priorities, results are organised into corresponding categories of research topics (

Figure 3) – which have been defined, through iterations, by experts (REEB partners and a Special Interest Group) on the basis of inputs provided by key target groups of the “ICT4EEB community”: **1)** Tools for energy efficient design and production management; **2)** Intelligent and integrated control; **3)** User awareness and decision support; **4)** Energy management and trading; and **5)** Integration technologies.

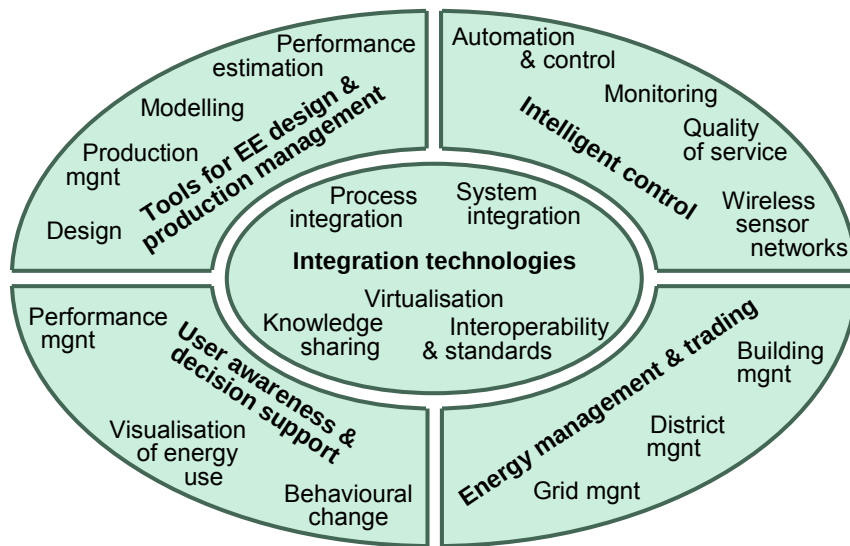


Figure 3: ICT enablers for energy efficient buildings

The ICT opportunities have been identified in REEB as follows (with detail of ICT support described in Table 1):

- ICT methods and tools supporting optimal design of products and services with respect to energy consumption and the related environmental impact;
- Integrated ICT-based systems enabling an eco-efficient production, conservation and distribution of energy;
- New ICT-based control and monitoring systems for all types and ages of buildings;
- Design, simulation, evaluation and strategy adaptation of energy use profiles.

Table 1: Summary of envisioned ICT support at various life cycle stages of product/service

Life cycle	Applications / systems
Design	▪ Capturing user/client requirements and formalising them into measurable indicators. Verification methods. Design for EE.
Product definition stage	▪ Catalogues of materials, components, connections, interfaces. Configuration design tools. Design for constructability and flexibility. ▪ Regulation data bases and automatic code checking tools. ▪ Design for operability and system integration. ▪ Applications for analysis, design, simulation, visualisation etc.

<i>Life cycle</i>	<i>Applications / systems</i>
<i>Production</i> <i>Product</i> <i>realisation</i> <i>stage</i>	▪ Translation of performance requirements to all stakeholders and verifying compliance. ▪ Tagging (e.g. RFID) and tracing of materials, products, equipment, vehicles etc. Access control. Quality control. ▪ E-Business. On-line construction site. Ambient production status information. Manufacturing automation. ▪ Off-site manufacturing of components and modules. Industrialised methods on-site production & renovation. ▪ Applications for constructability assessment, scheduling & planning. Recording as-built model.
<i>Operation</i> <i>Product</i> <i>usage</i> <i>stage</i>	▪ Recording as-used model. Facility management applications. Integration of BIM with real time information e.g. simulation based predictive control. ▪ Monitoring of actual performance and verifying compliance to requirements. Feedback to users. ▪ Sensors, actuators, wireless networks. Monitoring the condition and status of materials, components & systems. ▪ Intelligent and integrated automation & control. ▪ Energy management & trading. ▪ Predictive maintenance of installations and Renewable Energy Sources (RES).
<i>Integration</i> <i>Throughout</i> <i>all life cycle</i> <i>stages</i>	Collaboration support: ▪ Integrated design environments. ▪ Communication & teamwork support applications. ▪ Logistics & supply network management. ▪ Integrated project management environments. ▪ Platforms for service integration. ▪ Virtualisation of living & working environments. Interoperability standards: ▪ Exchanging and sharing building information models (BIMs). ▪ Technical and commercial information about products & services. ▪ Automation and control protocols, interfaces and gateways. Knowledge sharing: ▪ Catalogues of re-usable knowledge, guidelines, best practices. ▪ Catalogues of template solutions. ▪ Catalogues of products, services, suppliers. ▪ Adaptive and self-learning systems. ▪ Services/forums for benchmarking the performance of buildings.

3. The REEB roadmap

The REEB Roadmap is described under the form of 5 sub-roadmaps, providing for each category of research topics as identified in the REEB vision specific RTD challenges to face at short, medium and long term to achieve the vision. It also illustrates the long-term situation (and its evolution from now on) with the State-of-the-art and visionary scenarios of the future, and identifies drivers, barriers, impacts, and where applicable, related roadmaps developed in another context than REEB. Similarly

to the REEB Vision, the methodology, leading to the REEB strategic research agenda and its various RTD priorities for ICT supported EE buildings, has been based on the integration and synthesis of inputs provided by the REEB partners and key target groups of the “ICT4EEB community” including e.g. European Technology platforms and RTD projects in the 3 core areas of focus, and the European Commission. The baseline of the work is also relying on the EC policies and the visions and strategies of a number of related initiatives. The tables below form a snapshot of the REEB roadmap, which is detailed in the following public document: REEB (2010) - D4.2 Strategic Research Roadmap for ICT supported Energy Efficiency in Construction – dated 12th February 2010.

Table 2: Roadmap for EE design and planning

<i>Drivers</i>	<i>Increasing EE requirements.</i>	<i>Life cycle optimised buildings.</i>	<i>EE driven business.</i>
<i>Barriers</i>	<i>Lack of interoperability. Need of many special tools and extra efforts for EE considerations.</i>	<i>Lack of client awareness, incentives and financial instruments. National / regional regulations.</i>	<i>Prevailing business models focusing on delivery costs instead of value to client.</i>
<i>Impacts</i>	<i>Compliance at lowest cost.</i>	<i>EE services.</i>	<i>Branding.</i>

<i>State of the Art</i>	<i>Short term</i>	<i>Medium term</i>	<i>Long term</i>	<i>Vision</i>
<i>Design: Discipline-oriented analysis & dimensioning tools. General purpose CAD with discipline oriented add-ons. Web-based document mgmt systems.</i>	<i>Development of interoperable interfaces.</i>	<i>Development and population of catalogues with EE aspects.</i>	<i>Specialised tools for “creative design” and “configuration mgmt”. Template solutions for customised configuration.</i>	<i>Integrated model-based tools with embedded consideration of EE aspects in a transparent way.</i> <i>Catalogues of all re-usable knowledge.</i> <i>Standardised data model covering all EE aspects.</i> <i>Interoperability between all SW tools for design, production mgmt and operation.</i> <i>Contracts based on models and life cycle EE performance.</i>
<i>Production mgmt: Tools for contract & supply chain mgmt, procurement, logistics, on/off site production mgmt.</i>	<i>Material and product tracking systems. Adding EE aspects to existing tools.</i>	<i>Adding EE aspects to catalogues of materials and products. Tools to optimise production EE as part of life cycle.</i>	<i>Tools for rapid and flexible project team formation and mgmt.</i>	
<i>Modelling: Mostly document oriented tools. Model based tools are emerging.</i>	<i>Take up of available model based tools.</i>	<i>Enhancement of data models (ontologies) to cover EE aspects.</i>	<i>Model servers. Model based contracts and workflows. Integration of design models (BIM) with operational near-real-time information.</i>	

<i>Performance estimation: Numerous distinct tools for cost estimation, life cycle assessment and simulation.</i>	<i>Validation / certification of SW tools.</i>	<i>Integration of EE assessment into design tools. Interoperability with real time diagnostics [3.2]</i>	<i>Tools to estimate EE in a quantified and verifiable way.</i>	
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Table 3: Roadmap for intelligent and integrated control

Drivers	<i>Dynamic electricity prices, local production of electricity and storage</i>	<i>Increasing energy prices</i>	<i>Regulations and standards for energy efficiency of buildings</i>
Barriers	<i>ROI has still to be proven for users</i>	<i>Insufficient Interoperability</i>	<i>End-user acceptance</i>
Impacts	<i>Increasing demand for integrated BMS</i>	<i>Opportunities thanks to interoperability standard</i>	<i>“MS Home” (EnergyPlus for everybody)</i>

State of the Art	Short term	Medium term	Long term	Vision
Quality of service: Some self-diagnosis systems exist in the HVAC and lighting domains. Some sensors can also monitor their own functioning, and communication protocols also include error detection in the data frame. For communication protocols, many open or proprietary de facto standards co-exist with different properties.	<i>Enable diagnosis of EE-related building components (both “passive” ones like windows and active systems) has to be developed. Develop transmission protocols that satisfy specific ICT4EEB requirements (in terms of reliability, security, privacy...).</i>	<i>Generalize diagnosis of EE-related building components through the embedding of sensors in the components. Develop self-diagnosis abilities of sensors and integrate them in the sensors themselves. Develop a common shared standard of ICT4EEB-oriented communication protocol.</i>	<i>Develop BMS that will be fully auto-controlled and auto-monitored, discovering their own malfunctions. Achieve WSN that will be autonomous in their energy supply.</i>	<i>The future buildings, along with their components, equipments, and their environment will communicate and be able to provide information on their status ubiquitously. This real-time available information</i>

Monitoring: Existing Smart Meters enable real-time electricity consumption reporting and visualization as well as bidirectional communication with Smart Grids. All needed sensors, with the required sensitivity and accuracy, are not available at reasonable cost for a large scale deployment.	Develop new kinds of sensors when necessary, and decrease costs of manufacturing. Develop Smart Meters able to measure, record and visualize all kinds of energy consumption.	Make Smart Meters interoperate for the build-up of Smart Meter networks at district level. Embed more intelligence in sensors in order to perform a first level data analysis locally.	Tightly and securely integrate Smart Grids and Smart Buildings through Smart Meters, allowing the Smart Grid intelligence to directly control home appliances. Extend and distribute embedded intelligence to manage EE issues locally.	will be interoperable via common protocols for holistic automation & control. The whole building will be supervised by intelligent systems, able to combine information from all connected devices, from the Internet or from energy service providers in order to efficiently control HVAC (heating & cooling), lighting, and hot water systems along with energy production, storage and consumption devices inside the building, taking into account the users' needs and wishes.
Wireless sensor networks: Some "Plug & Play" sensors already exist, whose features can be automatically taken into account by WSN-based BMS to optimize control of the related actuators.	Improve sensors in terms of reliability, sensitivity, maintenance, testing and remote diagnosis, and communication abilities. Reduce energy consumption of WSN. Identify possible negative side-effects associated to WSN.	Define standardized roles and services for sensors and actuators to allow plug-and-play of new devices and self-(re)configuration of sensor networks. Allow WSN to support change of topology for network optimization. Develop powerful embedded OS that can provide more real-time functionalities.	Achieve completely autonomous sensors in terms of energy supply thanks to advanced energy harvesting technologies. Integrate several functions (light, temperature, air quality...) in a given sensor to reduce the number of necessary sensors. Integrate autonomous sensors in building components (windows, walls...) from the beginning of the construction process.	

Automation & control: Existing automation and control algorithms are most often restricted to sub-systems (heating, light, ventilation, μ -generation...), independent from each other, and hard-coded in the devices with little possibility to update or modify them by a centralized control instance.	Develop holistic control strategies that integrate all building dimensions, and develop a common conceptual framework for interoperability with the definition of a relevant set of services for sensors/actuators. Take user activities and building usage into account. Implement predictive control by considering weather forecast. Address all BMS components for predictive maintenance.	Design new holistic control strategies by simulation. Integrate simulation tools in BMS to optimize control strategy in real-time.	Introduce self-learning features in control algorithms to adapt to the user's preferences, the building age, and the possible change in the building environment. Allow control algorithms to suggest changes in the WSN (need of new sensors, disabling of existing ones...).	
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Table 4: Roadmap for user awareness & decision support

Drivers	Regulations, awareness, cost reduction	New business opportunities based on energy savings	Whole life performance of buildings
Barriers	Contractual practice based on initial investment cost	Lack of evidence to support investments into EE	
Impacts	Increased EE through user empowerment	EE and financial services	Life cycle optimised buildings. Users as active players in energy market.

State of the Art	Short term	Medium term	Long term	Vision
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Management of performance requirements: Currently only basic and aggregated energy monitoring indicators, lack of decision support functionalities	Benchmarking tools to assess theoretical models towards data from real operations Establishment of a performance track record database, including accurate building specifications	Communities for sharing and ranking energy information Data security privacy Decision-support tools for energy trade between buildings/parts of buildings	Energy efficient buildings certification	Energy efficiency of buildings will be ensured by established models, methods and tools for: understanding customer/client perceived values; capturing and formalising requirements; conveying the requirements to all stakeholders; assessing the estimated or actual performance and expressing it with verifiable performance indicators; communicating/visualising the performance for decision making by the involved stakeholders.
Visualisation of energy usage: Some emerging technologies but need for further experimentation to assess actual impact, and need for more research to fine-tune information presentation and content.	User motivation and incentives Interfaces for energy display Energy awareness impact on user behaviour	Integrated energy visualisation tools Integrated information on grey energy	Training sessions on energy awareness Decision support for long-term “lifestyle” strategy	
Behavioural change by real-time pricing tariffs: Basic existing systems that can be easily improved thanks to facilitated communication between consumers and energy providers	Tools for adjusting consumption to real-time pricing tariffs	Adaptive energy contracts	Personal energy rationing strategies	

Table 5: Roadmap for energy management & trading

Drivers	European and National Legislation Increasing availability of (renewable) energy sources	Holistic, integrated business models for Energy Management and Trading How to exploit energy data? What value-added services are required from customers?	Requirement to reduce the Carbon Footprint of the Built Environment.
Barriers	Privacy Who owns Energy Data? Where and how to manage energy data?	Restricted, non-standardised data-exchange protocols How to exchange energy data? What is the commercial value of Energy Data?	User Qualification What is the impact of my activities? What “upgrades”/actions create the most sustainable impact?
Impacts	Diversification for ICT-stakeholders:	Strengthening the Competitive Advantage of stakeholders from the Construction and the ICT-sector(s)	Reduction of Energy Consumption in Buildings Contribution towards the European Objective “20:20:20”

State of the Art	Short term	Medium term			Long term	Vision
Building energy management:	Embedded Sensing, automation & control Real-Time Self Assessment	Decision Support Algorithms	Performance Analysis and Evaluation Secure, ubiquitous communication	Network Planning	Condition and Performance-based maintenance:	To support the integrated and secure operation of “cascading” energy generation, storage and consumption capacities in the best interest of all energy consumers, the environment and the overall society – using a business model that enables the beneficial operation of integrated energy infrastructure systems.
District energy management:	Integrated System Platforms Low-latency communications				Plug and Play scalable integration of micro-generation & storage	
Grid management:	Demand Response Capabilities				Load Balancing Techniques	

Table 6: Roadmap for integration technologies

Drivers	Digitalization of building process and future generations Social awareness about relevance of energy efficiency and evolution toward real-time energy cost Integration of local generation in buildings
Barriers	Fragmentation and “project oriented approach” of building sector and complexity of dealing with existing buildings Lack of knowledge about building life cycle energy costs and current energy price policies
Impacts	Better knowledge about building life cycle energy performance More affordable energy efficient buildings and them integration in the smart grids concept. New business opportunities for ICT , energy and building sectors Higher sustainability with lesser consumption of resources (i.e. travel, energy, etc) via changes to the way we work

State of the Art	Short term	Medium term	Long term	Vision
Process integration: Files are the main integration mechanism and email the communication tool	Information server based workflows	Friendlier the interaction with the information systems	Automation of the workflows definition	EEB is managed in a holistic way through the seamless integration of the definition, realization and usage stages oriented design and operation tools and the collaboration of all the stakeholders in order to achieve the maximum energy efficiency in the building life cycle and taking advantage of the experience in previous
System integration: A wide variety of different technologies, from different vendors and companies, are coexisting	Definition of the gateway installed in each buildings and SOA based Integration Service Platform (ISP)	Making more efficient and friendly ISP and extending it neighbourhood level	Creating a common European vocabulary and new development methods and tools	
Interoperability & standards: Many non interoperable and partial standards	Definition of a common BIM for building life cycle energy efficiency	Unified open communication standard for monitoring and basic control operation	Uncertainty management and integration with standards from other domains	

Knowledge sharing: Even when knowledge exists, it is not discovered because is scattered in different non-compatible media and formats..	Continuous learning; community forums for discussion; digital catalogues of building products/services containing parametric information.	Easy access to knowledge about energy efficiency in building, which is modelled according to standards and easily accessible; user awareness tools (syndication).	Template solutions based on good practices; ubiquitous and context-based access to inter- organisational knowledge platforms	buildings
Virtualisation:	Definition of elements for “Office of the Future”; Application Virtualisation; human controlled avatar in 3D virtual meetings	Virtual Office Space; Virtualisation incorporating Cloud computing and Software-as-a-Service (SaaS); Head-Up Displays for virtual reality meetings	Virtual Personalised Desk and Energy Harvesting for Office of the Future’; real-time and self-predictive/adaptive virtualisation	

4. Conclusion and follow-up

Besides ICT for EE in buildings, there is a rationale for increasing cross-sectoral synergies between these sectors that are largely connected to the Construction one, namely lighting and manufacturing, and to investigate the potential of connecting Buildings to the future smart energy grids. Examples of potential synergies between these sectors (construction, manufacturing, lighting and grids) are highlighted in the following table:

<i>Sector</i>	<i>Links with other sectors</i>
<i>Manufacturing</i>	<i>Link with embodied energy in buildings and building materials. It is considered that about 10% of all CO2 emissions globally come from the production of building materials. In particular steel, concrete (cement), bricks and glass require very high production temperatures that can only be reached today by the burning of fossil fuels. Knowledge from Smart Manufacturing is of high interest here so as to take into account these constraints in future buildings.</i> <i>Processes in the Construction sector largely involve a complex supply chain – improvement from Smart Manufacturing considering Construction supply chain constraints will have impact in terms of reduction of CO2 emissions.</i>
<i>Electric Grids</i>	<i>Need for improvement in Smart Metering, including within the Built environment, and customers' communication / awareness.</i> <i>Home Energy Controlling box (Internet box).</i> <i>Development of ICT-based NMS (Neighbourhood Management Systems), considering future positive-energy buildings as potential active nodes (supply of energy) in future Electric Grids.</i>
<i>Lighting & Photonic</i>	<i>It is considered that about 12% of energy consumption in buildings is due to lighting. This figure increases in the non-residential building sector.</i> <i>Smart integration of new lighting technology (high performance technology) and devices (e.g. intelligent LED solutions) in Smart Buildings.</i>

This will be the objective of a new co-ordination action, named REViSITE (*Roadmap Enabling Vision and Strategy for ICT-enabled Energy Efficiency*), that will capitalise on the results of various national and international initiatives within the domain of ICT4EE. Results from these initiatives, which are in most cases sector specific will be analysed, synthesised with the view of identifying common themes and trends and identifying a common non sectoral specific methodology to assess the impact of ICT for Energy Efficiency.

Acknowledgement

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Building Information Modelling Processes: Benefits for Construction Industry

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Abstract

Many industry reports have enunciated on the nature of complications in some forms of construction problems. These include design errors, deficiencies in estimates, conflicts in design and implementations, and fragmented platforms that restrict information flow all through project life. The nucleuses of these phenomena have been expressed as major concerns on project performance and sustenance of innovation in the industry. A peculiar dimension to this challenge is the ability of conventional design, procurement and construction management protocols to generate, share and convey, without dissipation at any point, all necessary project data across all stages and discipline boundaries in construction development processes and project life. As some observations have been drawn in literatures on the implications of fragmented systems and spatio-temporal limitations of hand-drawn and entity-based 2D CAD design systems, there has been significant attention on the limitations of these conventional design tools. These include weak frameworks to facility design flexibility, automation, integration, visualization and robust capacity to drive data creation, storage, engineering and sharing between parties. Whilst these challenges are being addressed in Building Information Modelling (BIM) platforms, some potential opportunities have been identified in BIM as reliable alternatives in facilitating marked improvements in design, procurement, construction planning and facilities management processes. This study reviews literatures on evidenced benefits of BIM, especially on how it reduces confrontation and system inadequacies of entity-based 2D CAD through thorough integration, collaboration, communication and interoperation. Conclusions are drawn on the challenges of changes from conventional paradigms which are triggered by BIM in relation to construction project goals.

Keywords: building information modelling (BIM), construction processes, product development, project delivery

1. Background

Koskela (Koskela 2000) outlines the relationships between construction processes, formulation of design ideals and development of infrastructures in the industry. These processes, also known as *Construction Product Development Processes (CPDPs)*, are often described as risky, uncertain, complex, dynamic and inter-dependent (Flanagan et al. 1987; Lyons and Skitmore 2004; Wang 2009). Components of CPDPs, in no particular order, include infrastructure architecture, landscape architecture, architectural engineering, civil structural engineering, estimating, mechanical and plumbing engineering, electrical services engineering, project management, construction management, procurement and facilities management. Apart from risks and uncertainties that filter into CPDPs' systems in the directions of these disciplines, some recent studies on construction business models (e.g. (Shi et al. 2008)) have shown that most difficult complications are often triggered by stochastic frictions in commercial relationships between project stakeholders. Consequent upon these multiple dimensions of complexities, project stakeholders and teams often need to share information across trade boundaries to achieve project goals. These goals can be expressed in terms of the variables of feasibility and profitability, both in *hard* and *soft* measures (Barton 2000; Olatunji and Sher 2009a; Ustinovichius et al. 2007).

