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SOFTWARE INTEGRATION IN THE CONSTRUCTION INDUSTRY

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ABSTRACT: The authors observe that in a typical construction project, work is assigned to various groups of specialists such as architects, engineers, draftsmen, managers, fabricators, erectors and administrators and that information technologies (IT) have progressed in each corresponding field. They note that the existing software solutions have their own proprietary format and databases for input and output, and then argue that the lack of interdependencies between these software tools has created a major problem for the construction industry. The authors propose a virtual model concept for buildings with configurable views aimed at the various users such as the designers, estimators, engineers and, incrementally, the architects, draftsmen, fabricators and erectors, as well as various other construction trades. The virtual model concept could be used to improve software integration with consequent savings for the construction industry.

1. INTRODUCTION

This paper is presented in an attempt to analyze and better understand some complex problems in the construction industry and to pave the road for the authors to propose innovative solution concepts to specific sectors of the construction industry.

The problem of low productivity in the construction industry is well documented. Prominent researchers from the academic field have identified roots of this problem and have presented their points of view for possible remedies using Information Technologies (IT). A brief review of some previous work is presented in this paper in order to help and understand research motivations, interpretations and propose avenues for the solution of the persistently low productivity problems in the construction industry. A good understanding of the different points of view from within this field of research will sustain and enhance the efforts invested by various industry professionals and university researchers who are attempting to find innovative and applicable solutions. These contributions shed additional light on the construction industry information tunnels.

Long term solutions require a clear vision and innovations, which may be proposed by independent entrepreneurs and researchers willing to try alternative solutions that involve extensive research and complex application work. Once a solution becomes feasible, other issues will have to be addressed regarding the challenges of changing project mind-set, education of architects, engineers, draftsmen and technicians, assignment of work tasks to professionals, as well as defining new ways of using technology in the construction industry in order to achieve increased productivity and ensure business profits.

2. LITERATURE REVIEW

There are many existing research projects on the subject, with a very large number of available publications. The authors have reviewed about one hundred papers that cover a balanced view of the present situation in the construction industry. Only a few typical papers will be discussed herein.

In a paper called “Changes and the Unchangeable: Computers in Construction”, Claude Bédard (2003), Dean of Research and Technology Transfer at the École de technologie supérieure (ÉTS) in Montreal, presents a review of the changes in the areas of IT and construction during the past 50 years in North America and proposes possible future scenarios of development.

One way to characterize the recent advances of IT in many fields including construction is going from isolated very specialized applications to environments capable of communicating with others, performing several tasks and encompassing different concerns. The use of industry driven exchange protocols initiated by DXF files for drawings, lately followed by the more general IFC’s, are progressively making possible effective communications across firms that are geographically dispersed, even among different disciplines and distinct project phases. While the above holds true, innovative IT applications in construction have been sporadic and unevenly distributed across the industry, with a major impact only on a few sectors. This resulted in a loss of opportunities and a level of productivity that lags behind that of other industries. One of the fundamental reasons for this situation stems from the high level of fragmentation of the North American construction industry that is unparalleled in other large industries such as automotive, aerospace or communications. Typically, a construction project brings together a unique amalgam of design firms, suppliers, general contractor and subcontractors that may never work together again. Fragmentation gives rise to communication and coordination breakdown across project phases, disciplines and subsystems. A profoundly fragmented industry is incapable of neither developing a long term coherent vision of its own development nor investing modest amounts to fund its own R&D. Three areas for future developments of IT in construction are presented as integration, augmenting human capabilities and sustainability.

Integration is the obvious target. Hence, the primary focus of IT developments should be integration in the broadest sense, as well as developing the means to enable integrative decision-making as early as possible in the process, at a time when decisions have the greatest impact on the overall life-cycle performance of the facility. The author recommends the following:

- Promote the development and adoption of internationally recognized, industry supported electronic documents for all communications during a construction project, such as for drawings, schedules, specifications, legal documents.
- Develop enhanced means to share information and decisions across disciplines and participants.
- Civil engineering’s main interest must evolve from new construction to life-cycle facilities and encourage the development of interdisciplinary perspectives in education as well as in practice. New developments in sensor-driven models could greatly enhance the knowledge of construction professionals and companies who currently know little about the long-term behaviour of the facilities they design and build.

Future IT developments in civil and construction engineering must keep the human professional in charge and enable the end user to solve meaningful problems in a manner that is as natural as possible. Approaches should be more user oriented, enable communications more effectively with others and take routine out of construction tasks in order to focus human intervention where it really provides added value.

The environment has become a priority because the scale and rate of global environmental degradation is one of the major threats of the 21st century. Sustainability can be achieved by concerted and conscious efforts on the preservation of natural resources and the reduction of waste and negative environmental impacts through better design and operation of facilities. New software tools are emerging that allow the assessment and the reduction of the environmental impact of building structures directly from their 3D CAD representations thereby enabling professionals to make informed design decisions. The author concludes that what lies ahead in the future are more profound issues that will necessitate advanced IT, and even beyond technology the ability to change either processes or people's attitudes.

Zhigang Shen, Raja Issa and William O'Brien (2003) have proposed a model for integrating construction design and schedule data. Their research indicates that the difficulty of timely retrieval of useful information from heterogeneous data sources is a major cause of low productivity in the construction industry. Common product and process models appear to be the solution to problems caused by fragmented construction documents. A tree-structured product model is presented, which binds together design knowledge, cost data and schedule data, as a feasible solution for the data integration problem in construction projects. The product model integrates product, process and database, and supports dynamic multiple views from various domains at various detail levels. 3D CAD object data could be extracted from the application directly and the extracted dimension data could be input into the estimating application by linking variables directly. A mechanism needs to be developed for mapping explicitly the schedule activities to the corresponding design components. The proposed model will be composed of the following three major components:

- the abstract component tree, representing the building;
- the components libraries, storing the reusable design components;
- the costs database.

The contribution of this research is that it addresses the problem of integration between different domain applications as well as the dynamic nature of construction information.

Walid Tizani and Robert Smith (2003) proposed an incremental virtual prototyping as an IT tool for civil engineering project models. The authors claimed that an obvious improvement for IT in the construction industry is to attempt to integrate the design processes of as many aspects as possible in order to allow for the simultaneous consideration of their design constraints. Virtual prototyping is an effective design technique that consists of designing and developing a virtual model which represents a real life scenario and allows testing designs for compliance and performance through a series of virtual tests. A virtual prototype of the building system can thus be formed from major components and its performance tested both globally and locally for each of the specialist aspects generated from the prototype. The virtual prototype should be able to simulate its own behaviour, provide indication of its performance against set criteria and check its compliance with set constraints at the appropriate level.

The implementation of such a multi-disciplinary model representing a complete prototype requires an incremental approach, where all parties involved in design, construction and life cycle management of the facility can input requirements to and output solutions from a single virtual model in a sequential or concurrent fashion. Some requirements for the realization of the incremental virtual prototyping are indicated below:

- The shear scale and complexity of the domain and its inter-disciplinary nature must be accounted for.
- Each discipline requires that the information be presented in a suitable format for its particular problem solving method.
- There must be a more flexible approach to the management of information. It must be possible to change information and decisions about the building, but with sufficient integrity to allow testing and appraisal of the building.
- Adopting virtual prototyping within the building industry might require or lead to changes in the building design practices.

The industry has begun adopting standard product models that promote information exchanges by integrating the logical structure of building design data. Virtual prototyping is the next logical step to this as it proposes to store all design information and intents in a single coherent database, instead of side-by-side, and enhance the model with process exchanges. The full realization of virtual prototyping will ultimately provide a mechanism for storing the tools and processes required for building design.

A key statement in this work indicates the scale of the challenges facing the research community regarding the solution of some problems in the construction industry:

> *"The overall challenge to the research community is to prove the feasibility of such an approach and provide the necessary technologies for its implementation. The ultimate challenge is to make the concept of incremental virtual prototyping technically feasible and implemented in the fields."*

William O'Brien, Raja Issa and Ian Flood (2003) proposed a shift from information tunnels to configurable, user model driven environments as a vision for future Information Technologies. The authors advocate the need for information integration to support decision-making. They conclude that even with advanced applications based on shared data standards, professionals face considerable difficulty accessing needed information in a form useful for decision making. A primary reason is that most tools are designed for specific applications. This creates the problem of information tunnels: rich data and application areas with knowledge that is not easily transferable to other applications. The suggested alternative lands itself to the adoption of user models. Some distinct features of these models are indicated below:

- User models will provide project professionals with access to project information regardless of its source or tunnel.
- User models will structure data and metadata that professionals use in their work.
- User models are derived from the cognitive science community and are described as the mental picture a user has of how a particular software application should work.