A wealth of evidence have shown that construction processes improve when stakeholders and project teams collaborate, cooperate, integrate and communicate effectively throughout all stages in the project life (Campbell and Harris 2005; Winch 2001). However, the frameworks to facilitate these have, up and until now, been deficient in both manual (hand-drawn) and conventional computer-aided drafting and design (CADD) tools. Different studies have enunciated the limitations of these tools and the subsequent implications on project lifecycle (Maher 2008; Slaughter 2001). Many authors (e.g. (Pektas and Pultar 2006)) agree that hand-drawn design methods are time-consuming, bulky, prone to spatial limitations, conflicts and errors. Others (e.g. (Sommerville and Craig 2003; Succar 2009)) also posited that they support fragmented conventions and lack appropriate platforms to facilitate integration of non-graphic information into design components, as well as storage value and hygiene, compared to *e*-based systems. As panacea to these challenges, the construction industry has witnessed the deployment of two forms of CAD in CPDPs in the past decades; these are entity-based CAD (*e-b* CAD) and object-orientated CAD (*o-o* CAD). Whilst *e-b* CAD deploys only geometric data and “unintelligent” features like lines, arcs, splines and circles to create *design products* in 2D or 3D (two or three-dimensional) formats, *o-o* CAD uses *intelligent objects* that could store and engineer both graphic and non-graphic data in ways that spur integration and more sophisticated innovations.

As numerous potential opportunities avail for *o-o* CAD in CPDP systems, some empirical reports have argued that the industry has little to benefit from *e-b* CAD. (Aranda et al. 2008; Gu et al. 2008; Whyte and Bouchlaghem 2002) have averred strongly on the need to service project-based needs through strong and lasting balance between stored graphic and non-graphic data for convenient application in project life. Some of the specific constraints of *e-b* CAD being addressed and transformed into potential strengths of

o-o CAD include improved spatiotemporal capabilities (*nD*), system integration, design flexibility, automation and simulation (Häkkinen et al. 2007). Although, some authors have triggered fears on the perceived reluctance of the industry to adopt innovations being derived from *o-o* CAD – especially building information modelling (BIM), (Barista 2009) allays this fear. According to a recent survey reported by this author, about 80 percent of largest AEC firms in the United States now use BIM. This implies BIM and allied integrated technologies are rather integral parts of contemporary research and training in the industry than mere theoretical propagandas. This study therefore reviews, by way of collation and comparison with previous technologies, strongly evidence of BIM's potential benefits to the industry.

2. Building information modelling and construction processes

BIM represents a combination of fairly revolutionary ideals for design technology. Although some researchers (e.g. (Thorpe 2009)) aver that BIM related technologies were discovered in the early '80s, several others (e.g. (Norbert et al. 2007)) often refer to BIM as a nascent paradigm in the industry. Some studies have also argued that BIM adoption is still slow and some significant concerns about the reluctance of the industry to adopt or deploy potential change attributes in BIM have been evidenced (Succar 2009). As a panacea to this, (Gu et al. 2008) have suggested that this situation can be alleviated when industry stakeholders and disciplines understand their roles and opportunities in BIM. As BIM integrates multi-dimensional capabilities and facilitates major improvements in design and construction processes, there are strong indications that this could revolutionize project delivery in construction (Aranda et al. 2008). Some authors have conceptualized systemic benefits that associate with BIM deployment (e.g. (Al-Humaidi and Hadipriono Tan 2009)), however it is not yet definitive from those studies who gets what and how, and how this could affect existing conventions in the industry. Moreover, while other studies focus on underpinning business drivers of BIM (Aranda-Mena et al. 2007), other authors (e.g. (Holzer 2007)) have continued to resist popular opinions that BIM's potential "wind of change" could significantly revamp the industry's age-long challenges. The way forward therefore is to explore ways of comparing significant benefits (gains) with the demerits (pains) arising from BIM deployment.

2.1 An overview on BIM

Building information modelling (BIM) has been defined *indexically* by many authors (Aranda-Mena et al. 2007; Aranda et al. 2008; Gu et al. 2008 ; Holzer 2007; Succar 2009; Tse et al. 2005). These sources suggest BIM as a platform for integrated systems; although opinion varies on putting together a universal definition that will satisfy all discipline's perspectives about BIM. However, a simple definition of BIM

may be surmised on this concept as a highly flexible object-oriented design process that provides viable platforms for multi-disciplinary integration. Unlike conventional CAD tools, BIM uses intelligent objects to represent distinctive features in designs. Some empirical reports have elicited how this reduces misconceptions, confusion and errors when interpreting designs (Dean and McClendon 2007). Other capabilities identified from literatures include its ability to generate photo-realistic graphics, multi-dimensional spatial configurations, system integration and robust embedment of graphic and non-graphic data into design components. Whilst rigid features like lines, arcs, splines circles etc used in conventional CAD applications are time consuming and *redundant*, BIM makes use of design objects such as walls, roofs, floors, windows, furniture, and services' accessories etc which can 'auto-update' each time changes are made to the database. The use of design objects does not only improves productivity, its impact on the quality of professional services is overwhelming (Barista 2009). In addition, it also facilitates the simultaneous creation, access, management, storage, use, sorting, updating and sequencing of both geometric and embedment of non-geometric information into project databases to simplify in-line processes throughout facilities life-cycle management. The following section reviews these concepts as the benefit of BIM over conventional construction processes.

2.2 Benefits of BIM

Some evidence from technical reports from industry stakeholders, including software developers and vendors, CAD drafters, BIM modellers, construction administrators, researchers and contractors' testimonials have continued to echo how discipline-specific professionals, clients, institutions and the industry are likely to benefit when BIM is correctly deployed. An outstanding part of this however, is the feasibility of these benefits when combined across disciplines. As more capabilities of BIM could become more explicit in the nearest future, it is expedient to explore them in relation to the enablers of unusual paradigm shifts in construction conventions, especially as per possible changes in professionals' roles and responsibilities. However, while efforts are being made to document the directions of these changes, it is noteworthy that not many meaningful changes would come without a price. Some of the benefits of BIM are discussed as follow:

2.2.1 Simultaneous access

For many reasons, project stakeholders need to access project databases to input and move shared data across discipline boundaries speedily and repeatedly. This, in many occasions, needs to be simultaneous. Whilst this is impossible with manual systems, a possibility of multiple accesses to databases in conventional CAD systems is that of multi-user scenario. In Ohsuga's (1989) argument on the limitations of CAD, the author pointed out that certain fundamental challenges are inherent in the underlying conventional information processing technology of CAD which deprive it from facilitating *reactive* intelligence and simultaneous access. This was also underlined by (Dean and McClendon 2007) on *e-b*

CAD-based 3D systems. However beyond this, according to Maher (2008), BIM provides platforms for project teams and stakeholders to have simultaneous access into project databases or servers. This phenomenon does not potentially shorten design and communication times, it allows early detection of design conflicts and errors as stakeholders are able to communicate and share ideas quickly. Moreover, simultaneous access allows the respective disciplines to create, update, sort, engineer and input their design opinions and information in a give-and-take manner at the same time. Therefore BIM users benefit from BIM as it permit timely integration, data sharing and creation of robust information on design components which are transferrable through the entire project life. Figure 1 show how stakeholders integrate in BIM environment.

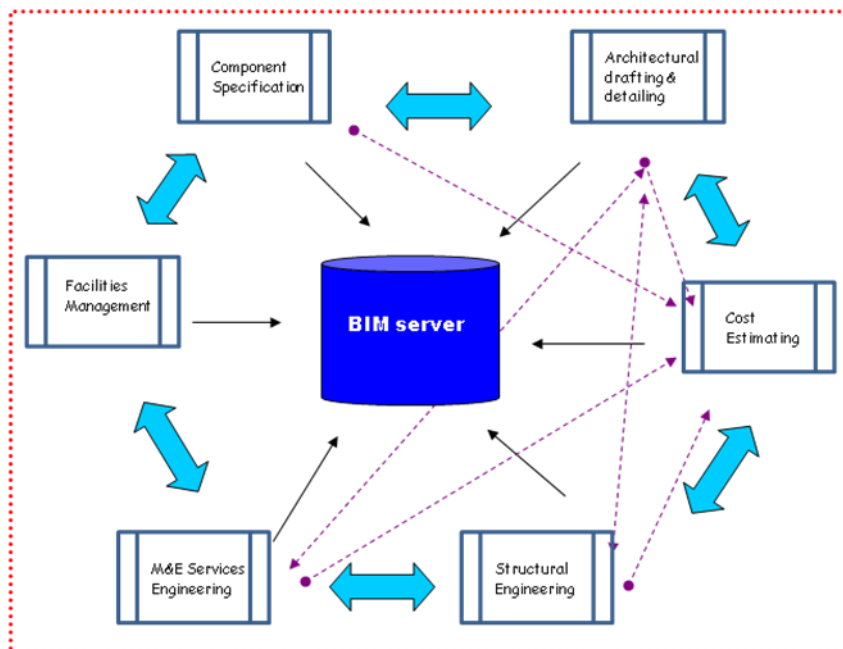


Figure 1: Integrated systems in BIM environment (Adapted from Olatunji and Sher, 2009a)

2.2.2 Robust information

Several studies have pointed out that construction processes are responsive to intense and complex information on design, components' applications and management. Construction processes are worse off when information flows inconsistently, subjectively and ambiguously (Pektas and Pultar 2006). Whilst

manual and conventional CAD techniques are arguably deficient in this respect, BIM integrates both graphic and non-graphic data to create project specific information. (Chiu and Lan 2005; Ozkaya and Akin 2006) have outlined how BIM facilitates collaborations in digital medium through which project teams share detailed information about design intentions, material applications, manufacturer's notes as well as guides to facilities operation and maintenance. As robust information reduces risks of conflicts and mismanagement, its effects are most evident in facilitating effective communication, inter-disciplinary interactions, estimating, construction, facilities management and dispute management. This

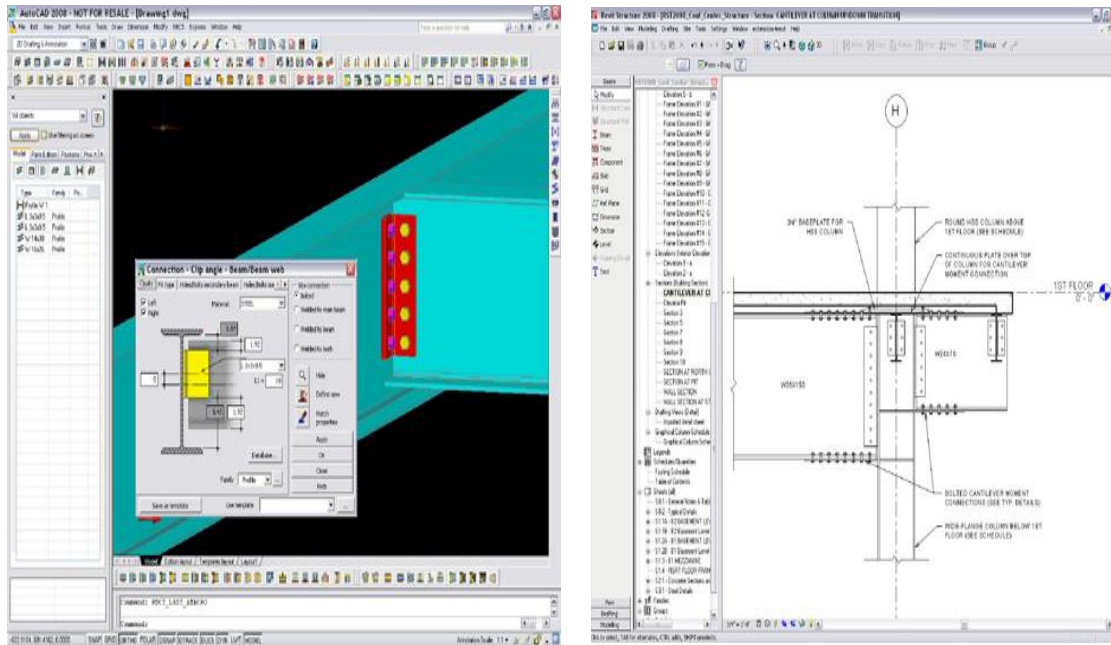


Figure 2: Model data in 2D and 3D drawings

phenomena breakthrough has been demonstrated by (Ballesty et al. 2007; Luciani 2008b). Embedded data in BIM are not limited to 3D models; they remain comprehensive even when designs are manipulated from 3D to 2D, and can be rendered fully functional in all parts of integrated systems. Figure 2 below shows model data in 3D and 2D drawings.

2.2.3 Auto-quantification

Interpretation of design information may be complex, and hence could be misleading when not definitive. Some studies have reported the implications of inconsistencies and variability in design quantification on project management (Aibinu and Jagboro 2002; Endut et al 2005). Sutrisna (2005) surmised that inefficient quantification methods might damage goals and genuine intentions in construction processes. There is yet no evidence that the shift from manual to *e-b* CAD applications in design have been able to eliminate this as they both tools are still delimited by constraints hampering consistent and accurate quantity measurement. According to (Gallelo et al. 2009), BIM has potential to conceptualize automated measurement of quantities in useable scales and formats that allow stakeholders to sort and analyse information they require at anytime. However, this does not mean that comprehensive estimates can yet be automated from BIM for all conventional purposes. Although a process was outlined by (Bakis et al. 2009) on useability of international foundation classes) (2 x 3 ifcs) for comprehensive estimation of building and civil engineering projects, this study also noted that the industry still has many hurdles to cross to automate the generation of comprehensive estimates from BIM designs. As Ho and Ng (2004)

have observed how construction professionals resort to strenuous denial of faults when confronted with error dilemmas, auto-quantification is a potential saving grace as it entrenches accuracy, accountability and value integration in CPDPs.

2.2.4 Quality communication

Many research efforts have been focused on the importance of communication in construction processes (Koskela 1992; Gorse and Emmitt 2005). Nevertheless, the limitations of manual and CAD design applications have evidently been proven. They have been linked to making construction processes more vulnerable to design errors and conflicts as well as other forms of inconsistencies in information flow (Acharya et al. 2006). Whilst manual and CAD applications do not have adequate frameworks for robust information and communication, BIM uses photo-realistic graphics, or convertible formats thereof, to transmit information. Moreover, some wealth of evidence from some industry reports (e.g. (Gorse and Emmitt 2004)) have suggested that project stakeholders are more likely to integrate and collaborate effectively when project information and communication are simplified. Consequently, BIM provides enduring platforms for on screen training, simulation, and information sharing and value integration. Thus, this reduces risks associated with errors, inconsistencies and subjectivity.

2.2.5 Multi-dimensional integration

Manifestation of risks is multidimensional in construction processes which explain why construction is highly fragmented. However, evidence abounds in empirical reports indicating that fragmentation renders construction processes vulnerable to many significant limitations. Manual and conventional CAD applications support fragmented processes, as they may be manipulated through limited dimensions that mainly reflect geometric data only. BIM represents designs in multiple dimensions and forms that are usable through collaboration for architecture, engineering, procurement, estimating, construction planning and co-ordination, and facilities management (Tse et al. 2005). Whilst most CAD applications do not communicate with each other, (Gallelo et al. 2009) have shown that the ability of BIM software to communicate with compatible applications facilitates collaboration and multi-dimensional applications. Figure 3 below shows how Vico Office®, a notable BIM software, relates with other modelling applications. This scenario, also known as also known as *nD* phenomenon, does not only optimise integration, it reduces process fragmentation and inconsistencies.

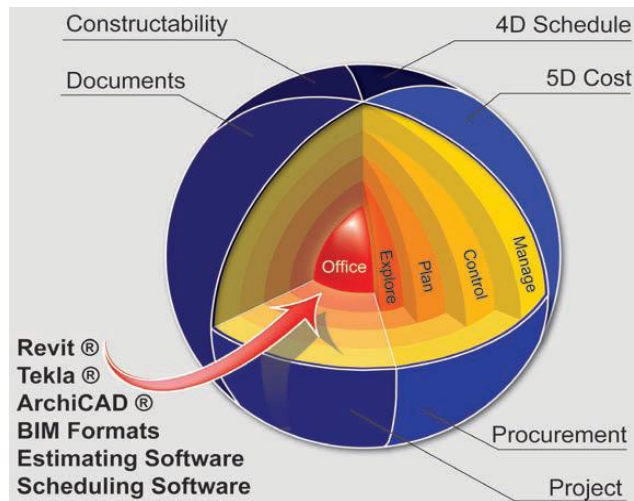


Figure 3: Typical integration platform between BIM software and other process applications

2.2.6 Project visualization

Project visualization enables project stakeholders to visualize and analyse design attributes through a phenomenon called *Second Life*. Second Life is a virtual life system where *avatars* are used to mimic human behaviours. This system is being used to teach, experiment and implement *gaming* and eConstruction (Gül et al. 2008). Benefits of this innovation include animation of real life concepts like the reactions of building components to thermal, illumination and ventilation factors, and other opportunities to review alternative options and ideals of value management. Barton (2000) outlines the impact of value management on clients' satisfaction and project delivery. Some evidence also shows that BIM's facilitation of project visualization and simulation of project components under different environments will be a significant competitive advantage for packaging CPDP business both now and in the future. This implies design and construction processes can better meet clients' expectations on project feasibilities beyond project economics, legal and technical indices than manual and conventional CAD tools would do. Additionally, while these tools have not been used for this, design and construction processes can now be visualized and simulated in BIM to replicate real life challenges such as sustainability, buildability, energy-efficiency, flexibility and so on (Olatunji and Sher, 2009b). Figure 4 shows a project visualization using BIM.

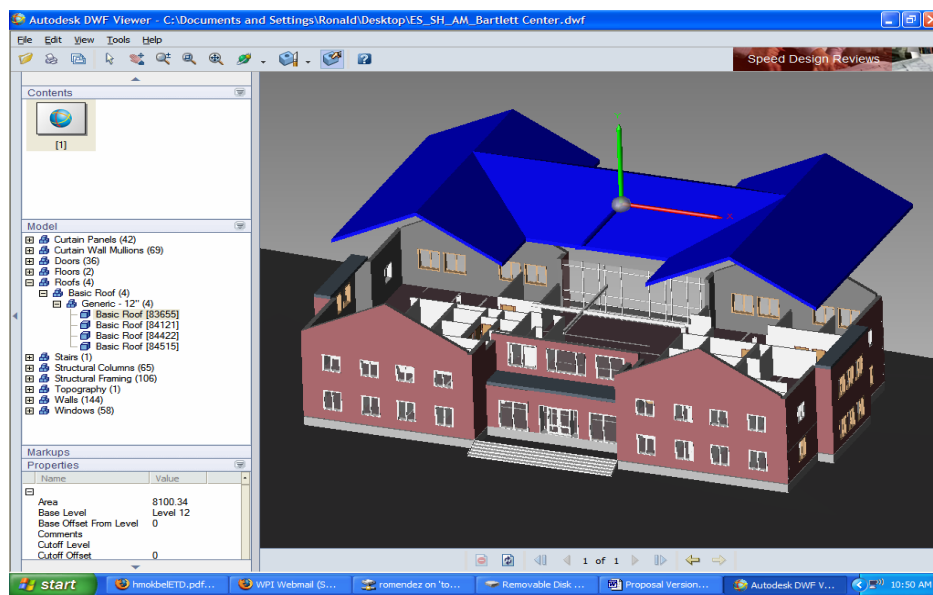


Figure 4: Project visualization using BIM (Adapted from Méndez, 2006)

2.2.7 Project documentation

As enunciated earlier, project packaging in manual and conventional CAD applications could both be time consuming and expensive. Apart from conflicts, inconsistencies and errors which are prone to fragmented processes, (Olatunji and Sher 2009b) have outlined other major disincentives to clients' interests when project documentation is fragmented electronically or manually. Although, (Sommerville, and Craig 2003) have shown how electronic document management system (EDMS) trigger cost savings, however interoperability in conventional CAD has been a major limitation. With collaboration and effective communication, BIM provides platforms for thorough integration of project documentation right from conceptualization through to detailed design, procurement, construction and facilities management. With BIM, contractors can now receive pre-quantified designs in electronic formats and still be able to modify fabrication and construction models, and store same for application in the project's life cycle model. This improves productivity, communication and innovation in CPDPs, even though the cost savings of this method have not been reported.

2.2.8 Digital facilities management

Facilities management professionals still grapple with problems of data inconsistency, design errors and fragmentation of information management processes (Luciani 2008a; Olatunji and Sher 2009a). However, BIM provides interactive platforms for streamlined information management from design all through project life. This, according to Ballesty et al., (2007), has been tapped into in the management of Sydney Opera House, a global iconic masterpiece. Process gains triggered by BIM in facilities management include simulation, auto-alert and value intelligence. As it is becoming increasingly possible in BIM for

developers and facilities managers to test and validate design options in relation to post-construction modifications, the integration of certain information into project databases can also facilitate cost-in-use and automated responses from facilities components regarding use and application limits, maintenance and management.

3. The cost of change triggered by BIM in construction

Each past century has provided distinctive eras of change in construction technologies and processes from Stone Age of the third century to the industrial revolution of the 20th Century. Although, the role and scope of such changes have not been well documented as they vary from place to place, yet they are evident. Arguably, the construction industry might, sooner rather than later, re-appraise and reposition its process in the direction of digital technology like the rest of the world. This would result into knowledge gaps as appropriate competences will be needed to service these innovations. As this becomes more evident, many construction disciplines will be challenged to either improve their knowledge base or modify their services. Although, few of these skill needs have been documented by (Sher et al. 2009), (Hardie et al. 2005) have enunciated concerns how some existing disciplines still grapple with generation and adoption of knowledge-based innovations in the industry.

Moreover, (Tse et al. 2005) have reported some basic hardware requirements for BIM implementations, while (Aranda et al. 2008) have outlined its business drivers. Further evidence suggests how revolutionary BIM is than any other alternatives that are currently available. As it is therefore becoming increasingly evident that construction professionals might no longer be excused to not deploy with BIM when it is finally adopted, their commitment to knowledge acquisition through training and constant retraining will attract some costs. Even though this may not lead to extensive gain in the short run, all stakeholders – the public, clients, contractors and construction professionals will be better off.