The presence of information tunnels has led to calling for data standards to support interoperability. However, data standards are a partial solution and support to all project participants is difficult to realize. Hence, information tunnels are likely to persist even with a significant adoption of data standards.

Haiyan Xie, Raja Issa and William O'Brien (2003) proposed a user model and configurable visitor for construction project information retrieval approach. The proposed system uses the user model of Construction Project Management (CPM) and a User Configurable Visitor (UCV) to retrieve information based on user's needs. Construction management databases include: 1) scheduling, 2) estimating, 3) purchase orders, 4) drawings, 5) specifications, 6) productivity, 7) contracts and 8) storage of information. Relationships exit between these databases used in construction management. Poor or missing information in this network leads to project delays, uneconomical decisions, even the complete failure of the desired facility. Different construction companies may have different sets of documents; nevertheless, they have documents in all eight categories. Information tunnels are present in database management systems. Even though the same data may be required in more than one tunnel, it is difficult to go from one tunnel to another. Oftentimes, for the purpose of answering some meaningful queries by the project manager or other users, the database management system (DBMS) must be able to manage queries to multiple databases such as scheduling, specification and estimating. Hence, it is proposed that user configurable visitors be used to retrieve information from these multiple databases.

Features of the user model and the relationship with DBMS design are presented below:

- The user model is a simplified view of a complex reality and an abstraction of the functions.
- Effective models facilitate discussions among different users, helping them to reach agreement on the key fundamentals and to work towards a common goal.
- Modeling is an established means of designing software. The domain in which the software systems operate must also be modeled, understood and improved as required.
- User modeling is an important part in the process of developing software systems.
- According to the perspective of the person creating the model, the user model will differ in details.
- This difference will be reflected in the different viewpoints, goals and visions of the process, including its efficiency and the various elements that are acting in concert within the business.

- The user model can act as the basis for communications, improvements or innovations, and define the information systems requirements that are necessary to support the business.

The components of a business user model are the views, diagrams, objects and processes, which are defined below:

- Views capture information about one or more aspects of the business. A view is an abstraction from a specific viewpoint, omitting details that are irrelevant to that viewpoint.
- Each view consists of a number of diagrams, each of which shows a specific part of the business structure or a specific business situation. The diagrams contain and express the objects, processes, rules, goals and visions defined in the business situation.
- Concepts are related in the diagrams through the use of different objects and processes. Objects are the physical or the abstract elements in the business. Processes are the functions in the business that consume, refine or use objects to affect or produce other objects.

Thomas Froese and Sheryl Staub-French (2003) proposed a unified approach to project management. These authors have observed that in current project management practice, the overall task of designing, managing and constructing a building is carried out by organizing the work into many distinct tasks assigned to many different groups. All design and management tasks on architecture, engineering, construction, and facilities management (AEC/FM) projects are fundamentally information processing tasks that take existing project information as input and produce new project information as output. There is very little shared vision of the project across all participants until the physical structure begins to emerge, which then provides a unifying common perspective for all participants. The authors proposed a unified approach to project management that brings an integrative view to the forefront, centered on the notion of defining multiple views of the project and the interrelationships that exist between views. By linking together disparate views of project information, a more integrated approach to project management is achieved. The virtual building created acts as a focal point, or unifying view, for all project participants, particularly during pre-construction design and management phases, much in the way that the physical structure does during the construction phase.

The unified approach to project management involves changes in the way participants think of the underlying project mechanism and their role in it. Every participant views his role as carrying out his tasks by drawing information from the project model, placing his results back into the project model, and using the model to explore the interaction of his work with others and to support communications.

Guillermo Salazar, Ismail Polat and Joao Almeida (2003) elaborated on the role of the 3D parametric building model (3D PBM) in the future education and practice of civil and construction engineering. Students in engineering and architecture face the challenges of learning and understanding not only the key aspects of design and construction, but also the myriad of current computer tools, software and technologies available on the marketplace. Similarly, professional organizations face an extremely competitive construction market where those that apply technology-driven packages seem to be gaining a sustainable advantage, mainly in the form of better coordinated designs, spatial visualization of the final product, more accurate and effective cost estimating as well as improved project communications.

The educational model for civil engineers needs constant and careful revisions and modifications. Educators cannot afford to stay behind in their understanding and application of new technologies. It is imperative for educators to assess, test and understand the introduction of the most recent technology available for civil engineering education in the context of modern and future professional practice.

One of the characteristics of the AEC industry is its fragmentation. This is due to the unique, one of a kind nature of construction projects. This fragmented structure makes it quite difficult for professionals to develop an integrated view of the project that is consistently shared among all participants. Likewise, the educational process of civil engineering is assembled in a similarly fragmented manner. Students are exposed to partial systems and components of the final product. Students do not develop an integrated view and understanding of the complete building. The 3D PBM is a promising avenue for creating an integrated view of the project within the present-day industry. It has tremendous potential for educating future generations of engineers.

The industry is gradually moving to 3D PBM software based on object oriented technology where the building information is created and defined as a collection of interrelated objects. The 3D PBM stores all information related to the building in one central database. Its parametric engine provides flexibility for changes, maintains consistency throughout the design and therefore minimizes errors and omissions.

3. RESEARCH ON THE INTEGRATION OF INFORMATION TECHNOLOGY AND PROJECT MANAGEMENT IN THE CONSTRUCTION INDUSTRY

Some of the main findings concerning the integration of information technologies and project management in the construction industry are summarized below:

- All design and management tasks on AEC/FM projects are fundamentally information processing tasks that take existing project information as input and produce new project information as output.
- With conventional project management, there is very little shared vision of the project across all participants until the physical structure begins to emerge, which provides a unifying common perspective for all participants.
- The industry has begun the adoption of standard product models that promote information exchange between conventional specific and rich applications in building design. Virtual prototyping is the next logical step to this, as it proposes to store all design information and intents in a single coherent database and to answer the ultimate goal and need for information integration to support decision-making.
- The industry is now moving towards virtual models which represent a real life scenario with configurable environments for the integration of construction information, products and design processes of as many aspects as possible, using a single database, as a solution to the industry fragmentation of information.
- A virtual prototype of the building system can thus be formed from the major components, and its performance tested globally and locally for specialist aspects.
- The virtual prototype should be able to simulate its own behaviour, provide indication of its performance against set criteria and check its compliance with set constraints.
- Virtual prototyping presents a unified approach to project management that brings an integrative view to the forefront, centered on the notion of defining multiple views of the project and the interrelationships that exist between views.
- User virtual models will provide project professionals with access to project information regardless of its source or tunnel. Hence, it is proposed that user configurable visitors (UCV) be used within the virtual model to retrieve information from the single coherent database according to the end user's specific view point and needs.
- A tree-structured virtual product model binds together design processes and knowledge, cost data and schedule data. The model supports dynamic multiple views from various domains at various detail levels. A mapping mechanism may be provided to map explicitly the schedule activities to the corresponding design components.
- 2D and 3D CAD object data and drafting could be extracted from the application directly and the extracted dimension data could be input seamlessly into the estimating application engine.
- Effective virtual models facilitate discussion among different users, helping them to reach agreement on the key fundamentals and to work towards a common goal. The model can act as the basis for communications, improvements or innovations, and define the information systems requirements that are necessary to support the business. By linking together disparate views of project information, a more integrated approach to project management is achieved. The virtual model created acts as a

focal point, or unifying view, for all project participants, particularly during pre-construction design and management phases, much in the way that the physical structure does during the construction phase.

- The virtual model acts as a unifying approach to project management were every participant views his role as carrying out his tasks by drawing information from the project model, placing his results back into the project model, and using the model to explore the interaction of his work with others and to support communications.
- The implementation of such a multi-disciplinary model to represent a complete construction building prototype requires an incremental approach, where all parties involved in the design, construction and life cycle management of the facility can input requirements to and output solutions from a single information virtual model in a sequential or concurrent fashion.