According to (Succar 2009), it is difficult to effect, monitor and manage change in the construction industry. However, BIM is not just a necessity; it is gradually becoming a key indicator of competence and business effectiveness. Also, it is rapidly becoming the focus of construction education, training and research for institutions that would not want to be left behind. This wind of change implies BIM will potentially narrow the technological divide between manual and CAD systems. The present slow rate of adoption will only improve if institutions and disciplines take every possible fair step to be involved in driving the change towards fuller adoption of BIM across all disciplines and geographical boundaries.

4. Conclusion

The need for effective information management in construction is increasingly becoming important. While the industry still grapples with the limitations of manual and conventional CAD applications, BIM

provides more efficient alternatives that can overcome these challenges. This study has identified and presented gains inherent in BIM over manual and conventional CAD applications. The pain however is that, for the industry to survive the change being propelled by BIM, all institutions, professional disciplines, and government policy makers must be involved to facilitate the changes necessary. BIM promises unprecedented changes in construction education, training and research. Therefore, for organizations to be relevant in the future, achieving corporate goals in implementing BIM should be a priority.

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Impact of Information Technology in Facilitating Communication and Collaboration in Libyan Public Sector Organisations

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Abstract

There is evidence that information technology already has significant impact on communication, organisational structures, management and functioning of most organisations. Information Communication Technology (ICT) results in changes to lines of command and authority, and may influence the centralisation or decentralisation of decision making and control systems. New technology, it is argued, typically results in a flatter organisational pyramid and with fewer levels of management required. In the case of new office technology it allows the potential for staff at clerical/operator level to carry out a wider range of functions and to check their own work. The result is a change in the traditional supervisory function and a demand for fewer supervisors. In this paper, a critical review of available literature is presented, which relates to the impact of information technology in facilitating communication and collaboration on communication behaviour in public sector organisations. This is in order to identify deficiencies in the area of study as well as to draw some lessons for future research. The focus is primarily on the effect of information technology in facilitating communication and collaboration in Libyan public sector organisations. Key issues associated with definitions of culture, organisational culture, communication behaviours, information technology, collaboration are presented and discussed. In addition, a critical review and synthesis of related studies on the effect of information technology on communication behaviour of individuals in organisations are addressed. In conclusion, the paper argues that the impact of information technology to facilitate communication and collaboration in communication behaviour in organisational settings is complex. The implications of these complex issues to research strategy and design are also documented together with recommendations for researchers.

Key word: communication behaviour, information technology, Libyan local culture, organisational culture, organisational structures, public organisations

1. Introduction

The theoretical and intuitional field of structural studies has developed over the past three decades, during which time various problems, issues and debates have emerged from within the literature. Thus, this review considers the impact of information communication technology on the communication behaviour of individuals in Libyan organisations. In this paper recent information communication technology studies are examined in order to investigate its impact on the organisational structure and communication among staff in Libyan public and private organisations and to provide suggestions for future research on this issue. It also analyses the impact of culture issues on adoption ICT and the extent to which information communication technology affect the communication behaviour of individuals in terms of harmony and organisational hierarchy structure in Libyan organisations.

2. Methodology

This paper draws on an ongoing doctoral study in the area of communication in Libyan planning organisations. This paper, however, is primarily based on a thorough and critical review of literature. It documents and discusses key issues drawn from related literature and areas of communication behaviour, organisational dynamics and power influences in public and private organisations in Libya. Academic journals, conference proceedings, text books and websites are the main sources of information.

3. Culture

Culture is strongly connected with communication and is defined in many ways. Martin et al, (2004, p. 337) have defined culture as “learned patterns of behaviour and attitudes shared by groups of people”. Moreover, the American Psychological Association (2002) defined culture as “The belief system and value orientations that influence customs, norms, practices and social institutions including psychological processes (language, care taking practice, media and educational systems) and organisations (media educational system)”. Thus, culture at the societal level is manifested in values and less in practice. However, culture at the organisation level is more likely to be manifested in practice and less in values (Hofstede, 1997). Therefore, culture can be defined as the shared patterns of behaviours and interactions, cognitive constructs, and effective understanding that are learned through a process of socialization. These shared patterns identify the members of a culture group while also distinguishing those of another group. Due to national cultural influences, Twati and Gammack, 2004 consider organisational culture in Libya as a strong culture, which resists organisational change in many ways, including the adoption of information communication technology, decision making process, communication, employment, professionalism and other aspects.

4. Information-communication technology

Information Communication Technology (ICT) was conceptualized by a number of researchers as electronic machines, devices, and their applications that have both computing and communication capabilities.

For example, Child and John (1987) defined ICT as technologies and applications which combine the data-processing and storage powers of computers with the distance-transmission capabilities of telecommunications.

Similarly, Huber and George (1990) defined 'advanced IT' as devices (a) that transmit, manipulate, analyze, or exploit information, and (b) in which a digital computer processes information integral to the user's communication or decision task. Exemplars of ICT are electronic mail (e-mail), conferencing technologies, electronic bulletin boards, file transfer, collaboration technology (e.g., group support systems), shared electronic databases, electronic data interchange, the fax, voice mail and the telephone. The last three, although often being classified exclusively as communication technologies, are enlisted here because they (1) are pervasive, and (2) are increasingly acquiring computing capabilities (e.g., v-mail systems rest on the computer, the fax can be computer-mounted, while the telephone is becoming part of integrated computer-telephone systems).

5. Organisation culture

Organizational culture refers to patterns of shared values and behaviours of organization members. Of interest for this review are those values and behaviours that have been researched in relation to ICT. Several studies in laboratory and organizational contexts found that e-mail and other ICT, due to the lack of social cues they imposed, could lead to relatively uninhibited behaviour, social equalization, decision, shifts and creation of new ideas (Travia, 1998).

The relatively uninhibited behaviour was sometimes interpreted as an undesirable aberration from social norms (Kerr and Hiltz, 1982), while at other times it was deemed stimulating to organizational innovation (Brennan and Dooley, 2005). The occurrence of uninhibited behaviour was attributed to personal and group characteristics rather than to ICT itself (Smolensky et al, 1990). Other findings were that ICT could help people to avoid conformism (Smilowitz, et al 1988), express feelings more honestly and create a community of spatially dispersed organization members when social communication bursts out in a bureaucratic organization (Foulger and Davis, 1990), or when scientists utilize ICT on a regular basis (Kerr and Hiltz, 1982). In addition, significant cooperation in knowledge sharing was discovered in ICT-rich organizations (Dhar et al 1989). Moreover, changes in accountability patterns were found among ICT users (Guttiker et al, 1988). Finally, many studies found that communication via ICT is likely to cross spatial and department boundaries (Hiltz and Starr Roxanne, 1984; Kerr and Hiltz, 1982).

6. Organisation structure

A number of writers have pointed out the importance of an organisation's structure and the relationship between it and organisation's size, strategy, technology, environment, communication and culture (Mintzberg, 1989), (Miller, 1989), (Burns & Stalker, 1961) and (Handy, 1990, 1993). Organisation structure is defined as "the arrangement of workflow, communication and authority relationships within an organisation" (Niewenhuzen and Rossouw, 2008). Analyses, such as those undertaken by Van den Van (1976), Jackson and Morgan (1982) and Fredrickson (1984) put forward a model of three dimensions: Complexity, formalisation, and centralisation. The relationship between ICT and organization structure dimensions was investigated by Thomas 1970, who found that a reduction of hierarchy layers was associated with the use of computers in the insurance industry. Similarly, Pool, 1983). argued that the telephone led to aberrations from hierarchical patterns in the old steel industry because it made possible for workmen to access executives. Next, smaller formalization was found to be related to the use of computer systems in manufacturing firms (Pfeffer et al, 1977) and in various industries (Wijnhoven and Wassenaar, 1990).

Centralization was also found to relate to ICT, although in a diversified fashion. The link between ICT and decentralization at the operational level was discovered in railroad management (Dawson and McLaughlin, 1986), and in city departments of human resources (Keon et al 1992). Overall, decentralization was related to ICT in manufacturing (Pfeffer et al, 1977), small newspaper organizations (Carter and Nancy, 1984), and in a hospital (Barley and Stephen, 1990).

However, it was also discovered that ICT related to increased centralization at the executive level in the insurance industry (Baker, 1992), large newspaper organizations (Carter and Nancy, 1984), and railroad management (Dawson and McLaughlin, 1986). Finally, ICT-related spatial dispersion was discovered in organizations of scientist (Hiltz, 1984; Kerr and Hiltz (1982) and a software vendor (ECSS, 2008). Thus, a key advantage of information systems is to be able to simplify organizational structures.

Therefore, there is a strong relation between organisation structure dimension and ICT, which would results in reduction hieratical levels, widening span of control, decentralisation at operation level and centralisation at executive level.

7. Communication behaviour

In the literature there are many definitions for organisational behaviour. Gibson, et al (2000, P.5) described organisational behaviour as follows: "The field of study that draws on theory, methods and principles from various disciplines to learn about individual perspectives, values, learning capacities and actions while working in groups and within the total organisation; analysing the external environments effect on the organisation and its human resources, mission, objectives and strategies". Also, Daft and Noe (2001, P.4) defined organisational behaviour as: "The actions and interactions of individuals and groups in organisations". Communication is widely studied as a means of transmitting ideas as part of culture (jandt, 2004). Communication can be divided into three types: verbal (use of

words with specific meaning), paraverbal (tone of the voice), and non-verbal communication. Nonverbal communication can be defined as communication without words while verbal communication is defined as communication with words (Remland, 2004). It has also various components, such as encoding, message, channel, receiver, decoding and receiver response in achieving success in communication. Therefore, communication behaviour is divided into verbal and non-verbal. In verbal communication in high context culture, as in the Libyan culture, people usually use fewer words in delivering messages, which is opposite in low context culture such as in America (Hofstede, 1997). Moreover, in Libyan society, large power distance cultures, formal and respectful behaviours are important in the organisational hierarchy to show differences between the leaders and other members. For instance, members of staff usually use formal title when they communicate with their leaders, such as Mr, Dr, and Madam (Hofstede, 2001). This may be due to social tradition which encourages respect and obedience to parents and elderly people (Abouhidba, 2005). Therefore, an understanding of the national culture has a serious influence on how managers and employees communicate to make decisions and interpret their roles (Hanky, 2004).

8. Public and private organisations

According to (McNamara, 2001), an organisation is a group of people working together to achieve the same goal. In the beginning, organisational studies concentrated on moral bases of management, leadership and dynamism of bureaucracy. In the second half of the last century there were different studies about organisational structures, activities and relationships between organisation and their communities (Boden, 1994). In traditional political science literature it is emphasised that there are distinct differences between private and public organisations (Lane, 1993). Most public organisations do not have the same strategic freedom that private organisations have since some of their strategic goals are decided by politicians. This puts constraints on public organisations' ability to operate and may in some instances force public organisations to make decisions that are not sound for society at large (Lane, 1993). This also affects the resources available to public organisations. They do not always have the resources needed in order to meet demands, making it necessary for public organisations to prioritise which customer/user to serve. This is a situation unfamiliar to private organisations (Eskildsen et al., 2004).

A further feature of traditional public organisations is that they are subject to political rather than market controls. External controls on private organisations are market controls such as competition, consumer constraints and shareholders interests. Instead, public organisations have traditionally been constrained by political authority and political activities. Their objectives, structures, and processes have often been defined by central bureaucracy agencies or constrained by legislation (Cole, 1988).

In Libya, communist public organisational systems are adopted in many sectors, such as business, education, health, and media in addition to other social and political organisations. The Libyan national culture is characterised by high power distance, low individualism, medium masculinity, High uncertainty avoidance (Hofstede, 1983). The most common form of organisations in Libya is the classical bureaucratic structure. This structure is inflexible, impersonal and high standardised. Furthermore, it is characterised by a tall structure, which have many hierarchical levels, there is a long distance between the top manager and the bottom manager, the more hierarchal the structure, the more

inflexible is like to be, the more difficult communication becomes. There are large number of job titles and a career path to employee. Fewer numbers of subordinates a particular manager is required to guide, the organizational structure would be taller. Libyan public organizations are owned by government, and are runned by general managers. They promote values of high power distance and collectivism (Twati, 2004). Therefore, the organisational culture in Libya as a strong culture resists change in many ways, including adoption of ICT, decision making process, communication and other aspects.

9. Technology's impact on organisation

The impact of information technology will have significant effects on the structure, communication, management and functioning of most organisations. It demands new patterns of work organisation and effect individual jobs, the formation and structure of groups, the nature of supervision and managerial roles. Information technology results in changes to lines of communication, command and authority, and influences the need for reconstructing the organisation and attention to job design. Computer based information and decision support systems influence choices in design of production or service activities, hierarchal structures and organisations of support staffs. Information Communication Technology may influence the centralisation/ decentralisation of decision making and control systems. New technology has typically resulted in a flatter organisational pyramid with fewer levels of management required (Edward et al, 1991).

In recent times, technology has become an ever increasing presence in organisations and it is one of the hot topics. More and more businesses, large and small, are trying to incorporate the latest technology into their operations. This notion is evidenced by the fact that the popular publications now have technology sections, and information systems departments are becoming critical components of most organizations. The appeal of the whole information technology arena is that arguably it is designed to make people and organizations more knowledgeable, efficient, and profitable.

The scope of technology that an organization can espouse or employ is huge. Regardless of the complexity of the system or the size of the organization, one thing is certain - the incorporation of such technology or information systems will accompany change. Implementation of technological systems can either act as a catalyst for change or be the means of achieving a desired change. Regardless of the motivation, a properly integrated system ideally will take into account the impact on the organization before it is put into place. The contribution of information technology and its impact on the organization is emphasized by Nadler in (Gerstein, 1992 p.5), who states "perhaps the largest single influence on organizational architecture and design has been the evolution of information technology, certainly has its place among the key elements which shape an organization. The model used by Andersen consultants is typical when it lists technology as an equal attribute, along with strategy, people, and business processes. The interconnectivity of these elements should be obvious, for one cannot be changed in a transformational sense without at least consideration of the others. While the formal structure or arrangements within an organization will likely be affected by the arrival of new technology, this does not have to be the case in all situations. More specifically, information technology can be linked to changes in factors such as job design, physical layout or

location, supervisory relationships and autonomy, cooperation inside and outside the organization, and formation of work teams.

One advanced idea whose time has come is the notion of the virtual workplace. This concept is based on the idea of employees being able to work independently as a result of having access to information. One article proposes "the virtual workplace provides access to information you need to do your job anytime, anyplace, anywhere. Employees do not have to be tied to their offices to do their jobs."(Jenner, 1994 P.16). The idea of not even having a set office space certainly would be a change from the typical routine of showing up at the office from 9 to 5 (ideally) and performing your work at your desk. Such a plan would obviously be dependent on the job to be accomplished, but it is interesting to think of the supervisory implications. Such employees would have the ultimate amount of autonomy and would have to be managed accordingly. Tasks would have to be more objective or goal oriented and measures of job performance could no longer depend on face to face interaction, but rather would have to be tied strictly on the ability to complete assigned tasks.

It seems to be a common theme that information systems will change even more traditional supervisory relationships. Computer networks allow people to communicate quickly, share ideas, and transfer information without regard to physical locations, or to a reasonable extent, even without regard to the temporal dimension. Therefore, a supervisor will be able to monitor the activities of a larger number of subordinates without requiring them to report directly to him/her. Both David Nadler and Jeremy Main refer to this "span of control" as a measure of how many individuals or teams that a supervisor can effectively manage. Main makes the point that such spans will give way to "spans of communication" which he defines as the number of people that an executive can reach through a good information system (Main, p.52). Nadler makes the prediction that such an executive could supervise hundreds of empowered individuals and groups (Gerstein, 1992 P.173). It is important to note that again interdependency of people and technology comes up in the form of empowerment. Obviously, such relationships would not be possible under traditional job limitations, but through empowerment of employees; such a stage can be appropriately set. This implies that the employees are properly trained on the technology and that they understand the direction taken by the organization and their role in it. Thus the informal organization is also affected because now the culture is changing by giving employees more authority and self-direction. The theorist Peter Drucker sums up the autonomy of this new empowered employee by saying " employees in the new information-based company will know what they have to do without a flock of vice-presidents feeding them information and orders."(Main, 1988 P.50).

The use of information systems can also impact the organisation's relationship with other organisations. The ability to gain information from others up or down a process or distribution channel makes having control over that process or entity less of an issue. This is especially true of organisations that may have considered a vertical integration strategy, but now realize that "vertical integration becomes less necessary when organisations use information systems imaginatively."(Main, 1988 P.51). The ability to share information and the ease of transferring designs can also lead to an increase in outsourcing, which is a growing trend as organisations try to reduce their own workforces and may find themselves shorthanded. The tasks that employees perform within an organization are being drastically affected by the increased mechanization and application

of technology as a part of the production process. In many settings, tasks previously performed directly by human operators are being automated, changing the human's task to one of supervisory control. "Now the expectations of an average employee in such an environment has to change, because they are no longer performing repetitive tasks, but rather must be able to recognize and react to problem situations" (Fleck, 1999 P.625). The fact that today such work has been automated to a great extent leads to the issue of restructuring the work. A pattern which seems to be catching on is illustrated by Rosenbrock 1993 in his description of a workforce which shares in the purpose of production through the organization of production 'islands' or 'cells'. These cells would be self-managing and responsible for scheduling, quality, supplies for their area, and the maintenance of their machinery.(Rosenbrock, 1993 P.169). He basically sees the automated facility as an opportunity to shift the emphasis towards work teams with a great deal of autonomy. Although the formal structure does not have to change to qualify as a transformation, the above discussions point to the fact that the structure will nearly always be affected by the implementation of technological systems. In his Fortune article, Main 1988 speaks about winning companies, saying "they will adopt fluid structures that can be altered as business conditions change. More than being helped by computers, companies will live by them, shaping strategy and structure to fit new information technology."(Main, 1988 P.50). This emphasis on flexibility points out the fact that there is no one formula for determining how the formal organization will look after such a change. In his simile between organizations and architecture, Nadler points out that "in organizational terms, the role of the hierarchy as the principle means to coordinate, control, and facilitate communication is dramatically impacted by the capabilities of information technology. The existence of these capabilities, however, does not determine the organizational architecture of the future; it simply makes a new architecture possible."(Gerstein, 1992 P.25). Nonetheless, the efficiency gained from technology and associated information systems will generally serve to reduce the number of people in an organization; except perhaps in the information systems department/area. But with tightening budgets, even these departments are feeling the need to downsize. Main 1988 also makes the prediction that corporate staff could disappear, and that after implementing IT programs, it is common for an organization to move from a dozen layers of middle management between the front-line supervisor and the Chief Executive to about six (Main, 1988 P.52). IT affects the nature of individual jobs and the formation and structure of work groups. There is a movement away from large scale, centralised organisation to smaller working units. Processes of communication are increasingly limited to computer systems with the rapid transmission of information and immediate access to their national or international offices

Thus, a key advantage of information systems is to be able to simplify organizational structures. Although they served a purpose at one time, the benefits of improved coordination and increased supervision discussed earlier arguably replace the need for tall, hierarchical organizations. In fact firms with well-developed management information systems lend themselves to a move towards flat structures. However, caution needs to be exercised. One author warns that delayering is not right for every organization and should not be done unsystematically (Nelson, 1988 P.56).

10. Widening the span of control with information technology

As has been mentioned Information technology can be utilized to widen a manager's span of control. According to (Monge and Fulk, 1999), "Hierarchical organization forms are social structures based on

domination and control through rules, programs, procedures, and goals. Communication and information technology can now assume these functions by programmed routines that are built into the technology..." Organisations that use computer-based technology, then, can eliminate middle management, allowing them to widen the span of control of managers and thereby flatten the organizational structure. Decreasing the layers of control increases communication and the flow of information across departments and groups. On the other hand it makes organizations more complex, differentiated, and decentralized.

Employees required to make decisions that in the past might have required managerial input can use decision support systems (DSS) and expert systems. Even unusual or unique problems, which have not yet been incorporated into a DSS or a searchable database, still can be solved more easily with IT. While in the past, managers had to solve such problems by communicating directly with employees, today, IT allows for communication that is asynchronous (at different times and places). Thus, computer-based technology removes temporal and spatial barriers to communication and collaboration. Moreover, a manager can receive E-mail from numerous employees and solve dozens of problems when he or she has the time and from various locations.

The geographic proximity of the employees being supervised is irrelevant to organizations that utilize the latest IT, which makes it possible for these organizations to coordinate necessary tasks. Managers who take advantage of the latest group support systems (GSS) software, which aids group decision-making, and who make use of E-mail and videoconferencing can widen their span of control, even if employees are spread all over the world. Geographic proximity between managers and employees is no longer necessary. Today, employees at many companies telecommute. One company can utilize computer programmers working in India, manufacturing facilities in Singapore, and information officers in California. GSS software, such as Lotus Notes, allows for asynchronous interaction by, as well as between, employees and managers. Moreover, by having computer-based technology, it makes it possible to reduce layers of management and flatten the organizational structure.

Emerging computer-based technologies offer an ideal teaching and learning environment. As such, they can be harnessed to train and to improve the abilities of employees. For example, continuing skills-based education can be accomplished through the use of IT (e.g., educational software utilizing multimedia, simulation, teleconferencing, web sites). Training materials can be placed online, enabling employees to learn at their own pace. Furthermore, employees who have questions can go to the Internet and/or Intranet (an individual firm's private network using Internet technology) and find solutions, thereby freeing management from having to answer every question.

In giving employees direct and immediate access to knowledge and information previously possessed solely or primarily by middle management, IT makes possible the empowerment of employees. Under empowerment models of management, a participative workplace climate is created with decentralized decision-making, employees are given decision-making authority and are held accountable for results (Rominger, 1996; Sheridon, 1998). Empowerment allows well-trained and experienced employees to swiftly make decisions in a changing global marketplace. By dispersing information throughout the organization, then, IT enables employees to improve their abilities and to be entrusted with decision-

making, thereby eliminating middle management, widening the span of control and flattening the hierarchy.

Today, face-to-face communications have been replaced, to a large extent, by E-mail; thus increasing the speed of decision-making. Companies need managers who understand technology and know how it can be used to make companies more efficient. It is necessary for today's managers to have the ability to envision solutions through the use of technology, for example, the various types of computer support that enhance decision-making and creativity (Klein, and Dologite, 2000). Moreover, even an "ordinary" manager with the ability to harness the knowledge available over the Internet and Intranet can become extremely effective. A good manager, today, is not one who relies solely on the knowledge learned in the past, but rather one who is willing to find the latest information using the most recent technology. By improving and supplementing the communication and decision-making abilities of managers, IT allows managers to widen their span of control, resulting in the thinning of the ranks of middle management.

While implementation of information systems and technology in general can be a gain to an organization and be part of a transformation that results in vital improvement, it is also essential to at least consider the drawbacks associated with this progress. By doing so, the organization can avoid some of the associated pitfalls. These disadvantages can be categorized as behavioural and non-behavioural. To begin with the second of these groups, there are potential problems with the networks that would be established to allow information to flow. First of all is that as the number of users increases, strains on the system and on the ability to monitor users' activities will begin to emerge. Furthermore, organisations want systems that can cross organizational boundaries, which would be needed for the utmost level of outsourcing or collaborating design efforts. As many frustrated computer users would understand, there are potential constraints due to compatibility between systems. In addition, such a system would make it easier for a potentially hostile company to gain sensitive information that it could use to its advantage (Friedmann, 1994).

The behavioural issues revolve around two major themes. One is that people and organizations tend to reject new technology because they are reluctant to change. For this reason it is important that the change come about as part of accompanying change in the organizational practices and culture. It is also essential to incorporate organizational learning in to the acceptance of information technology. It is through learning (with coaching from those familiar with the technology) that the organization's members will allow the change to take hold and reach new heights of productiveness (Seybold, p.264). The second theme concerns employee involvement in the change and the resulting job satisfaction. This aspect relates back to the discussion of empowerment needed to effectively implement automated processes. If it is not viewed as part of an overall transformation, the addition of technological process improvements or information systems which on the surface take away human responsibility is likely to lead to job dissatisfaction. In one sense such advancements remove the last bit of skill that employees put into their job. Evidence of such discontent is given by absenteeism within the auto industry and by acts such as sabotage at a state-of-the-art General Motors facility at Lordstown, Ohio.(Alexander, 1977, P.401). The bottom line is that as good as technology may be, it cannot act alone as a cure-all to improve organizational effectiveness.

Many information systems departments themselves are also discovering that they can stimulate improvement in overall company performance by integrating information systems to internal structural change. To do so involves establishing self-directed work teams with more responsibility and freedom. For example, West Coast Energy, Inc. is a natural gas transportation company in Vancouver, British Columbia. They found that the original support provided by their systems and information systems staff did was not align with the way that the company did business. After failing at one attempt to fix the problem, they realized that the key was in the linkage between the processes and the information technology. The division manager of information systems and technology summed it up as "originally, we tried to disperse the staff out to the business units, but we were getting little receptiveness. Later, we implemented a reorganization to align IS with business processes. We used to be functionally aligned. Now we are business process aligned "(Goff, 1994, P.100). Another example of this same issue in a different industry is Metronic Corp in Minneapolis, which makes medical implant devices. Their 90 member information systems department is organized into sixteen functional teams that are aligned with the corporation's six lines of business. But there still is flexibility. As the project load changes, team members may cross over to other teams to provide assistance (Panepinto, 1993 P.84).

11. Knowledge workers in organisation

The above study has highlighted a number of characteristics that are relevant to effective functioning of knowledge workers in the learning organization. A knowledge worker is anyone who works for a living at the tasks of developing or using knowledge (SearchCRM.com, 2003). For example, a knowledge worker might be someone who works at any of the tasks of planning, acquiring, searching, analyzing, organizing, storing, programming, distributing, marketing, or otherwise contributing to the transformation and commerce of information and those (often the same people) who work at using the knowledge so produced. At a fundamental level, the objective is to achieve the synergy of data and information processing capacity of information technologies, and the creative and innovative capacity of their employees. Hence, the knowledge workers need to be facile in the applications of new technologies to their business contexts. Such understanding is necessary so that they can delegate "programmable" tasks to technologies to concentrate their time and efforts on value-adding activities that demand creativity and innovation. More importantly, they should have the capability of judging if the organization's practices are aligned with the dynamics of the business environment.

12. How an organisation nurture their knowledge workers

Technology enables the knowledge worker. It provides the foundation for making full use of data coupled with employees' skills and ideas. There is a need to automate and centralize the sharing of knowledge to deliver only the relevant information to employees from every possible source. They ensure the right information goes to the right person at the right place and at the right time. The challenge for many organizations is to capture an employee's knowledge and share it with others, thereby empowering the entire organization to make best use of its information. Furthermore, single organization employee rarely performs an entire work process, therefore staff must be able to

collaborate and work as team on different project documents and databases which usually reside in disparate back-end systems.

Organization can empower their employees by developing new service processes and exploiting open Web-based technologies that enable easy integration among applications, devices and data storage. Automated workflow, document management, data warehouses, intranets and extranets can all work together to ease the flow of communication. They allow organizations to optimize processes on a team-oriented basis. They also enable employees to move naturally back and forth from working within a document to working within a group of people. No matter what they are doing, common applications are always at hand. Colleagues can respond easily to day-to-day questions and unplanned events in real-time. Employees throughout a department can contribute to a goal without major interruptions in the flow of their work.

From this discussion, it is apparent that technology is a critical element of organisational transformations. While it is generally viewed as progressive and a means to increase the efficiency and overall performance of the organisation, this can only happen if it is done as part of a larger change effort, regardless of whether the change is driving the technology, or technology is driving the change. Organisations that are able to successfully undergo such changes will be better prepared for the future, since there is no doubt that the emphasis on increased use of information technology and advanced automated systems will continue. As one source put it, "the trend toward a highly mobile, flexible, dynamic, informed and networked workforce is growing exponentially." (Jenner, 1994 P.15).

13. Conclusions

From the literature review of information communication technology studies, it can be concluded that the impact of information technology have significant effects on organisational structure, communication processes, management and functioning of most organisations. Decreasing the layers of control increases communication and the flow of information across departments and groups, while also making the organizations more complex, differentiated, and decentralized (Edward, et al 1991).

Libyan organisations are characterised by a bureaucracy and tall hierarchal structure. The more complex organisations, made up of many horizontal and vertical divisions , have a more important need for efficient communication (Hatch 1977) . In conclusion, Libya as a case has not been sufficiently researched. Therefore, there is a necessity for more empirical studies to investigate the cultural and structural issues that inhibit the adoption of information communication technology within the Libyan context. Research in the future should investigate the role of information communication technology on eliminating layers of bureaucracy in Libyan organisation's structure.

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Building Information Modelling: Literature Review on Model to Determine the Level of Uptake by Organisation

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Abstract

Building Information Modelling has been recognised as one of the Information Technology/Information Systems that could assist construction delivery in achieving Integrated Practice. However, the level of uptake currently varies between one organisation to another and has raised the need to determine whether the uptake is moving towards integrated practice or not. Through a literature review, this paper discussed a few models that that could be used to determine the level of uptake and they are CMMI, (PM)², SPICE, BEACON, VERDICT, i-CMM and BIMMi. This paper concludes that VERDICT, i-CMM and BIMMi can be used to determine the level of uptake. The selection of the model, however, depends on the purpose and area of evaluation.

Keywords: building information modelling, level of uptake, integrated practice

1. Introduction

It has been eleven years since the report of Rethinking Construction by Construction Task Force was released. The report which is also known as Egan Report (1998), was produced to initiate improvement in quality and efficiency in the U.K construction industry, citing that low profitability, low investment in research and development, inadequate training and low client satisfaction as particular area of concern. As a recommendation, the report also identifies five key drivers for change and they are committed leadership, a focus on the customer, integrated process and teams, a quality driven agenda and commitment to people. Since then, much effort has been driven by the industry and academia to support the national agenda.

Recently, to review the progress of the construction industry, another report has been produced in 2009 by Constructing Excellence. The report, which was entitled Never Waste a Good Crisis: A Review of Progress since Rethinking Construction and Thought for Our Future, produced by several voluntary industrial player, has conducted a survey in 2008 to seek for validity of Egan's original drivers and also to track progress. The result shows that Egan's original drivers are still valid in today's market condition. The overall result however, shows that although there has been significant improvement, it has not been on the scale anticipated by the task force and according to Sir John Egan, on a scale of 10, only the score of 4 could be given since the expectation was that the industry could have had a revolution and a bit of improvement was achieved instead. On the other hand, Sir Michael Latham, also shared the same opinion by saying that, what has been achieved was more than expected but less than hoped.

As thoroughly discussed in the Egan Report, fragmentation was identified as one of the critical problem and many agree that by resolving the fragmentation issue, the industry could improve significantly. Consequently, many approaches and concepts have been identified, developed, introduced and tested to provide the solutions which lead to the term "integrated practice" in construction. Such of them are, to name a few, concurrent engineering (Anumba et al, 1998) , web based project management (Anumba et al, 2008; Alshawi and Ingirige, 2003), partnering (Bresnen and Marshall, 2000), Building Information Modelling (Eastman et al., 2008; Sacks et. al., 2005; Howard and Bjork, 2007), 4D modelling (Fischer, 2001; Heesom and Mahdjoubi, 2004), nD modelling (Aouad et al., 2007; Lee et al. 2003) and Integrated Project Delivery (AIA, 2007).

Among the solution, the used of BIM as the repository is identified as an important tool to achieve the collaboration required for integrated practice. One of them is Integrated Project Delivery (IPD) which has been introduced by the American Institute of Architects (AIA) where in the the guide to assist effective delivery of IPD, the utilisation of BIM is very important and the full potential benefits of both, BIM and IPD are achieved only when they are used together. On the other hand, a well known association, International Council for Research and Innovation in Building and Construction, CIB is also supporting integrated practice in the construction industry by launching Integrated Design Solution as a priority theme of CIB. The theme "Improving Construction and Use through Integrated Design Solutions" (IDS)

has been under development since early 2006 and in June 2009 the CIB IDS 2009 First International Conference was held. The theme aims at speeding up the adaptation of techniques and practices that guide the traditional document-based work methods towards the use of Integrated Building Information Modelling.

The use of BIM has also been extended by the work that has been carried out by the University of Salford's (UoS) From 3D to nD Modelling project which aimed to integrate an nth number of design dimensions into a holistic model which would enable users to portray and visually project the building design over its complete lifecycle. In the project, the model developed is based upon the Building Information Model where the BIM will be a repository that stores all the data objects with each object being described only once. In the project, the dimensions that have been incorporated into the model are whole-lifecycle costing, acoustic, environmental impact data, crime analysis and accessibility. The uniqueness of the work carried out by the university however, is that it could enable the what-if analysis to be carried out before the real construction takes place; for instance what are the knock-on effects for time, cost, maintainability, etc of widening a door to allow for wheelchair access (Marshall-Ponting and Aouad, 2005).

The aforementioned effort by CIB, UoS and AIA, perhaps could be the target of implementing BIM. Since BIM has many potential, which to some extent, influence the government policy of tendering (General Service Administration, 2010). Many companies are moving towards BIM and claims that they are BIM capable but the real question is, to what extent they are really capable since the applications of BIM itself are very wide. Is it enough to categorise a company as a BIM capable company if the implementation of BIM is in a small fracture of the process, for instance, drafting purpose. Or would it be equal to label a company implementing the BIM for the purpose of visualisation only as compared to the company which using it for the clash detection application where several models are needed to be developed and brought together. Clearly, the level of uptake of BIM plays an important assessment to understand the current position of the industry whether they are moving towards the achievement of integrated practice or simply satisfy the need to stay in an isolated application.

This paper tries to bring forward the assessment model that could be used to determine the level of BIM uptake. To start with, general discussion of BIM will be drawn followed by the general model for assessing performance of Information Technology/Information. After that, the models which related specifically to BIM, will be discussed in details and finally a recommendation will be drawn upon.

2. Definition of BIM

In the context of application within construction industry, it is really important to understand the definition of Building Information Model and Building Information Modelling. According to Kymmel (2008), by using software and hardware related to computer application, Building Information Model represent the building virtually where the physical characteristics of the project and all information are

contained or attached to the component of the model. The model may include any or all of the 2D, 3D, 4D (time element-scheduling), 5D (cost information), or nD (energy, sustainability, facilities management, etc., information) representations of a project. While on the other hand, Building information Modelling is defined as the act of creating and/or using a Building Information Model. In this context, the Building Information Modelling is taken as a tool that may help in achieving the team's project goal.

Also, in defining Building Information Modelling as a tool, the concept is also supported by AIA where according to AIA (2007) BIM is defined as a digital, three-dimensional model linked to a database of project information. It is identified as one of the most powerful tools to support IPD. Because BIM can combine, among other things, the design, fabrication information, erection instructions, and project management logistics in one database, it provides a platform for collaboration throughout the project's design and construction.

In comparison Eastman et. al (2008) argued that BIM is just a software or tool. In their context BIM is defined as a modelling technology and associated set of processes to produce, communicate and analyse building models. Building information modelling is a verb to describe tools, processes and technologies that are facilitated by digital, machine-readable documentation about a building, its performance, its planning, its construction and later its operation. Therefore BIM describes an activity, not an object. In this context, the building information model on the other hand, is the result of the modelling activity and further explained as a digital, machine-readable record of a building, its performance, its planning, its construction and later its operation.

According to Hardin (2009), Building Information Modelling is just not a tool but it is a process and software which agrees with Eastman et. al (2008). This is supported by the explanation that "many believe that once they have purchased a license for a particular piece of BIM software, they can sit someone in front of the computer and they are now doing BIM. What many do not realise though is that building information modelling means not only using three-dimensional modelling software but also implementing a new way of thinking. In the authors' experience, as a company integrates this technology it begins to see other processes start to change. Certain processes that have made perfect sense for CAD-type technology now do not seem to be as efficient. As the technology changes, so do the practices and functions of the people using the technology."

3. Application of BIM

From inception through handover the project, BIM application could be applied for every single phase of the project. According to BIM Project Execution Planning Guide by The Pennsylvania State University, there are twenty- five uses of BIM for consideration on a project as can be seen in Figure 1. And as the guide suggest, it is not appropriate to implement all of the application of BIM. The most importantly is to

understand the main reason why BIM is used in the project and to set objectives of adoption. Only then, the use of specific BIM application can be selected.

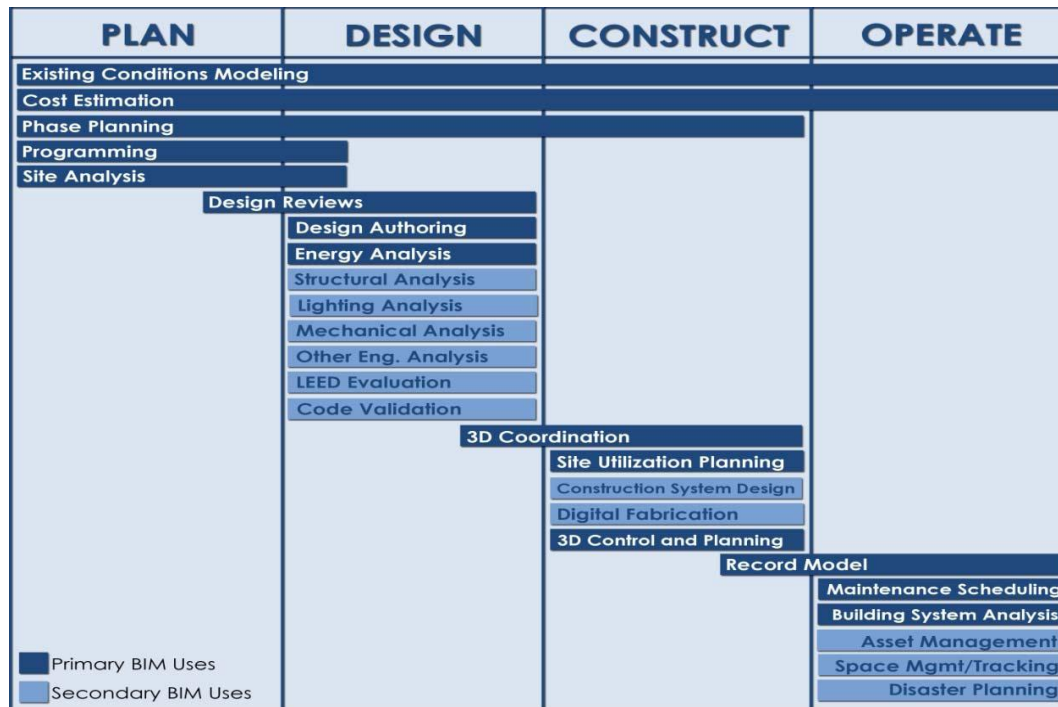


Figure 1: BIM application in project life-cycle (BIM Project Execution Guide, 2009)

4. IT/IS performance measurement

BIM is a part of Information Technology/Information System (IT/IS) and a lot of issue regarding to the uptake of BIM are overlapping with general IT/IS uptake. Therefore, the IT performance measurement model, especially those related to construction industry need to be reviewed. Since 1970, according to Alshawi (2007), high percentage of failure of IS/IT projects to meet their intended business objectives has been a major concern for many organisations. A lot of projects were either abandoned, significantly redirected or to the extend, kept alive in spite of the failure has lead to the need for the development of evaluation methods to measure the effectiveness of IS/IT.

In measuring the IS/IT success, Salah and Alshawi (2005) then classified the method into three categories depending to the focus of the evaluation. By referring to the table 2 below, the first category is concerned with those approaches that evaluates IS/IT as a product, followed by approaches that evaluate the process which underpin the development of IS/IT and lastly the category which assess the maturity of IS/IT within an organisation in terms of IS/IT planning, infrastructure, utilisation and management.

Table 1: Type of IT/IS performance measurement

<i>Approach</i>	<i>Type</i>	<i>Details/Example</i>
<i>Product-based</i>	<i>System quality</i>	<i>Focuses on performance characteristics such as resource utilisation and efficiency, reliability, and response time</i>
	<i>System use</i>	<i>Reflects the frequency of IS usage by users</i>
	<i>User satisfaction</i>	<i>Widely used approach which is based on the level of user satisfaction</i>
<i>Process-based</i>	<i>Goal centred</i>	<i>Measure the degree of attainment in relation to specified targets. Examples: GQM and ITIL</i>
	<i>Comparative Improvement</i>	<i>Benchmarking approach Assesses the degree of adaptation of a process to the related changes in requirements and work environment</i>
	<i>Normative: Compared to external standards : CMM, ISO standards</i>	<i>Maturity-Based : Measures performance Non-maturity Based :</i>
<i>Organisational maturity</i>	<i>General Model</i>	<i>Example of such models are those by Nolen;Earl;Bhabuta;and Gallier and Sutherland</i>

In respond with the Table 2, generally in construction industry there are many models that could be applied to measure either the success and/or readiness towards certain concept. The purpose of the model varies depending on the concepts that are going to be taken. Such models are summarised as follows:

CMMI : Capability Maturity Model Integrated is a normative model, consist of best practice which can be used by many industry to improve process within a project, a division, or an organisation. Succeeding from Capability Maturity Model (CMM), which initially developed specifically for software industry, the model was formed to sort out the problems of using multiple CMM. Basically the assessment is looking for the maturity of the process and it has 5 maturity levels which are Initial, Managed, Defined, Quantitatively Managed and Optimised. Depending on the areas of interest, there are three models available which concentrates on Product and service development, Service establishment, management, and delivery and Product and service acquisition. (Software Engineering Institute, 2009)

(PM)² : Project Management Process Maturity which is also a normative model where it is a collection of best practice by the industry and purposely developed to measure the maturity of project management process. The model follows a systematic and incremental approach that progresses from an unsophisticated level to a sophisticated PM maturity level. Each maturity level consists of major PM characteristics, factors, and processes and demonstrates sequential steps that outline an organization's improvement of its PM processes. Basically, It has 5 maturity levels

which are: Initial, Planned, Managed at Project Level, Managed at Corporate Level and Continuous Learning (Kwak and Ibbs, 2002)

SPICE: Standardised Process Improvement for Construction Enterprises which was developed by University of Salford is a framework for continuous process improvement specifically for construction industry. The scope of the model is to incorporate the process that directly related to the design, construction and maintenance procedures of a construction organisation. Adapting from CMM, it indicates the management processes in a step-wise framework and consists of 5 maturity stages which are Initial/Chaotic, Planned & Tracked, Well Defined, Quantitatively Controlled, and Continuously Improving. (Finnemore and Sarshar , 1999)

BEACON : Benchmarking and Readiness Assessment for Concurrent Engineering in Construction is a concurrent engineering readiness assessment model which is used to assess the readiness of construction companies to improve their project delivery processes through the implementation of concurrent engineering. It is conducted before the introduction of CE within an organisation, and investigates the extent to which the organisation is ready to adopt CE. Adapted from Readiness Assessment for Concurrent Engineering Model (RACE), which is used in manufacturing, the model has 5 level of maturity which are Ad-hoc, repeatable, characterized, managed and optimizing and consists of four elements of measurement which are People, Process, Technology and Project. (Khalfan, Anumba, & Carrillo, 2001)

VERDICT : Verify End-User e-Readiness using a Diagnostic Tool is an e-readiness model that assess the readiness of organisation to adopt e-commerce tools, such as web based collaboration tools. The model can be used to assess the e-readiness of construction companies, department (s) within a company or even individual work groups within a department. The model, identify four elements of measurement which are people, process, technology and management. The assessment is carried out using 6 value of Likert scale in which 5= strongly agree, 4= Agree, 3=Neutral, 2=Disagree and 1=Strongly Disagree and finally 0= Do not know. In classifying whether an organisation is ready or not to adopt e-commerce, there are 3 levels were identified which are Red Level: average score equal or greater than zero but less than 2.5, Amber : average score equal or greater than 2.5 but less than 3.5 and lastly Green: where average score greater than or equal to 3.5. The Red value indicates that urgent attention needed to be e-ready, Amber indicates moderate attention needed to be e-ready and lastly Green indicates that the elements have adequate capability and maturity which equal to e-ready to adoption. (Ruikar, Anumba , and Carrillo, 2006)

The previous model, however, was not developed to specifically satisfy the need for BIM application within an organisation. Some of them are just concentrates on one aspect of measurement such as process improvement which could be seen in (PM)², SPICE and CMMI. Whereas, on the other hand, even though the models do measure the whole elements of an organisation, the application is specific to certain concept such as BEACON model where the model was built to measure the implementation of the

concept of Concurrent Engineering. Meanwhile, for the VERDICT model, the element of assessment could potentially be adjusted and adopted for the use of assessing BIM uptake since the model is generic enough for any ICT tool. For the record, in VERDICT, the e-readiness is defined as the ability of an organisation, department or workgroup to successfully adopt, use and benefit from information and communication technologies such as e-commerce.