4. CONCLUSIONS

Professional construction organizations face an extremely competitive construction market where firms that apply technology-driven packages seem to be gaining a sustainable advantage, mainly in the form of more accurate and effective cost estimating, better coordinated designs and spatial visualization of the final product, as well as improved project communications and minimized errors and omissions.

It is predicted that virtual model prototyping as described above will play a significant role in the construction industry. Organizations which will apply such technology will gain a lead in the market place and will increase their revenue shares.

Educators cannot afford to stay behind in their understanding and application of modern and new technologies. 3D virtual models have tremendous potential for educating future generations of engineers to better understand all aspects of building design and construction.

Staub-French and Fisher (2001) have summarized their anticipation to find a viable solution for the low productivity in the construction industry by stating:

> *"Commercial tools that can electronically integrate design, cost, and schedule information provide many benefits to project teams throughout the design and construction process. Specifically, they enable the early detection of design conflicts, shorten estimating time and improve estimating reliability, improve the communication of schedule intent."*

This statement indicates concisely and very clearly that the solution relies on an integrated commercial technology and not solely on academic concepts. The authors share that view and indeed believe that a challenging work starts here. Staub-French and Fisher's valuable request will be answered by recommending the creation of the *Virtual Steel Building*™ software (SAFI, 2005).

The best of the academic researchers, reputable software developers and innovative fabricators of all sizes will need to collaborate in a collective effort in order to plan for a successful solution of an integrated virtual model for the construction industry. The present paper intended to provide a partial review of some relevant concepts presented by researchers in this field and will pave the road for a specific solution oriented towards the construction industry, in an incremental approach towards a global solution.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Bédard, C. 2003. Changes and the Unchangeable: Computers in Construction. *Towards a Vision for Information Technology in Civil Engineering, Fourth Joint International Symposium on Information Technology in Civil Engineering*, ASCE, Nashville, TN, USA.

Froese, T., & Staub-French, S. 2003. A Unified Approach to Project Management. *Towards a Vision for Information Technology in Civil Engineering, Fourth Joint International Symposium on Information Technology in Civil Engineering*, ASCE, Nashville, TN, USA.

O'Brien, W., Issa, R.R.A. and Flood, I. 2003. Moving from Information Tunnels to Configurable, User-Model Driven Environments: A Vision for Future Project Information Technologies. *Towards a Vision for Information Technology in Civil Engineering, Fourth Joint International Symposium on Information Technology in Civil Engineering*, ASCE, Nashville, TN, USA.

SAFI, 2005. *Virtual Steel Building*™. SAFI Quality Software Inc., Québec, Canada.

Salazar, G.F., Polat, I.H. and Almeida, J.C. 2003. The Role of the 3D Parametric Building Model in the Future Education and Practice of Civil Engineering and Construction. *Towards a Vision for Information Technology in Civil Engineering, Fourth Joint International Symposium on Information Technology in Civil Engineering*, ASCE, Nashville, TN, USA.

Shen, Z., Issa, R.R.A. and O'Brien, W. 2003. A Model for Integrating Construction Design and Schedule Data. *Towards a Vision for Information Technology in Civil Engineering, Fourth Joint International Symposium on Information Technology in Civil Engineering*, ASCE, Nashville, TN, USA.

Staub-French, S. and Fisher, M. 2001. *Industrial Case Study of Electronic Design, Cost, and Schedule Integration*. CIFE Technical Report No. 122, Stanford University, Palo Alto, CA, USA.

Tizani, W. and Smith, R.A. 2003. Incremental Virtual Prototyping as an IT Tool for CE Projects. *Towards a Vision for Information Technology in Civil Engineering, Fourth Joint International Symposium on Information Technology in Civil Engineering*, ASCE, Nashville, TN, USA.

Xie, H., Issa, R.R.A. and O'Brien, W. 2003. User Model and Configurable Visitor for Construction Project Information Retrieval. *Towards a Vision for Information Technology in Civil Engineering, Fourth Joint International Symposium on Information Technology in Civil Engineering*, ASCE, Nashville, TN, USA.