5. BIM performance measurement

For performance measurement, specifically developed for BIM application within construction industry, there currently 2 models that are available which is the one developed by National Institute of Building Sciences under National Building Information Modelling Standard and another one is Building Information Modelling Maturity Index (BMIMI) proposed by Succar (2010), which at the final stage of validating the model. The next section discuss in more detail regarding to these models.

5.1 The interactive capability maturity model

The Interactive capability Maturity Model has been released in year 2007 by National Institute of Building Sciences. Under the U.S National Building Information Modeling Standard (NBIMS), the model was developed to be applied as according to McCuen and Suermann (2007):

- a) to serve as a tool for the user to evaluate the practice and process regarding to the BIM implementation
- b) portfolio-wide analysis to establish an organization's current strategic or operational BIM implementation
- c) to set goals for achieving greater information maturity on future BIM projects

The models however, developed to be used internally within an organization to provide information about the level of BIM information management and the level of maturity of individual BIM as measured against a set of weighted criteria and is not intended to be a tool to compare BIM implementation as further explained by McCuen and Suerman (2007). There are two versions that has been released where the first version is the tabular CMM, which is a static Microsoft Excel workbook consisting of three worksheets and the second version which has the same content with the first one, but be presented more interactively where the worksheets are interactively and actively update the BIM's maturity level as the user enters information. (laman web nBIMS). As to validate the model, according to smith and tardiff (2009), in late year 2007, the model was tested by NBIMS testing team, led by Professor Tammy McCuen and Air force Major Patrick Suerman by evaluating the BIM maturity of the 2007 American Institute of Architects (AIA) Technology in Architectural Practice (TAP) BIM Award. Although some

refinements were made, the testing result showed that the variance in score did not exceed 5% in any instance and frequently varied by no more than 1 or 2 percent.

Generally, the assessment of the I-CMM is focused on the maturity of building information model and the process used to create it (Smith and Tardiff, 2009). As can be seen in Table 2, the model consist of 10 level of maturity which assess 11 areas of BIM which is A data richness, life cycle review, change management, business process, timeliness/response, delivery method, graphical information, spatial capability, information accuracy and interoperability/IFC support.

Table 2: Index for interactive capability maturity model (National Institute of Building Science, 2007)

Maturity Level	A Data Richness	B Life-cycle Views	C Roles Or Disciplines	G Change Management	D Business process	F Timeliness/ Response	E Delivery Method	H Graphical Information	I Spatial Capability	J Information Accuracy	K Interoperability/ IFC Support
1	Basic Core Data	No Complete Project Phase	No Single Role Fully Supported	No CM Capability	Separate Processes Not Integrated	Most Response Info manually re-collected - Slow	Single Point Access No IA	Primarily Text - No Technical Graphics	Not Spatially Located	No Ground Truth	No Interoperability
2	Expanded Data Set	Planning & Design	Only One Role Supported	Aware of CM	Few Bus Processes Collect Info	Most Response Info manually re-collected	Single Point Access w/ Limited IA	2D Non-Intelligent As Designed	Basic Spatial Location	Initial Ground Truth	Forced Interoperability
3	Enhanced Data Set	Add Construction/ Supply	Two Roles Partially Supported	Aware of CM and Root Cause Analysis	Some Bus Process Collect Info	Data Calls Not In BIM But Most Other Data Is	Network Access w/ Basic IA	NCS 2D Non-Intelligent As Designed	Spatially Located	Limited Ground Truth - Int Spaces	Limited Interoperability
4	Data Plus Some Information	Includes Construction/ Supply	Two Roles Fully Supported	Aware CM, RCA and Feedback	Most Bus Processes Collect Info	Limited Response Info Available In BIM	Network Access w/ Full IA	NCS 2D Intelligent As Designed	Located w/ Limited Info Sharing	Full Ground Truth - Int Spaces	Limited Info Transfers Between COTS
5	Data Plus Expanded Information	Includes Constr/Supply & Fabrication	Partial Plan, Design&Constr Supported	Implementing CM	All Business Process(BP) Collect Info	Most Response Info Available In BIM	Limited Web Enabled Services	NCS 2D Intelligent As-Built	Spatially located w/Metadata	Limited Ground Truth - Int & Ext	Most Info Transfers Between COTS
6	Data w/Limited Authoritative Information	Add Limited Operations & Warranty	Plan, Design & Construction Supported	Initial CM process implemented	Few BP Collect & Maintain Info	All Response Info Available In BIM	Full Web Enabled Services	NCS 2D Intelligent And Current	Spatially located w/Full Info Share	Full Ground Truth - Int And Ext	Full Info Transfers Between COTS
7	Data w/ Mostly Authoritative Information	Includes Operations & Warranty	Partial Ops & Sustainment Supported	CM process in place and early implementation of root cause analysis	Some BP Collect & Maintain Info	All Response Info From BIM & Timely	Full Web Enabled Services w/IA	3D - Intelligent Graphics	Part of a limited GIS	Limited Comp Areas & Ground Truth	Limited Info Uses IFC's For Interoperability
8	Completely Authoritative Information	Add Financial	Operations & Sustainment Supported	CM and RCA capability implemented and being used	All BP Collect & Maintain Info	Limited Real Time Access From BIM	Web Enabled Services - Secure	3D - Current And Intelligent	Part of a more complete GIS	Full Computed Areas & Ground Truth	Expanded Info Uses IFC's For Interoperability
9	Limited Knowledge Mngmt	Full Facility Life-cycle Collection	All Facility Life-Cycle Roles Supported	Business processes are sustained by CM using RCA and Feedback loops	Some BP Collect&Maint In Real Time	Full Real Time Access From BIM	Netcentric SOA Based CAC Access	4D - Add Time	Integrated into a complete GIS	Comp GT w/Limited Metrics	Most Info Uses IFC's For Interoperability
10	Full Knowledge Mngmt	Supports External Efforts	Internal and External Roles Supported	Business processes are routinely sustained by CM, RCA & Feedback loops	All BP Collect&Maint In Real Time	Real Time Access w/ Live Feeds	Netcentric SOA Role Based CAC	nD - Time & Cost	Integrated into GIS w/ Full Info Flow	Computed Ground Truth w/Full Metrics	All Info Uses IFC's For Interoperability

As identified by Succar (2009), the i-CMM suffer several limitation which could restrict its application. Some of the limitations are listed as follows:

- a) The model employs 10 maturity levels with slender division between respective level which and slightly different with most capability maturity models where the maturity level normally in the range 4 to 6.
- b) The variability of scoring-weights assigned to Areas of Interest in accordance to organisational preference (or the elusive ‘national consensus’) – as encouraged within the NBIM Standard - will minimise the usefulness of the I-CMM tool and neutralise the ‘certification’ process
- c) The variability of the ‘minimum score for the Minimum BIM’ will cause scoring inconsistencies. Pre-assigning the minimum score according to calendar year and allowing it to be changed ‘according to demands by owners’ are in sharp contrast. Also, it is difficult to imagine that industry’s BIM maturity will increase (or can be encouraged to increase) in a pre-defined linear fashion or that owners’ BIM requirements can be established/ represented through a generic minimum score
- d) The NBIM’s CMM Areas of Interest are only useful in assessing Models and not the teams, organisations or project-teams which generate them
- e) The NBIM’s CMM in both its static and dynamic versions can only be applied ‘internally’ through self-assessment or peer-revision.
- f) Most importantly, the inability of the NBIM’s CMM – in its current form - to assess any BIM metric beyond ‘information management’ (NIST, 2007) severely limits its applicability and usefulness.
- g) The current configuration of the I-CMM tool allows organisations/projects to accumulate high total scores even if they achieved very low scores on a number of Areas of Interest (‘platinum’ certification can be achieved even when a project has no Change Management or Spatial Capability)

6. Building information modelling maturity index

Succar (2009) proposed a comprehensive model which covers the whole aspect of an organisation to uptake the BIM process and technology. The model Building Information Modelling Maturity Index (BMMI) has been developed by analyzing and integrating several models from different industries and tailored to reflect the specifics of BIM capability, implementation requirements, performance targets and quality management. It consists of 5 level of maturity (Initial, Defined, Managed, Integrated, Optimised) and 3 categories of key maturity area which are Technology, Process and Policy. The technology area then consist of 3 sub item for assessment which are Software: which focus on applications, deliverables and data, Hardware: which focus on equipment, deliverables and location and Networks: which focus on solutions, deliverables and security/access control. Meanwhile, in Process area it consists of Leadership: which focus on organizational, strategic, managerial and communicative attributes and innovation and renewal, Infrastructure: focus on physical and knowledge-related, Human Resources: focus on competencies, roles and dynamics. Products & Services: focus on specification, differentiation and R&D, Subsequently, in Policy key maturity area, it consists of Contractual: focus on responsibilities, rewards and risk allocations, Regulatory: focus on codes, regulations, standards, classifications, guidelines and benchmarks and Preparatory: focus on research, educational / training programme and deliverables

In the model, the author also makes a clear distinction between the term Capability and Maturity which contradict with most of the models mentioned in previous section where most of them simply assess the capability and maturity by using the same index of assessment where as in the BMMI model, since the terms are clearly defined, the index of assessment also varies significantly. In the model, maturity is defined as the quality, repeatability and degrees of excellence of BIM services. In other words, BIM Maturity is the more advanced ability to excel in performing a task or delivering a BIM service/ product.

On the other hand, BIM Capability is defined as basic ability to perform a task or deliver a BIM service/product. The author then, introduce BIM Capability Stages to define the minimum BIM requirement, the major milestones that need to be reached by a team or an organization as it implements BIM technologies and concepts towards the achievement of Integrated Project Delivery or even a target beyond that. According to Bilal (2008), generally, BIM Stages are defined by their minimum requirements. As an example, for an organisation to be considered at BIM Capability Stage 1, it needs to have deployed an object-based modelling software tool and

the application of BIM takes place in an isolated condition within the organisation. Similarly for BIM Capability Stage 2, an organisation needs to be part of a multidisciplinary model-based collaborative project. While, to be considered at BIM Capability Stage 3, an organisation must be using a network-based solution like a model server to share object-based models with at least two other disciplines. Figure 2 and 3, summarised the BIM capability model and process to deliver BIMMI assessment, respectively

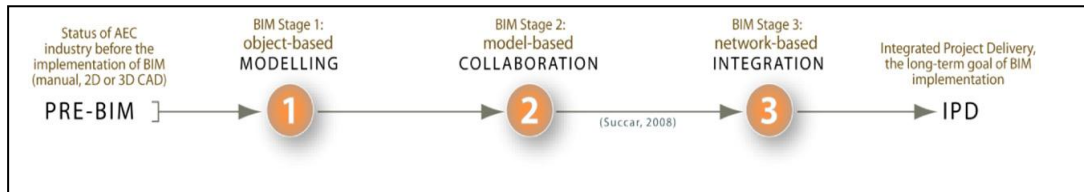


Figure 2: BIM Capability Model (Succar 2009)

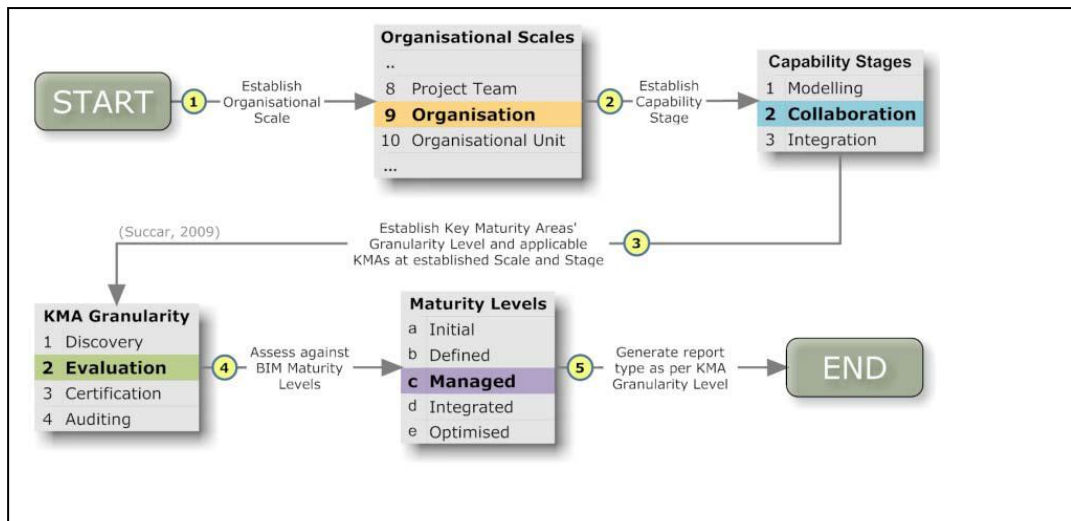


Figure 3: Flow of process to evaluate BIM Capability and Maturity (Succar 2009)

7. Conclusion

Application of Building Information Modelling in construction industry could provide many advantages to the construction industry. The uptake, however, varies from one organisation to another. Through literature review, in order to determine the level of BIM uptake, it is concluded that the model that can be used are VERDICT, CMMi and i-CMM. The measurement could be a basis for the organisation to monitor their progress towards the higher level of uptake and notifying them any area that need serious attention. Also, it could help in choosing the right team in delivering a construction project. This papers it a part of the author's PhD work at University

of Salford. At the time the paper was written, the element for measuring the level of uptake have been identified and the next stage of the research is to explore the current BIM level of uptake and also determine what are the minimum requirement needed to achieve the level.

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Agent-Based Negotiation Mechanism for Automatic Procurement in Construction

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Abstract

This study tries to change the traditional negotiation of procurement in construction by manpower to automated pattern, and the concept of intelligent agent is applied to develop a bilateral negotiation model which contains synchronous and asynchronous circuit. The proposed structure is based on the Game Theory to discuss the feasibility of automatically negotiate by applying intelligent agent, such as the establishment automation negotiation and confirmed, the automated renewal concessive strategy in their supply chain. Therefore, the subject in this research process is to present situation of this purchase flow, the negotiable strategy and the key factors of decision-making in purchase, and the following topics will be discussed: a) Understanding the procurement system and exploring the characteristic of knowledgebase, b) Establishes purchase attribute for the agent adjusting concession by dynamic state to raise negotiation efficiency, c) Base on the framework to develop an agent negotiation model about one demand to many suppliers. The purpose of this study is to develop a one-to-many negotiation system by using the agent-based technology, which includes a knowledge base, utility function and a negotiation mechanism. For construction procurement, it will not only reduce the management costs but also speed up the information processing time.

Keywords: agent, negotiation, procurement, construction, automatic

1. Introduction

Procurement management is a necessary and an important procedure for each industry, except material control and procurement management of manufacturing as well as industrial management performed procedure analysis and the strategy application. However, for construction, currently, there is no certain automatically model of procurement with knowledge management. Presently, most of researches of e-procurement papers emphasized on automatic inquiry and bargain as well as automatic investigation and setting of transportation and material received, furthermore, regarding to important bargaining strategy and negotiation model of purchase still less applied on Internet.

For construction industry, e-procurement currently is a common basic facility of e-construction, but it usually restricts on information inquired of single product or orders conforming. Therefore, for important bargain and negotiation process of practical purchasing activities still not yet carry on e-trade activities.

2. Related work

Currently, most of B2B supply chain bargaining systems are e-model and also need to perform and assist by manpower. Due to agent information technology has been successfully developed, and it will increase both side of supply and demand bargaining efficiency as well as changes of condition model. According to currently procedures of E-business bargaining system, such as bargaining behavior of automatic price negotiating still need to be involved by suitable manpower. So, regarding to how to reduce the bargaining cost of purchasing negotiation-Intelligent agent has been common recognized as a feasible critical factor to reduce user involving and make automatic bargain successful. In the practical bargaining of construction procurement, it is still uncommon on one-to-one bargain habit of procurement on the Internet; furthermore, it inspired the researching motive of on-line bargain of this research.

The research aims to currently auction website of on-line bargaining where applied agent technology extensively and attempts to change the supply and demand negotiation mode in construction that the primary producing by manpower mainly. By agent technology, applying Game Theory to study feasibility in construction is more important. Gattman and Maesm addressed the Market Framework and according to both side of suppliers and buyers to divided markets into four main types -Auction, Reverse Auction, Markets and Negotiation (Guttman, R. H. and Maes, 1998). It states Negotiation when one to one trading by a supplier and a buyer. The paper which will aim at negotiating model on both sides of suppliers and buyers is a main research direction. In e-commerce developing history, it used agent program to instead of user to negotiate and related negotiating researches. There are currently existent several automatic negotiation researches, such as units of AuctionBot, Fishmarket, MAGMA, CASBA etc. proceeded negotiation by auction. Software Agent Group, MIT Media Laboratory developed multi-agents bargaining system-Kasbah by customs to customs and also performed the test of consumers bargaining in 1996. All users could created several factors, such as their own agents, selected bargaining strategy, setting initial bargaining price, maximum or minimum

acceptance price...etc. and let all agents bargained at centralized agent marketplace(Harsanyi J.,1967).

Jae-Yeon & Eun-Seok Lee mentioned that e-commerce could divide into 2 major systems in their research; one is negotiating agent system and another without this model which the negotiating system based on agent to share knowledge by the information data base to achieve negotiation strategy. Base on Maes, P stated Buying Behaviors in 1999(Maes, P.; Guttman R.; Moukas A.,1999), currently most of bargaining systems could provide parts of function to fulfill staged requirement, such as T Kasbah, Auction Bot, Tete-a-Tete.

Chen et al. stated basic assumption of Game Theory in 1992, and it will affect competitions' decision by payoff. The decision also based on the dependence of payoff between competitions to selected the best strategy (Weigl et al. 1992). When proceeding negotiation, usually analyses and studies by Game Theory, and supplier and buyer take the payoff into consideration which divided Zero-Sum Game and Non- Zero Sum Game. Zero-Sum Game indicated the payoff equally between winners and losers, totally net income is Zero. Cross research on bargaining problems by Non-cooperation and from dynamic point of view. Under insufficient information, the bargaining game exists unequally between suppliers and buyers and it is easy to produce Nash Bayesian Equilibrium during Non-cooperation Game. The Nash equilibrium solution also affected by bargaining effect of competitions, therefore, the researches will be considered and discussed the bargaining effect of both side. The bargaining problems –Payoff Matrix is the basis for efficiency theory.

In related economical behavior researches of bargain, most of them study on contract zone and uncertainty about the opponent. Riffa stated zone of agreement in 1982 and considered both side of competitions kept few price, the acceptance zone of bargaining price could be produced by setting target of competitions (Jennings, N. R, 2001). Liang and Doong stated the core of the Internet bargaining activities is the concessive strategy. This strategy not only affects users' satisfaction, rate of bargain but also decides the benefits of both sides. Such as Kasbah, system provides three kinds of different bargaining strategy for both sides. They are to define time to be a function, to select excluding bargaining strategy, including Anxious, Cool-headed as well as Greedy, and also set initial price and time of final price negotiating. The agent will be according to users' setting to bargain until the bargain function match with each other and deal will be done.

3. Design of negotiating model with multi-attribute purchasing

In aspect of negotiating behavior, according to researches of J.Y. Kangs in 1998, they generalized the requirements of negotiating behaviors in commercial activities: (1) to provide the negotiating model of Multi-Attribute, such as price, deliver time quality etc. (2) to dynamically adjust negotiating strategy while negotiation or bargain. (3) to consider users' favor. In products of multi-attribute negotiation, M. Barbuceanu group stated a Multi-Attribute Utility Theory to achieve negotiation of products.

The suppliers and buyers set each price of property at three kinds of utility –low, middle and high range in advance and then divide the price of property into low, middle and high level variation which will result different proposals to count its sum of efficiency. In accordance with the highest efficiency proposal, suppliers and buyers start to negotiate with each other until the proposal submitted by both side have been intersected, and then came to an agreement.

The article describes the negotiating behavior by Game theory and guides Nash equilibrium bargaining model concept into automatic construction procurement negotiating system as well as considering applying agent programs to assist behavior of natural persons to bargain with a supplier or a buyer. Using the meaning of Game Theory and Nash's concept of bargain model to explain bargaining behavior, but Nash equilibrium will be affected by the game bargaining ability from suppliers and buyers. Bargainer with more bargaining ability could get more benefits during re-bargain. The research considers the fair problems on selecting negotiation subjects, the agent bargaining will be performed under equal bargain-ability circumstance.

For gaining the bargaining solution from transferring line (refer to Fig.1), it is suggested to integrate and analyze by Game Theory and Bargaining Theory. On the other hand, according to Utility Theory method gather all proposals and establish utility space of bargaining game, thus, the bargainers select one best efficient combination from the feasible set (agreement point of Bargaining space, shown as table 1) and also guiding intelligent agent to make a non-zero negotiation and decision and let bargaining became deadlock. It will be easier to break the deadlock as well as completing. Therefore, providing market model is to be the dynamic pricing negotiating model during whole course, as illustrated in Fig. 2. The entire document should be in Times New Roman. Other font types may be used if needed for special purposes.

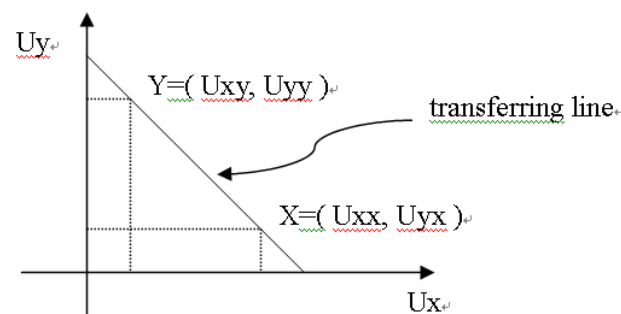


Figure 1: H-Z Model

(If $U_{xy}=U_{xx}$, $U_{yy}=U_{yx}$, and then both of bargainers will achieve a common consensus as well as also get the Nash solution which means $U_x+U_y=W$.)

Table 1 Bargain model

Player	Program	A's utility value	B's utility value
A	X	U_{xx}	U_{yx}
B	Y	U_{yy}	U_{xy}

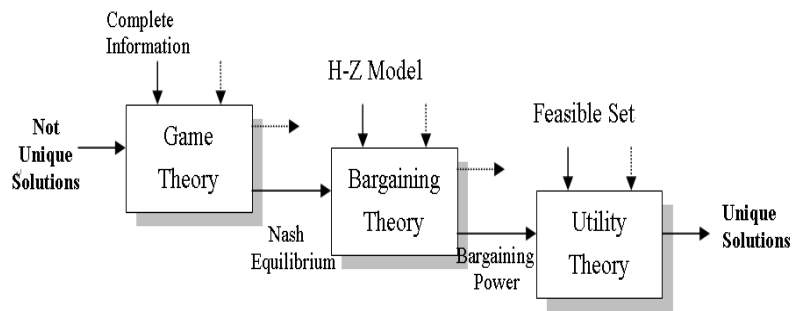


Figure.2 Negotiation mechanism of procurement

4. Automation negotiation model of purchase in construction

In the complete transaction system, except import game theory to descript negotiated behavior, and Nash negotiated model performance supply and demand both sides bargaining of power by. Finally it restrains the calculation by utility theory to rely on again. This article takes building negotiation of construction purchase as a background to design the pattern of automation system, and it shows on Fig. 3.

Carries on front the automatic system, supply and demand both sides must confirm execution its game possibly takes to both sides the effective profit, and then each other feasible has several to discuss belief set. Therefore, the system model must satisfy game theory including players, strategies, payoffs. It also means that using Nash equilibrium and intelligent agent to construct this system by the negotiated price mechanism. Based on the algorithm, the agent will carry on price space in the negotiated process to gather the unique solution search, and then deduce and compute the result from information of supply chain transaction record, dynamic strategy application and utilities function. Its goal lies in achieves payment duty the user. Therefore, in the control and the coordinated mechanism, the superintendent of agent relies on rules base, case base and common services in the knowledgebase to operate it.

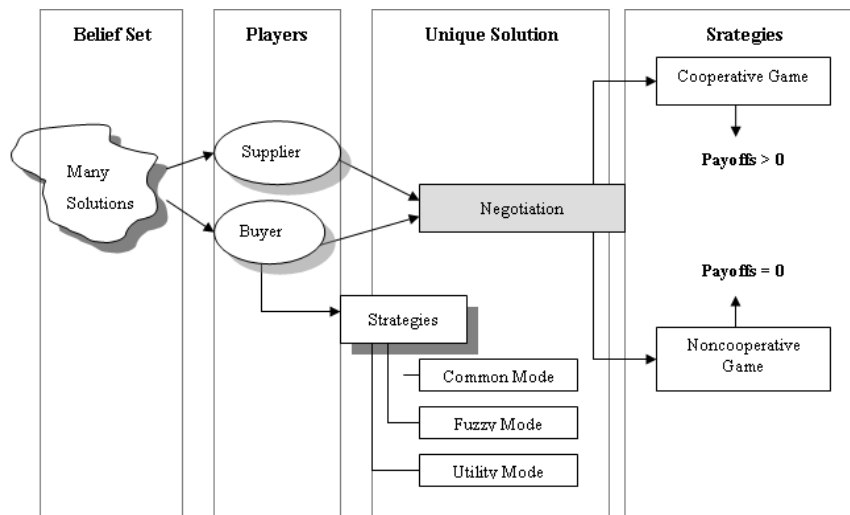


Figure.3 Automatic model of negotiation

Usually negotiation synchronized or the non- synchronized to many suppliers, payoff function of the negotiation game is for the key to influence the bilateral profit and the satisfaction in transaction. Therefore, how to change the negotiation mode in real world to on-line automated system, it needs to apply agent with simulation function to performance negotiating process in synchronization condition. However, the agents will get lots of the subject statistics and the decision-making in the process, and then the manager of agents will carry on the overall plan and the analysis. For automation system of negotiation, to build knowledgebase could lead the manager to decide the parameter for procurement.

In agent system, we will aim at negotiation system state method (for example Belief Set) and inference engine and so on to analysis the agent pattern with to construct.

Affiliation by simulation results, we can confirm that the agent technology is building feasibility of the transaction negotiation system. Agent provides the service in the automatic system, as follows arranges in order:

- 1) To formulate the customizing strategies of bargain.
- 2) Long-term to monitor negotiated process and to inform the user.
- 3) To transact to many supplier by synchronic and non- synchronic negotiation.
- 4) To provide agents mechanism for sharing the experience.
- 5) To trace result on the same time and getting it back coupling and the revision.

5. Conclusion

Before starting to negotiate, the demand can first establish Initial Price / Hope Price / Top Price. However in the most purchase structure based on unit price, the attempt reduces Initial Price and Hope Price by other subjects and the time enable the worst unit price to approach to or is lower than Top Price. Therefore, applying utilities function of negotiating is more important. Regarding negotiation benefit and success, the important of key aspect is effective strategy application and negotiated concessions scope or number of times.

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Preliminary Performance Evaluation of an ORDB-based IFC Server and an RDB-based IFC Server by Using the BUCKY Benchmark Method

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Abstract

Many IFC servers, based on RDB systems, suffer from poor processing speed and performance. We suggest that an ORDB, which is based on a concept similar to EXPRESS, is a suitable alternative database management system (DBMS). This paper reports the results of a preliminary performance evaluation between an object-relational database (ORDB)-based IFC server and a relational database (RDB)-based IFC server by using the BUCKY benchmark method. The results showed that an ORDB-based IFC server was faster than an RDB-based IFC server. Since we have not yet conducted the full-model test, this result has not been confirmed. However, the benchmark test showed the potential for improvement in the performance of the IFC server. More reliable results should be observed through a full-model test in future work.

Keywords: IFC server, ORDB, BUCKY Benchmark, IFC, BIM

1. Introduction

The effective exchange of building information is an important aspect for BIM (building information modeling) throughout the entire life cycle of a building. For this reason, buildingSMART was developed with the goal of providing data interoperability. This study, which addresses the problem of data storage and management, also seeks to address this concern.

Industry foundation classes (IFC) is a data schema that exchange relevant information between different software applications. A data schema comprises interdisciplinary building information that is used throughout the building's life cycle (buildingSMART, 2009). Most projects that use IFC exchange data by using a conventional file-based system. File-based systems, however, have several problems, including inconsistency as well as poor accessibility, integrity, and authority. (Silberschatz et al., 2006). Database management systems (DBMS) have been developed for this reason. The aeronautical engineering and mechanical engineering fields already apply web-based database servers. Several recent studies have addressed the use of DBMS in architecture (Adachi 2002; Chen et al., 2005; Karola 2002; You et al., 2004).

One problem to be resolved is the implementation of IFC into a physical model. IFC uses the EXPRESS language developed by the International Standard Organization (ISO). Since EXPRESS is an object-flavored data-modeling language that relies heavily on inheritance and aggregation, mapping to an object-oriented database (OODB) would be a logical approach, but few studies have been conducted. There has been some effort to map relational databases (RDB), such as IFCsvr by VTT in Finland, SECOM in Japan, and EXP2SQL at Georgia Technical University (Adachi 2002; You et al., 2004). RDB was mapped first because they are commonly used in many areas, have many users, and conform to a well-organized standard. Mapping EXPRESS to RDB is very complicated, and it cause bigger file sizes and processing delays. Some attempts have been made to store EXPRESS directly without mapping by using an EXPRESS repository, such as the EDM server (Jotnes EPM Technology) and EMS (Eurostep). Also, the speed and stability of the system can cause problems when mapping large models (Plume and Mitchell 2007).

As buildings get larger and more complex, improved performance is essential in order to process very large files. Therefore, this paper examines the possibility of using an object-based IFC server as an alternative.

2. Research scope and methodology

Since the system is still under development, we could not test the full model, but instead used a wall object. Thus a limited schema, objects related to the wall, was set up as a benchmark test.

This paper presents alternative databases for IFC server, and shows the relationship between IFC and ORDB. Next, RDB and ORDB based on IFC server are developed by using previously reported research methods. The two systems are evaluated for performance by using the BUCKY benchmark method.

3. IFC schema implementation

3.1 Types of database

Relational database (RDB) generally consists of tables, and match data by using common characteristics found within the data set. RDB is the most widely used database due to its technical stability and reliability. It can easily extract the results needed by using a standardized query method, such as the structured query language (SQL). However, this approach is complicated, is limited in usefulness for large multimedia files, and does not adequately express such information at the object-based concept.

Object-oriented databases (OODB) can better express realistic situations by relying on aggregation and inheritance. This means that a complicated data design can be simplified. Without “join” tables, data can be extracted by using its physical address, called object identifier (OID), which leads to good performance. Standard query methods and development support do not completely resolve the problems. Therefore, OODB was developed but was not widely accepted by users who were accustomed to RDBs.

Object-relational database (ORDB) supports several object structures and rules, and add to conventional RDB services, including image, audio, and video data. ORBD also supports the encapsulation, inheritance, and aggregation that OODB supports. The combined advantages of RDB and OODB have resulted in a rising market share. As a result, ORDB is becoming a relevant research model.

3.2 Relationship between EXPRESS and ORDB

IFC was developed as an exchange standard for building information (buildingSMART, 2009). IFC consists of EXPRESS (ISO 10303-21), a data modeling language. EXPRESS is also standard in STEP (ISO 10303) and has the following characteristics:

- An object-favored language, relevant for expressing hierarchical structure, including inheritance.
- Includes aggregation data type, such as set, list, array, and bag.
- Frequent references among different objects.

Since most previous studies were RDB-based, it was necessary to create a number of tables to cover the above characteristics. It was also necessary to join the tables in order to extract the needed results. This led to complex queries and performance problems. Thus, this study applied an ORDB-based structure to implement on an IFC server. The advantages of ORDB, compared with RDB and OODB, are as follows:

- Since it can express object-flavored data like EXPRESS, a hierarchical data structure can be implemented.
- By using an OID, it is possible to access data connected directly without an additional “join”

process.

- Aggregation data can be expressed in single cell.
- User friendly by employing a pre-defined query.
- Possible to program in an object-flavored language like C++ or JAVA.

However, there are few examples of mapping from IFC schema to ORDB. Therefore, this paper conducted a performance evaluation by using the developed ORDB-based IFC server.

3.3 Mapping process

The mapping logic for ORDB is partially derived from Kang's (2009) method. In this paper, the function and rule sections were not considered because they are still under development. Previous studies (Adachi 2002; You et al., 2004) were used to implement RDB with Cubrid as the platform. Cubrid, used as the platform was developed from the first object-oriented DBMS, which was called UniSQL. Both approaches, RDB and ORDB, can be supported in Cubrid, therefore it was considered to be a relevant DBMS for this study.

4. Performance evaluation

4.1.1 Preparation for test

Considering IFC server developing status, specific object was selected for the test. Wall, selected object, includes several entities in IFC schema, and reflects major features of EXPRESS. Thus it is relevant preliminary performance evaluation.

4.1.1.1 Define subset of parts related to wall

The subset of parts related to the wall, which is the range of the performance test, must first be defined. The subset was extracted based on the basic entity of wall schema "ifcwallstandardcase." The Yonsei IFC MV Extractor was used as an extraction method. The Yonsei IFC MV Extractor automatically extracts a valid subset of the IFC model that is related to a certain IFC concept (Lee 2009). The minimum valid subset was defined as the range for the test by selecting all instances of ifcwallstandardcase in IFC2X3 (a total of 13 entities). Figure 1 shows the process.

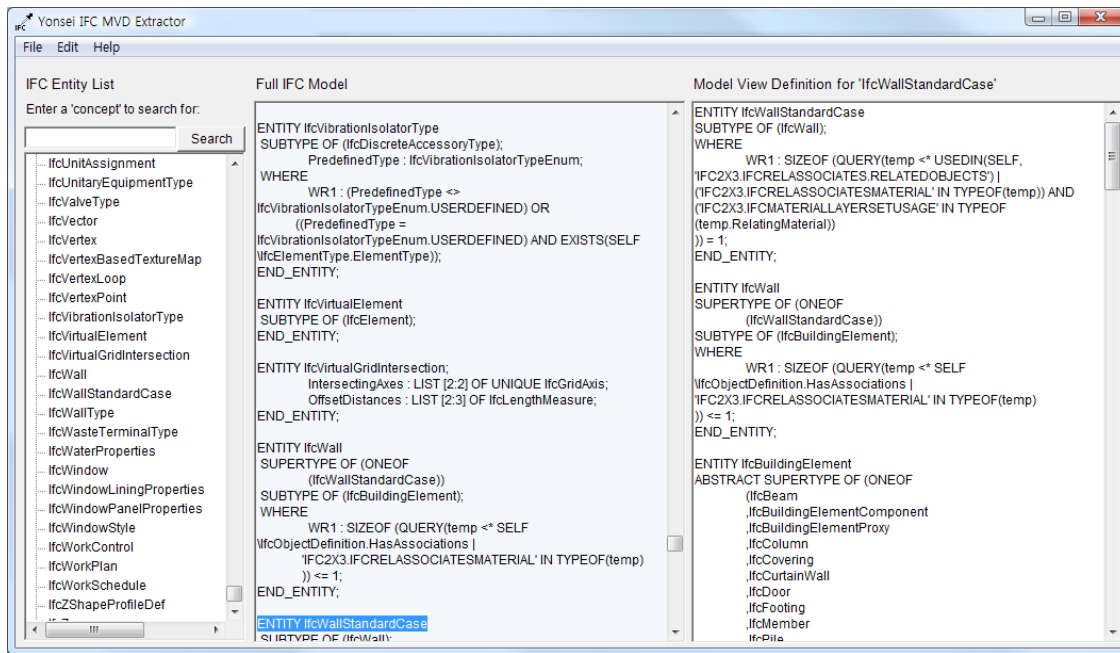


Figure 1: Extraction subset of ifcwallstandardcase (Yonsei IFC MV Extractor)

4.1.1.2 Instance input

Since the server system is not complicated, it is difficult to input an actual IFC2X3 file. Therefore, virtual files similar to real IFC data were inserted. The input method was “loaddb,” which can upload large files in a short time and is supported by Cubrid. For ORDB, attributes referencing other entities use the OID for directional access. “Table 1” shows that identical IFC instances were inserted to RDB and ORDB (a total of 9155 instances). The number of classes using an OID was 2000.

Table 1: Virtual instances input

Class	Instance
Ifcwallstandardcase	1153
Ifcwall	1002
Ifcownerhistory	1000
Ifcpersonandorganization	1000
Ifcapplication	1000
Ifcperson	1000
Ifcorganization	1000
Ifcactorrole	1000
Ifcaddress	1000
Total	9155

4.1.2 BUCKY benchmark method

We use the BUCKY benchmark method for performance evaluation of RDB and ORDB. BUCKY is a query-oriented benchmark that relies on many of the key features offered by object-relational systems, including row types, inheritance, references, and path expressions (Carey et al., 1997). Originally, BUCKY was developed for ORDB performance evaluation, but an RDB version also exists. Therefore, BUCKY can be used to compare different types of databases. Considering the developing process, six of the 16 queries supported by BUCKY were used for the performance test. Table 2 shows the queries used.

Table 2: Query used in BUCKY benchmark method

Query definition	Brief description
<i>SINGLE-EXACT</i>	<i>Exact-match over one table</i>
<i>HIER-EXACT</i>	<i>Exact-match over table hierarchy</i>
<i>SINGLE-JOIN</i>	<i>Relational join query</i>
<i>HIER-JOIN</i>	<i>Relational join over table hierarchy</i>
<i>1HOP-NONE</i>	<i>Single-hop path, no selection</i>
<i>1HOP-ONE</i>	<i>Single-hop path, one-side selection</i>

4.1.2.1 Running BUCKY

To derive the same result from RDB and ORDB, six queries were manipulated. Generally, queries for ORDB were shorter than those used for RDB. The length of the query depended on which entity was referenced and differed by more than five times. Some examples are as follows.

Table 3: Examples of queries

<i>SINGLE-EXTRACT</i>	
<i>RDB</i>	<i>ORDB</i>
<i>SELECT *</i> <i>FROM ifcwallstandardcase</i> <i>WHERE objecttype = 'Basic Wall:90mm</i> <i>wood:289498'</i>	<i>SELECT *</i> <i>FROM ifcwallstandardcase</i> <i>WHERE objecttype = 'Basic Wall:90mm</i> <i>wood:289498'</i>

<i>HIER-EXACT</i>	
<i>RDB</i>	<i>ORDB</i>
<i>SELECT globalid, ownerhistory, name</i> <i>FROM ifcwall</i> <i>WHERE description='\$'</i> <i>UNION ALL</i> <i>SELECT globalid, ownerhistory, name</i> <i>FROM ifcwallstandardcase</i> <i>WHERE description='\$'</i>	<i>SELECT globalid, ownerhistory, name</i> <i>FROM ALL ifcbuildingelement</i> <i>WHERE description='\$'</i>

Elapsed time was measured to evaluate performance. Response time, supported by Cubrid, was heavily affected by pre-conducted queries. By using the Cubrid OLE DB, an application was developed and used to measure time automatically from the start of the query to result (before print

out). To flush the cache memory, a large database that was not used for the test was scanned in the middle of each test. The average of thirty tests was calculated, and the process was verified due to the fact that no significant differences existed between the first and thirtieth results. The application was developed by using the C# language in Microsoft Visual Studio 2005.

4.1.2.2 Benchmark result

The results of the benchmark test are as follows.

Table 4: Result of the test

<i>Query</i>	<i>RDB (sec)</i>	<i>ORDB (sec)</i>
<i>SINGLE-EXACT</i>	<i>0.0052</i>	<i>0.0057</i>
<i>HIER-EXACT</i>	<i>0.0219</i>	<i>0.0146</i>
<i>SINGLE-JOIN</i>	<i>3.0377</i>	<i>0.0781</i>
<i>HIER-JOIN</i>	<i>5.0368</i>	<i>0.1092</i>
<i>1HOP-NONE</i>	<i>0.0977</i>	<i>0.0364</i>
<i>1HOP-ONE</i>	<i>0.1134</i>	<i>0.0047</i>

Excepting SINGLE-EXACT, the elapsed time of the ORDB was faster for the rest of the queries. In the case of SINGLE-EXACT, the manipulated queries were exactly the same, but it can be supposed that ORDB had a higher load because the data are stored by using their OID. Since the majority of the performance tests included inheritance and reference relationships, ORDB showed better performance than RDB. This implies that the ORDB has great potential. However, it can not cover the full range of IFC schema, but is limited to a specific entity (the wall). Full model should be tested in future work, the other queries also be added.

5. Conclusion

This paper reported the results of a performance evaluation for a wall object between an ORDB-based IFC server and an RDB-based IFC server by using the BUCKY benchmark method. Because previous RDB-based IFC servers have experienced speed and performance problems, this paper shows that another approach (ORDB) can provide superior performance. Although this was not a complete server system but only one object, this method can be improved in an ORDB-based IFC server. We will continue developing the ORDB IFC server and are planning to run a full test in a pilot project. Also, other features, such as set and function should be added. Moreover, it is necessary to introduce test-data exchange at each step in the actual AEC industry by using IDM (information delivery method). Those approach will observe more reliable result.

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A Conceptual Framework for Research in Spatial Data Sharing

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Abstract

Spatial data is information that is defined spatially (in location) by four dimensions (geometry and time) related to the earth (Groot and Mc Laughlin, 2003). With the advancement of technology, most decision makers from many disciplines tend to rely on up-to-date accurate and accessible spatial data to support their operational and strategic decisions. The demand to access multi-organization spatial data continue to increase and has pushed the organization to share their spatial data as rarely all these data sets reside within one organization. However, persistent challenges exist in utilizing available spatial data across the multi-organization.

This paper provides an analysis of the state of spatial data sharing and examines intricate issues that hinder the utilization of multi-organizations spatial data. Content analysis and cognitive mapping techniques were applied using qualitative software 'Nvivo8' to help conceptualised the key issues.

A preliminary framework for research in spatial data sharing was derived from these findings and later refined by case studies in three different government departments in Brunei to produce the proposed conceptual framework.

Keywords: spatial data, spatial data sharing, framework

1. Introduction

Spatial Data (SD) is information that is defined spatially (in location) by four dimensions (geometry and time) related to the earth (Groot and Mc Laughlin, 2003). With the considerable advancement in technology, spatial data plays an important role in supporting many operational decisions from many disciplines such as the planners, engineers, architects and other profession. The ability to access a more comprehensive data sets will allow these professionals to undertake comprehensive analysis and would therefore, improve in decision making. However, data sets do not normally reside within one organization. Different organizations have different roles and responsibilities and most organizations have their own data sets stored in their own system for their own used. This has resulted in fragmented datasets as ‘island of data,’ which may be access if the sources were known (figure 1a), or sources were known but spatial data is inaccessible.

Spatial data gathering, conversion and maintenance are the most expensive aspects in any project, and time consuming task. Repeating the whole process means more cost, time and effort wasted on the same processed. Considering these issues, the concept of spatial data sharing seemed to be a sensible move (figure 1b). .

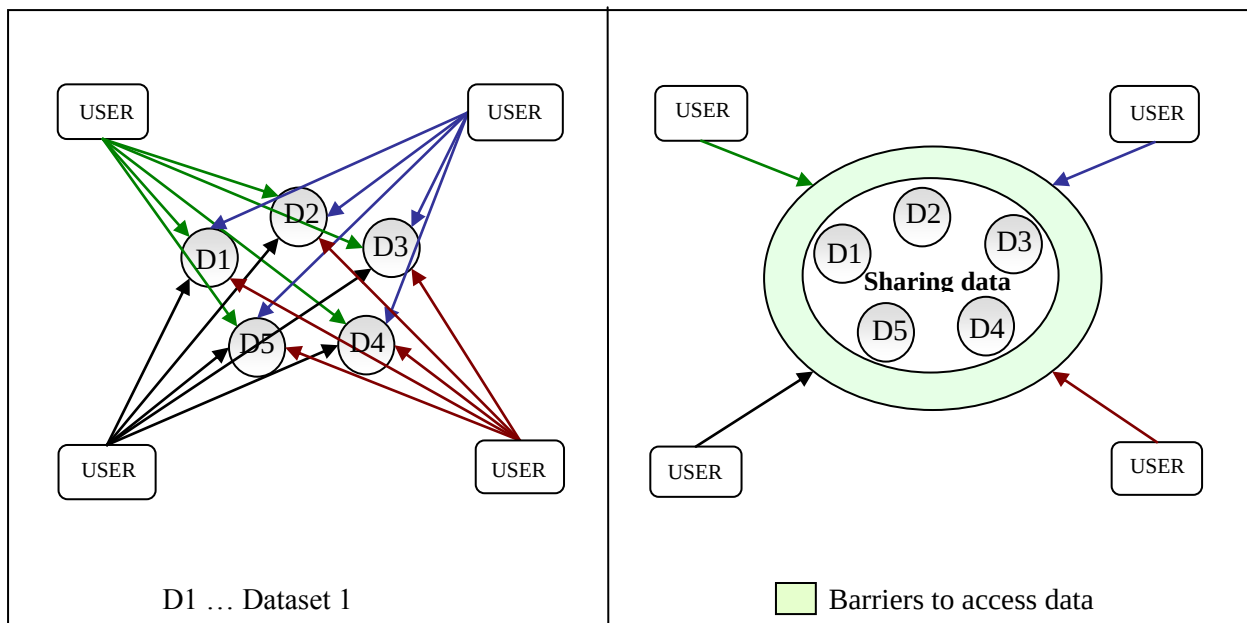


Figure 1: (a) : accessing spatial data
(current mechanism)

(b) : accessing shared spatial data
(proposed)

2. Why share spatial data?

The need to share spatial data was clearly summarized by the Mapping Sciences committee of the National Research Council in 1993. 'The principle of a spatial data sharing program is to increase the benefits to society arising from the availability of spatial data. The benefits will accrue through the reduction of duplication of effort in collecting and maintaining spatial data as well as through the increased use of this potentially valuable information. The exposure of these data to the wider community of users may also result in improvements in the quality of data. This will eventually benefit the donors and other users.'

The benefits of multi-organisational spatial data sharing cited in the existing literature are generally positive. Nedovic-Budic & Pinto (1999) highlighted spatial data sharing can reduce time spent in data collection and decision making, inclusion of more diverse maps and increased availability of data.

The value of data increases as more users' access to it. Onsrud and Rushton (1995) inferred the value of spatial data comes from its use, the more it is used, the greater the number of people evaluated and addresses the wide range of pressing problem to which data may be applied and thus increased the value of the data. The author further added sharing also allowed the data to be used rapidly for different process and resulted in greater use of the data without increasing the cost of developing and maintaining it.

Other benefits cited in the literature are user's access up-to-date common data, allow cross-jurisdiction and cross-sectoral decision making, improve services and reduce time in accessing the data (National Research Council, 1993; Nedovic-Budic & Pinto, 1999; Azad & Wiggins, 1995; Onsrud & Rushton, 1995; Kevany, 1995; I.Williamson et al., 2003; Masser, 2005).

Sharing also creates intangible advantages such as improved staff morale and self confidence (Nedovic-Budic & Pinto, 1999). Improved moral was by encouraging staff to communicate with other organizations and by providing necessary staff training would help to boost their self-confidence.

3. Challenges in spatial data sharing

Despite all these benefits, there were persistent challenges to multi-organizations spatial data sharing. These challenges can be categorized as technical and non-technical factors (Onsrud & Rushton, 1995).

The technical factors relate to problems in coordinating system requirements (Calkins & Weatherbe, 1995) lack of common data definition, formats, and models (Dawes, 1996), differences in data quality (Frank, 1992) and networking costs (Nedovic-Budic and Pinto, 1999). Campbell & Masser (1995) argued that technical factors were well studied and mostly resolved, the non-technical factors which are equally important and needs more attention.

Non-technical factors relate to data confidentiality, liability, pricing (Campbell & Masser, 1995), lack of negotiation, institutional inertia (Craig, 1995), fear of losing autonomy over control of information and organizational power (Pinto & Azad, 1994; Azad & Wiggins, 1995; Meredith, 1995), legal and public policy (Onsrud & Rushton, 1995), different data access policy established by individual organization (Nedovic-Budic & Pinto, 2001; Warnest, 2005), little coordination among various organizations (When de Montalvo, 2003; Omran et al., 2006), inadequate planning and consultation about data use, insufficient staff, institutional disincentives, historical and ideological barriers, power disparities, differing risk perceptions, technical complexity, political and institutional culture (Dawes, 1996).

Calkins and Weatherbe (1995) criticised that organizational resistance to sharing data was due to lack of motivation, where organization are normally motivated if there are needs and capabilities. The author further inferred that 'people' were the main challenges to spatial data sharing because they represent the need to better isolate and address the human factors that are likely to impede free data sharing across organizational boundaries.

On social perspective, Wehn de Montalvo (2003) investigated the theory of 'planned behavior' as an organizational framework for the willingness to share spatial data. Omrans et al., (2006), purports that individual and organizational behaviour are crucial factors to spatial data sharing. The author proposed a theoretical model that interacts between organizational behavior of spatial data sharing and social and cultural aspects.

All these frameworks and theories were not well grounded (except for When de Montalvo and Nedovic-Budic framework), and most of them draw on authors' extensive understanding and experience with data sharing. However, it had provided a very useful basis to understand the current issues. They emphasized the importance of developing an improved understanding at the organizational level of the motivations and barrier for organizational cooperation. This finding has provided a solid foundation to conceptualise a preliminary framework for research in spatial data sharing (figure 2).

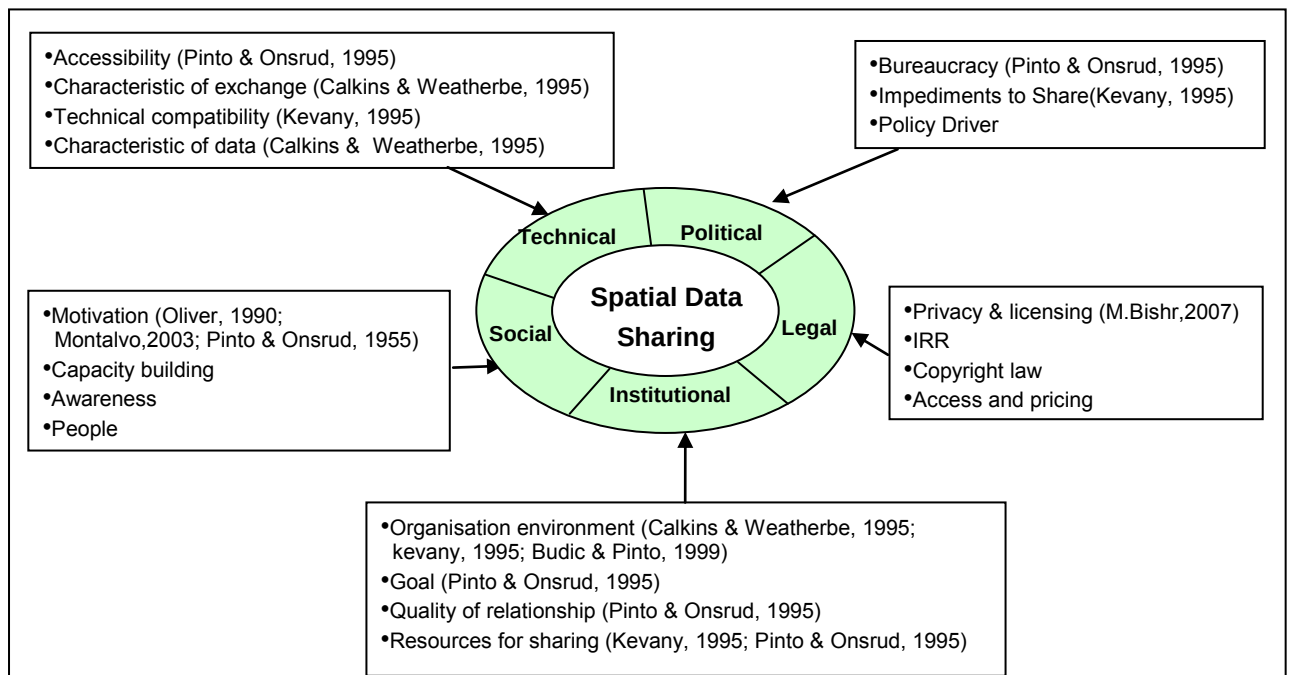


Figure 2: The conceptualisation of issues pertaining to spatial data sharing from critical analysis of literature

The above figure, illustrates a preliminary framework with 5 main factors that impede spatial data sharing, which includes political, legal, social, institutional and technical. This framework was used as a basis for data collection in this research.

4. Analysis

In this research, two stages of data collection were undertaken. The first stage is the preliminary investigation where a simple questionnaire was distributed to government departments for two purposes:-

1. Investigate the level of usage and knowledge of spatial data in government departments.
2. Targeting the most suitable government departments for case studies.

The result revealed that usage and knowledge of spatial data within government departments in Brunei are very limited, where only 10.5% had experienced in using spatial data and only 7.9% had visited Brunei Spatial Data Infrastructure (BSDI) website. The infancy stage of knowledge in spatial data in government departments and not to mention in sharing them, the second purpose cannot be fulfilled. At such, common data for Global Spatial Data Infrastructure were used as set of core data in this research. A numerical scoring scheme was derived to aid in discriminating the spatial data provider, spatial data users, value added user and occasional user of these core dataset. The point allocated to the individual department is then accumulated and the top 3 were selected for the case studies.

The second stage of data collection was through the semi-structured interview, focus group meetings and review of relevant documents. This was to understand the holistic view of the whole process in each selected department focussing on spatial data development, usage, dissemination, access, maintenance and other related activities. A set of questions was prepared based on the finding derived from the literature (figure 2).

Twelve numbers of personnel from all the selected departments, ranges from the director to the technician's level, who is responsible in spatial data development, dissemination, maintenance, used data for analysis, design and decision making were interviewed. Two focus group meetings with a lower level of staff were also conducted to compliment these interviews' findings. The findings were then classified into the theme of factors (table 1).

Table 1: classification of issues into theme of factors (case studies finding)

<i>Political</i>	<i>Social</i>	<i>Legal</i>	<i>Institutional</i>	<i>Technical</i>	<i>Economic</i>
- Bureaucracy - Policy - Power - Disparities - Constraint - Security	- Insufficient staff - Motivation - Behaviour - Awareness - Experts - Budget	- Confidentiality - Liability - Pricing - Security - Policy	- Roles - Responsibility - Procedures - Structures - Resources to share - Outcome - Security - Budget - Staff - Experts	- Infrastructure - IT capacity - Data format - Data access - Maintenance - Experts - Security - Budget	- Operational cost - Continuous - Funding - Staffing - Experts

The grouping of factors in table 1, shows a number of issues such as security, data pricing, lack of staff and budget have been identified to occur across multiple areas. This explains that the factors are interrelated. To help in understanding the relationship among these factors, a cognitive mapping technique was adopted (figure 3).

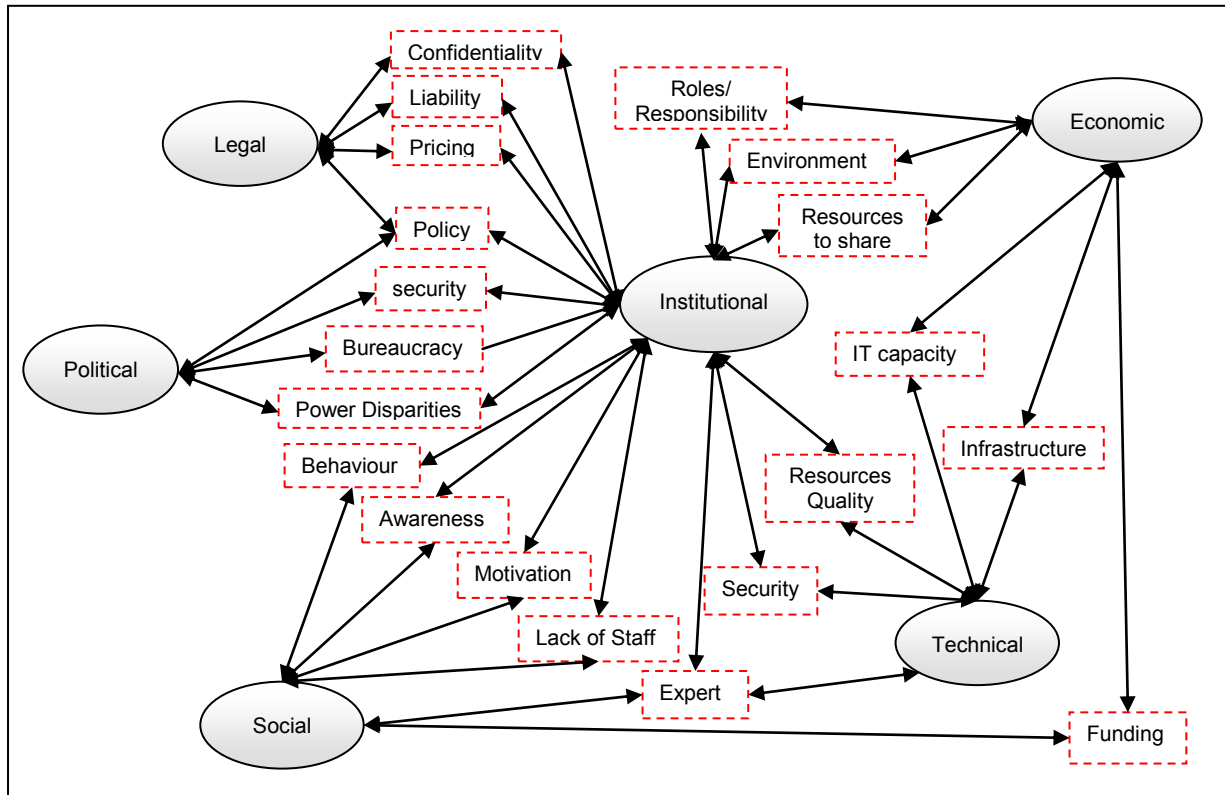


Figure 3: Cognitive mapping from the 3 case studies

Cognitive mapping above shows the relationship among the factors. For example, the economic impact on government budget and priorities affected public sector staffing levels and expertise (social factor) which contributed to the limited ability of government to support the development and maintaining (technical factor) spatial data. The issue of liability, pricing and confidentiality (legal factor) restricted the department to expose their spatial data. Security (political factor) and pricing forced the department to implement a long winding process (political factor) in accessing spatial data. This can be articulated that Institution in this case, government departments in Brunei is influenced by political, legal, social, technical and economic factors.

Content analysis was also adopted in this research to quantify the issues raised in the case studies, and also to find the most common obstacle within government department in Brunei. A qualitative software Nvivo8 was used to aid in performing this analysis. The interviews and focus group meeting transcripts were transfer to Nvivo8, where main issues were coded and grouped into a theme of factors as in figure 2. The result from the case studies was then compared to the finding from the literature review (table 2).

Table 2: A comparison of issues pertaining to spatial data sharing gathered from the literature review and case studies.

		CASE STUDIES			
Factors	Issues		Hits	Issues	Factors
<i>Institutional</i>	<i>Roles & Responsibility</i>		12	<i>Roles & Responsibility</i>	<i>Institutional</i>
	<i>Environment</i>		21	<i>Environment</i>	
	<i>Resources to share</i>		10	<i>Resources to share</i>	
	<i>Outcomes</i>		0	<i>Outcomes</i>	
<i>Political</i>	<i>Bureaucracy</i>		13	<i>Bureaucracy</i>	<i>Political</i>
	<i>Policy</i>		5	<i>Policy</i>	
	<i>Power Disparities</i>		0	<i>Power Disparities</i>	
	<i>Constraint & Impediments</i>		3	<i>Constraint & Impediments</i>	
			7	<i>Security</i>	
<i>Legal</i>	<i>Confidentiality</i>		3	<i>Confidentiality</i>	<i>Legal</i>
	<i>Liability</i>		5	<i>Liability</i>	
	<i>Pricing</i>		11	<i>Pricing</i>	
<i>Social</i>	<i>Insufficient Staff</i>		13	<i>Insufficient Staff</i>	<i>Social</i>
	<i>Motivation</i>		0	<i>Motivation</i>	
	<i>Behaviour</i>		1	<i>Behaviour</i>	
	<i>Awareness</i>		2	<i>Awareness</i>	
<i>Technical</i>	<i>Data Format</i>		14	<i>Data Format</i>	<i>Technical</i>
	<i>IT Capacity</i>		13	<i>IT Capacity</i>	
	<i>Infrastructure</i>		4	<i>Infrastructure</i>	
			12	<i>Expertise</i>	
			7	<i>Continuous Funding</i>	<i>Economic</i>

The above table shows that the case studies had identified most issues that were well supported by the literature. In addition, security and economic factor were raised as main concerns in Brunei.

5. Development of conceptual framework for research in spatial data sharing

The case studies' finding has revealed that the economic is an important factor to spatial data sharing. Its impact contributed to social and technical factors such as shortage in supporting staff and lack of expertise which are crucial for the implementation. With this finding, economic was treated as one of the main factors and was included in the framework as the sixth factor (fig 4).

Figure 3.1 illustrated a proposed conceptual framework for research in spatial data sharing, which was extended from figure 1.1(b) to include the 6 main factors.

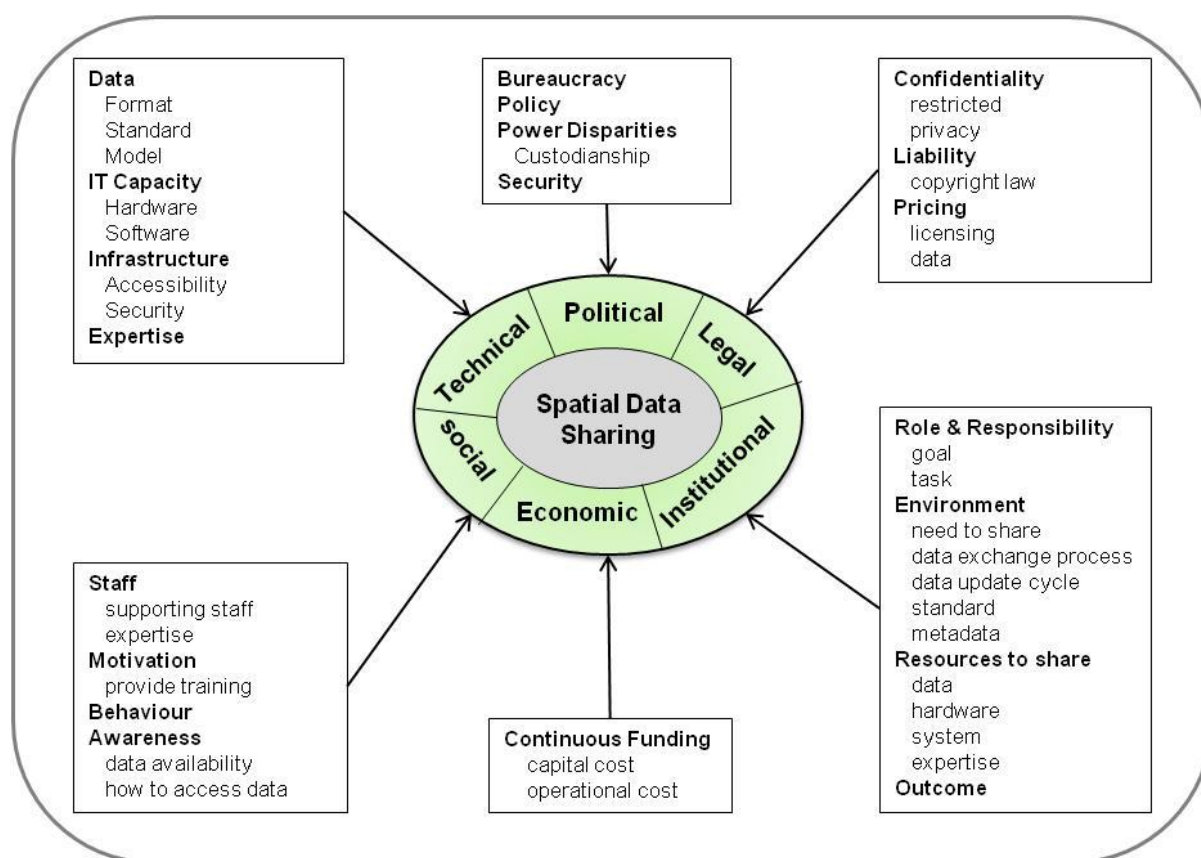


Figure 3.1 : Proposed conceptual framework for research in spatial data sharing

Figure 4: Conceptual framework for research in spatial data sharing

The above figure shows the conceptual framework for research in spatial data sharing with 6 main factors and list of related issues. The main factors include Political, Legal, Institutional, Social, Economic and Technical.

All these factors need to be considered in implementing spatial data sharing and thus the issues listed under each factor has to be understood and group accordingly in order to be able to come up with solutions. As stipulated in most literatures that Political, Legal, Social and Economic can result in policies (Nevodic-Budic 1999, Williamson et al. 2003, Warnest 2005, McDougall, 2006).

6. Conclusion

This paper addressed the problem associated with issues to spatial data sharing. A solid foundation from the extensive literature review helps in conceptualising a framework (figure 2). The framework

was used as a basis for data collection in 3 selected government departments in Brunei. The finding identified issues collected were well supported by the literatures. In addition, economic issue was raised as an important factor in Brunei because it can impact social and technical factors, which are crucial in the implementation of spatial data sharing.

The final framework for research in spatial data sharing has 6 main factors, which include political, legal, social, institutional, technical and economic. This framework provides a simple guideline that can be used as checklist in preparing policy for spatial data sharing, and it can also be used for investigating the success or failure of multi-organisation spatial data sharing. Furthermore, the result achieved from this framework can as well be used to target main obstacles that need priority attention. It is important to note that this framework was derived from case studies in Brunei. Therefore, there tend to be additional or fewer issues in other countries because of difference in culture and administration.

This framework will be validated to prove its efficiency by using these finding to develop a model for sharing and maintenance spatial data in Brunei government departments.

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The Changing Perception in the Artefacts Used in the Design Practice through BIM Adoption

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Abstract

When CAD (Computer Aided Design) was generally adopted in the early 1990's, the hand drawn process was replaced with the CAD drawing but the nature of the artefacts / deliverables and the exchanges of information between disciplines remained fundamentally the same. The deliverables remained 2D representations of 3D forms and Specifications and Bill of Quantities. However, the building industry is under great pressure to provide value for money, sustainable design and construction. This has propelled the adoption of Building Information Modelling (BIM). BIM is a foundational tool for a team based lean design approach. It can enable the intelligent interrogation of design; provide a quicker and cheaper design production; better co-ordination of documentation; more effective change control; less repetition of processes; a better quality constructed product; and improved communication both for the architectural practice and across the supply chain.

As BIM enables a new of working methodology, it entails the change in perceiving artefacts used and deliverables produced in the design and construction stages. In other words, defining what the informational issues are, who does what and who is responsible for what and the level of detail required at each stage in design and construction is critically important to adopt and implement BIM in the construction sector.

This paper presents the key findings through the action research methodology about the change in the nature of artefacts and deliverables resulting from the BIM adoption in the KTP (Knowledge Transfer Partnership) project undertaken by the University of Salford and John McCall Architects.

Keywords; lean construction, building information modelling, coordination, collaboration, integrated design process

1. Background: Artefacts used in the building design process

“How complex or simple a structure is depends critically upon the way in which we describe it.”
Herbert Simon (1996)

The construction industry is facing a dilemma with a demand to simultaneously reducing costs, increasing quality and improving efficiency. The challenge is how to meet this demand for improvement.

Historically information within the building process has been fragmented, unconnected and characterized by sub-optimal informational exchange. Yet the building design process has a disproportionate influence on the life cycle value of the built environment (Paulson 1976). So optimal design and the intermediate stages by which good design is achieved are particularly important.

Within the construction industry there are many disciplines or communities of practice. Each community has its own area of specialist knowledge. Artefacts are the method adopted to transfer information and ideas between these communities. (Lave and Wenger, 1991)

When the effectiveness of artefacts (boundary objects) is considered from a lean perspective, any waste residing in or in the production of the said artefacts should be removed. This waste in lean terms could be over-processing, rework, overproduction, conveyancing, waiting, inventory or motion.

Artefacts of the building process are the intermediate creations required to ensure that intermediate and final building project requirements are met. The components that go to make up an artefact are prescribed by the importance given to quality, cost and time considerations. The format of the artefact is often prescribed by legacy systems, historic methods and practices. According to Cooper (1989) in each period of our history, design and communication have evolved synchronously with the technology of the time. Each new medium has extended our sense of reality and each has looked to its predecessor for language and conventions, referencing and adapting characteristics until its unique capabilities can be explored and codified.

2. The case study company: John McCall's Architects (JMA)

JMA was established in 1991 in Liverpool in the UK, and has been involved in architecture and construction for almost 20 years designing buildings throughout Northwest England. Focusing primarily on social housing and regeneration, the company is known for good quality, economical, environmentally sustainable design. JMA works with many stakeholders from the design through to building construction process and the associated information is very fragmented. Projects in which JMA are involved are typically of 2½ years duration, involving many stakeholders and requiring considerable interoperability of documentation and dynamic information.

2.1 Knowledge transfer partnership project with JMA

The specific academic challenge of the KTP is to link BIM implementation with Lean process improvements. The KTP project aims not only to implement BIM and therefore assess the degree of the successful implementation, but rather to position this within the context of value-add offerings that can help the company place itself at the high-end knowledge-based terrain of the sector. The KTP adopts a socio-technical view of BIM implementation in that it does not only consider the implementation of technology but also considers the socio-cultural environment that provides the context for its implementation. Within this context change management and adoption strategies will be a challenge.

BIM has actually been utilized by large architectural practices and on large building projects e.g. London Underground, but it is not widely (if at all) used by SMEs. The KTP will enable JMA to establish itself as the vanguard of BIM application giving them a competitive edge because BIM can enable the intelligent interrogation of designs; provide a quicker and cheaper design production; better co-ordination of documentation; more effective change control; less repetition of processes; a better quality constructed product; and improved communication both for JMA and across the supply chain.

The impact of the KTP will be also to improve the process at every level and stage: eliminating the risk of miscalculation, misinterpretation of design, improve communication, provide interoperability between stakeholders and, ensuring control and sharing of documentation. This is because BIM is a foundational tool for implementing an efficient process and invariably leads to lean-orientated, team based approach to design and construction therefore BIM will allow JMA to demonstrate the entire building life cycle including the construction and facility operation during the design phase.

3. Research methodology

A soft system methodology to improve the shared understanding of the existing architectural practice in JMA was employed as the method of research. This is achieved by making models in order to diagnosis and vision the working process. The contextual design approach was adopted to find out how the members of staff carried out their activities at JMA and identify the correct needs and user requirements through contextual inquiry. This was undertaken by a series of interviews of members of staff in their working situation.

Artifact models have been generated based on the syntaxes prescribed in the contextual design approach in order for the diagnosis of the current practice in regard to the artifacts in use. This is then followed by the storyboarding technique to pictorially describe and model the artifacts to be used in BIM implementation. Flowcharts and diagrams were produced for the artifacts modeling.

3.1 The properties of the artefacts (in JMA's design practice)

Artefacts created and used at JMA include models, sketches, drawings, specifications, bills of quantities, outline and full planning submission documentation, building control submissions, CDM submissions, contracts, program and construction plans of work and as built documentation. The specific artefacts required depend on the method of procurement. Artefacts are often used as milestones and are often used as approval points on projects.

The format and contents of the artefacts produced is generally determined by recipients and the client. Sometimes the formats are prescribed at the outset in the terms of agreement. In order to change the deliverables, discussions with the recipient and confirmation of the validity of new artefact formats need to take place. Construction projects are typically information-intensive collaborations between diverse collections of stakeholders and organisations. Contributions to the artefacts may be created by different disciplines within the building process. But they are often integrated into a single combined artefact by the project architect.

Artefacts are defined by the following properties:

- a) Physical or virtual form: An artefact can exist in both a physical and/or virtual form. Examples of physical artefacts could be printed drawings or construction mock-ups. Examples of electronic artefacts could be files in many formats for example dwg, dgn, skp, pdf, etc.
- b) Shelf Life and time of influence: Artefacts have a shelf life. It is appropriate to use artefact for a certain length of time after which it is necessary to confirm whether the artefact and the information in the artefact has been superseded. If obsolete artefacts are used, abortive work or unforeseen problems may arise.
- c) Accuracy: Many developers worry about whether their artefacts -- such as models, images, or documents -- are detailed enough. The accuracy required depends on the intended use. Accuracy can be measured against any property and how correctly it reflects the condition in the real world. However, it is more appropriate to measure accuracy against the fit for purpose. This raises the issue that information that is sufficient for one purpose may not be sufficient for another purpose. For example, it may not be necessary to have artefacts accurate to the nearest millimetre for outline planning whereas it may be necessary for construction.
- d) Objectiveness (addressing an issue) and the fit for purpose: An example of an artefact meeting an issue would be information submitted to achieve building control approval or planning permission. An example of an artefact created to achieve a milestone would be an approved preliminary design report. How well an artefact achieves its objective is a measure of its effectiveness. Artefacts may address one or many objectives.
- e) Creator or Developer: All artefacts have a creator or developer and this is as likely to be a team of people as it is to be an individual. It is usually the case that artefacts are constructed using constructs or acquired earlier in the development process. Where constructs are used the artefact is developed as opposed to being created. If the processes change, who the creator or developer of a particular artefact may also change.
- f) Perceived recipient and method of communication: Every design-construction problem can be represented in multiple ways. The clarity and comprehensibility of intent and meaning in the

artefact is a function of human perception and interpretation. Artefacts are required to generate a common shared understanding about the project related issues. These are issues of organisational semiotics. Organisational semiotics (OS) is the study of sign generation, exchange and interpretation in organisational contexts. Artefacts may be generated not only for human validation but also for machine based checking. Particular artefacts are designed to be communicated in particular ways.

- g) Codes and Standards: the design artefacts that are prepared to discuss the scheme with the users are constrained by project factors; timescales and the conventions adopted by a practice. For example, planning applications is a good example of an artefact prescribed by legislation. The Town and Country Planning (General Development Procedure) Order 1995 sets out a statutory list of information that is required to accompany planning submissions. The standardisation of artefacts is to some extent understandable because at times it is necessary to compare and contrast artefacts.
- h) Ease of creation: One facet of an artefact is how easy it is to construct. This is particularly relevant in the business area where cost competition exists.
- i) Responsibility: Where an artefact is created to meet a specific purpose, someone or a group of people will be assigned with the related responsibility associated with the artefact.
- j) Stepping stone: Building process artefacts are effectively stepping stone in the building process. As such they are tailored to a specific objective.
- k) Standalone Value: Artefacts often have a value in themselves even though they are a stepping stone to something else. For instance, a building model that is to show the design to a prospective owner may have a value in itself.
- l) Static and responsive artefacts: Some artefacts remain in a static state while others are responsive to external changes. An example of a responsive artefact would be a model with solar louvers that respond to daylight levels. As computerised models become more widely used more responsive and interactive artefacts are likely to be developed.
- m) Orphaned or connected: sometimes an artefact is an orphan and sometimes it remains connected to its source.

3.2 Changes in artefacts via BIM adoption and implementation

The use of Building Information Modelling and the associated changes in the nature of the artefacts produced are bringing about changes in the construction industry. In the new way of working a methodology that is brought in by BIM, it would be wrong to consider artefacts as individual entities rather as data models. From this model information is extracted and filtered to provide artefacts of the appropriate level of detail for their purpose. Often the additional textual or graphical overlays are added. The elaboration of these artefacts is carried out in four steps:

- Step 1: the elaboration of the artefacts that are created to develop and understand the design solution,
- Step 2: the elaboration of the artefacts that are created to achieve approval of designs
- Step 3: the elaboration of the artefacts that are created to facilitate construction and
- Step 4: the elaboration of the artefact so-called “single lifecycle building model”.

3.3 Artefacts for design development and its understanding

The analysis of spoken interaction between architects and users in the early stages of a building's design has revealed that artefacts serve a dual purpose. Artefacts embody the current status of the design and to act as mediating devices to develop an understanding of the design in conversation (Luck 2007). Traditionally during the design development the information moves from one point of stasis to another. During intervening periods the information may be in an inconsistent unresolved form. Knowledge is developed not so much through relatively stable boundary objects (artefacts) but through constantly unfolding epistemic objects (Ewenstein 2009). Epistemic objects are objects abstract in nature, they are objects of inquiry and pursuit. During this stage there is a development through iterative design cycles from the fuzzy conceptual ideas to the geometric representations.

Evidence suggests that architects as a group cannot predict the public's aesthetic evaluations of architecture (Brown & Gifford, 2001). Many research projects in environmental psychology have revealed that architects and non-architects perceive architecture differently (Devlin, 1990; Hubbard, 1996; Gifford, 2002.) This means that the creation of artefacts is particularly important to transfer ideas and concepts in order to establish a good communication and shared understanding amongst the stakeholders and users of a project.

Traditionally design representations fail often to articulate the future experience of a space to clients and stakeholders. Individual drawing which are the legacy artefact of the building process have no value other than in a printed form. Traditional CAD systems have assisted in the production of such representations but the inherent intelligence of the information contained is minimal. BIM enables the use of three-dimensional virtualization of buildings with additional information on demand in a way which is impossible using two dimensional ideas and concepts on paper.

The type of representations used has to be tailored to the awareness of the clients. The correct approvals can only be solicited if first a correct understanding is transferred to the person responsible for approval. This is partly to do with organizational semiotics and also partly to do with the mechanism of information transfer. Drawings presented to clients may sometimes look impressive but are in fact symbolic artefacts and they conveying actual information poorly. Such symbolic artefacts are sometimes referred to as illuminated scrolls because the embellishments overlaid do nothing to enhance understanding of the content. As an artefact for further development, illuminated scrolls traditionally have been considered as not maintainable due to the diligence it requires to preserve the symbolic quality. With the uses of BIM less informational atrophy needs occur during the development cycle.

BIM is one solution to enabling shared understanding and successful communication for effective design development. This is achieved by the creation of virtual preconstruction models so that the client or recipient can drive the direction of his or her design interrogation. This means that the design review is not prescribed with predetermined images and views taken from preset perspectives. As a result, the traditional artefact is replaced by a more effective virtual artefact. Although the initial role of the virtual artefact is to explain, ultimately the role of the artefact should initiate meaningful dialogue and interaction.

3.4 Artefacts developed to gain approval

Examples of artefacts created for pre approval are planning and building control submissions, costing and other criteria prior to the commencement of construction. With the change from man to machine validation, the nature of the artefact will change through the implementation of BIM. For example, Rule checker software has achieved increased interest and is often regarded as one of the big benefits by using BIM/IFC based software in the design process. When new BIM based artefacts are used, it is necessary for them to have equivalent contractual and legal status as the traditional artefact. The CORENET system in Singapore represents a an advanced development that is an Automated Code Checking system based on intelligent IFC2x objects, which allows automated approval of building plans over the Internet. Developments in the UK may also occur along the same lines.

3.5 Artefacts developed to facilitate construction

Architects create constructs of what is to be built; contractors then deconstruct these in elements and associated activities. By creating artefacts that can be deconstructed and undergo analysis BIM can be used to facilitate the construction process. The object orientated approach of BIM has the ability to separate the building by element which in turn facilitates breaking down the production information into smaller work packages.

Earlier involvement of the contractor can enhance the design process. But in a traditional contract process, contractor involvement only occurs at tender stage shortly before construction starts on site. This means that the knowledge from the contractor for constructability is not feed into the early stages of design development. A package approach can also be used to facilitate CAD/CAM and site manufacture. Particularly when working with elemental building packages being able to undertake clash detection and deviations becomes an important issue.

3.3 The concept of the lifecycle model

BIM as a lifecycle evaluation concept seeks to integrate processes throughout the entire lifecycle of a construction project. The focus for the stakeholders is to create and reuse consistent digital information throughout the lifecycle (Figure 1). BIM incorporates a methodology based around the notion of collaboration between stakeholders using ICT to exchange valuable information throughout the lifecycle. Such collaboration via use of BIM artefacts is seen as the answer to the fragmentation that exists within the building industry (Jordani, 2008).

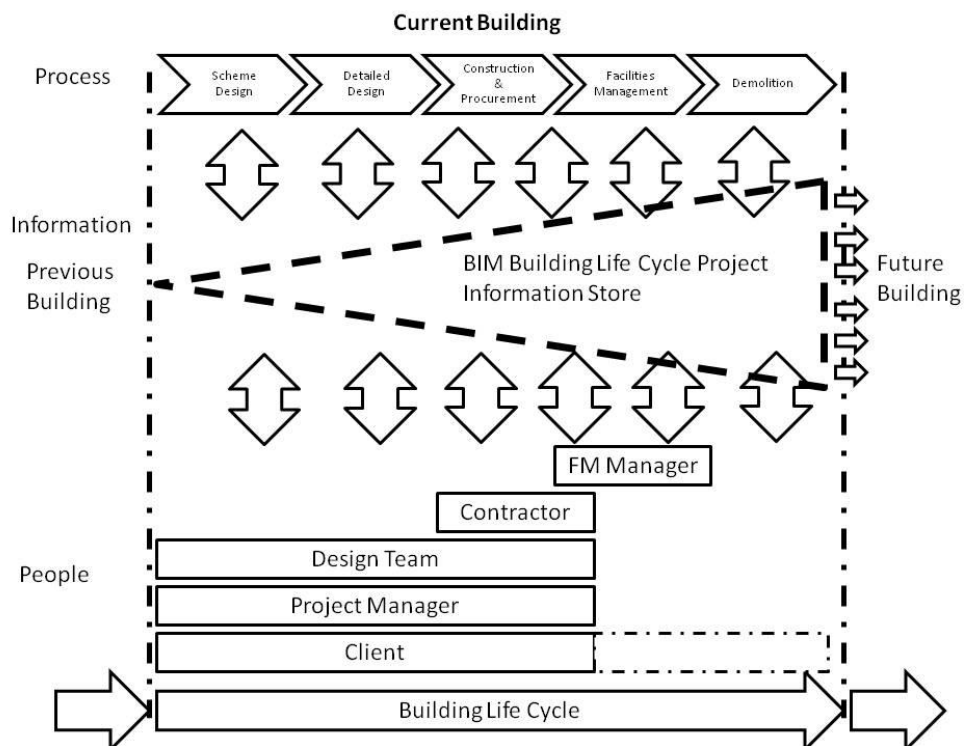


Figure 1: The BIM Lifecycle of information

3.4 The artefacts in JMA's BIM enabled design process

The table below concisely considers the ongoing changes in the artifacts used in JMA's Design Process via BIM adoption.

Table 1: the changes in the artefacts used in JMA's Design Process

Stages in the Design Process	Non BIM Artefact	BIM Artefact	Intelligent BIM Artefact
Feasibility Report	Hand sketches, basic costing from areas.	Massing Model, basic costing generated from the model	Bidirectional model and costing information with decision support system
Preliminary Sketch Design	Sketch-up model, material lists and costing from areas	3d database, with areas volumes and materials and costs	Multidiscipline collaborative models with intelligent feedback
Final Sketch Design	Sketch-up model and plans in powerdraft, material list and costing from areas	3d database, with areas volumes and materials and costs	Multidiscipline collaborative models with intelligent feedback
Planning Design	CAD drawings created from 2d representations, materials noted on drawings	3d database, with areas volumes and materials and costs, with non required information removed, planning specific info added	Models that can be placed in context allowing review in virtual reality
Detailed Design	Plans, sections, elevations and details produced as 2d representations and outline specification, colours, finishes and build ability	3d database – details extracted and worked up in 2d, schedules generated direct from the database	Links to product information databases and supplied specification and direction. Link to sustainability database and design for manufacture considerations
Production Information	Plans, sections, elevations and details produced as 2d representations and full specification, full details	3d database, all representation connected reducing inconsistencies, automated BOM	3d database – all information in 3d, shop drawings generated direct from the model, construction support system
Construction Documentation	Plans, sections, elevations and details produced as 2d representations and full specification, full details and shop drawings and construction sequence drawings	3d database usable by the contractor with possible automated manufacture	Models indicating sequence of construction, and method of construction
As Built Drawings – Life Cycle Info	2d representations of what has been built	3d database of what has been built, suitable for facilities management	Intelligent identifiable objects with attached maintenance information

3.4.1 Feasibility report

Feasibility has not been a major focus in the development of BIM systems. In JMA's case and generally feasibility is undertaken to acquire project funding. To achieve funding schemes need to achieve a certain level on the housing quality index. There are ten indicators that measure quality. Each indicator contains a series of questions that are completed by the applicant organization. Indicators concerning the site are visual impact, layout and landscaping, open space and routes and

movement. Indicators concerning the units are size, layout, noise, light, services and adaptability, accessibility within the unit, sustainability and building for life. Though the use of BIM these factors can more easily be investigated potentially leading on to the development of rule based systems in this area.

3.4.2 Preliminary sketch design

The objective of the preliminary sketch design is to validate the design against the brief, scales of accommodation, site constraints, target costs and to determine the main issues related to construction and engineering. In the preliminary stage of the design the issues and road blocks for the design are researched and evaluated. Using BIM massing models the level of detail can be increased and alternative options explored. The particular benefit of BIM at this stage is the ability to undertake rapid prototyping to find the optimal solution meeting the requirements of the brief.

3.4.3 Final sketch design and planning submissions

The final sketch design is to confirm the final form, appearance, construction method, services installations, landscaping, roads, car parking and construction phasing. This information should be sufficient in order to make a planning application. The objective from the client's perspective of making planning applications is to gain planning approval. Yet at the same time not restricting possible further design development which might be beneficial to the client. By appropriate filtering of design information using BIM these combined objectives can be achieved. The means it is not necessary to develop a data set purely for planning application purposes.

3.4.4 Detailed Design and Production Information

The objective of this stage is to integrate detail design decisions of all disciplines into a unified scheme and to obtain all the necessary approvals. Building control submissions are usually made as part of this stage. The traditional problem with construction documentation is clashes between disciplines. The ducts clash with the structure etc. With the use of combined models clash detection can be undertaken both construction. This represents a major gain in the process.

But the question is how can the tradition production information offering be improved? The consistency of representations generated from a single model avoids many discrepancies that occur using traditional methods. With the structuring of elements in BIM the production of elemental work packages becomes easier. Also because objects are used substitution of elements also becomes easier.

3.4.5 As Built Drawings-Lifecycle Information

As built information is the cornerstone of effective facilities management. With the use of IFC models JMA has the potential to provide a more sophisticated form of as built information. Discussions with clients are currently taking place to develop better artefacts in this area.

4. Conclusion

New artefacts are emerging. At JMA a proactive approach is being taken to discover more effective methods of conveying building design information and concepts. Yet artefacts fall short in their ability to fulfil what is required. In the construction or creation of an artefact there is an inevitable trade off between the ease of creation of the artefact and how effectively it conveys its message to its recipients. Using IFC compatible objects as the building blocks for artefacts in the design process has the potential to facilitate and add value to the work of both the recipient and the creator. By creating more intelligent boundary objects specialist knowledge can more easily be shared. Major benefits to the contractor and end user can be realized with intelligent objects being used to construct the artefacts of the building process. To improve the ability of BIM to communicate the correct messages common BIM standards need to be adopted by all stakeholders in the building process and working practices also need to change.

With the adoption of BIM it is easy to focus on 3d building representations when other forms of representation should be considered. The form of representation could be a pie chart, a venn diagram, a flowchart or a synergy diagram the most appropriate form should be adopted. Building Information Modelling (BIM) offers a new way of documenting, designing and streamlining the building lifecycle processes. Therefore, with the move towards BIM, it is more realistic to envisage a holistic building model which promises a way of working that gives speed, efficiency and clarity to the construction process.

Finally, we must not lose sight of the fact that the end goal is a building that meets its requirements on all levels. Efficiency in design process and construction are merely the method to facilitate this end objective.

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