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Integrating design and construction through virtual prototyping

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ABSTRACT

Construction Virtual Prototyping (CVP) is the use of integrated product, process and resource models of construction projects to support the construction planning in virtual environment. This paper describes an integrated framework and process for efficient application of CVP to support project teams on construction planning. It includes specific examples of models and objectives as well as detailed suggestions on how to implement CVP in practice.

1. Introduction

A comparison of productivity data between manufacturing and construction industries is interesting and revealing. For example, Fig. 1 indicates that within last 40 years, the non-farm industries, which primarily refer to the manufacturing industry as it has a dominant share of over 80%, have made approximately 10% incremental annual improvements while the construction industry continuously declined.

This phenomenon is observable in almost every country, and it may be explained by the following three differences between the two industries:

1. the construction industry does not have an effective platform to capture and re-use knowledge generated in design and construction stages;
2. the construction industry does not have a fixed production line; and
3. the construction industry does not have the ability to 'try before build'.

It is necessary to note that the above differences are identified through authors' own experience and knowledge. It is expected that these can generate further research interests and discussions with in the research community.

The manufacturing industry adopts a decomposition model in which an artifact is decomposed into basic components which can be designed in isolation. These basic components are frequently defined as shapeable blocks and stored in element libraries in graphical modeling systems. A new design is therefore a hierarchy of components which are modified to fit new requirements. The production process of the new design is also a slight modification of the existing process. In other words, the manufacturing industry is able to capture and re-use its knowledge in design and production. New design and production processes are obtained through incrementally improving existing versions. The construction industry, however, does not have this capacity. A design process in construction typically starts from a blank sheet of paper. Although certain components and building details may be re-used, the design process differs significantly from that of the manufacturing industry where only slight improvements are made on existing designs. This goes through the entire construction process where new contract, new teams and processes are formed. When the project is completed, little knowledge is captured and retained.

In addition, the manufacturing industry has a fixed production line where the productivity is dominated by the speed of machinery [13]; whereas the construction industry does not have a production line and project participants have to exercise personal judgments to find the best way to complete their tasks.

Moreover, the lack of ability to 'try before build' turns construction to a very risky business. A construction project is by and large an experimental process guided by design and planning information which is particularly full of incompleteness and mistakes. As a result, many projects are completed at the expenses of ubiquitous time and cost overruns.

The authors propose that the above three issues are the bottleneck that hinders the incremental improvement of the construction industry. In order to remove the bottleneck, research team at The Hong Kong Polytechnic University started a research project in 2004 to develop the virtual prototyping technology. Virtual prototyping (VP) is a computer-aided representational process concerned with the construction of digital product models ('virtual prototypes') and realistic graphical simulations that address the broad issues of physical layout, operational concept, functional specifications, and

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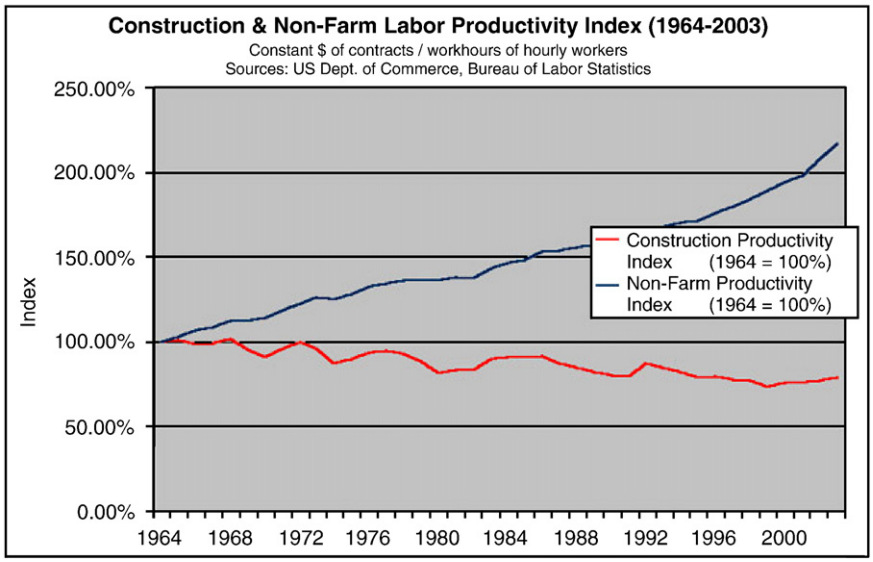

Fig. 1. Productivity comparison between construction and manufacturing industries.

dynamics analysis under various operating environments [1–3]. Dedicated VP technology has been extensively and successfully applied to the automobile and aerospace fields [4,14,15]. However, the development and application of VP technology in the construction industry (i.e. construction process simulation) has been limited. This is probably because that each construction project is unique in terms of the site conditions, requirements, and constraints. Sarshar et al. [5] identified three major industrial barriers to uptake VP technology, including cultural and risk issues related to information sharing, fragmentation of business interests and the lack of piloting on real construction projects.

3D/4D models support planners by relating building components from a 3D CAD system to construction activities from a project planning system, using a graphical interface. The construction process can then be simulated by executing the process modeler built in the VP system and the user can visually check how the process proceeds. 4D CAD systems can be used for construction analysis and communication [6]. Hartmann and Fischer [7] developed an integrated process of how project teams can use 3D/4D models efficiently to support the knowledge communication and generation needed during the constructability review on construction projects. Although 3D/4D model can help the planners to analyze the design, find out the collision and discover missing or conversed sequence, the 4D process developed by Hartmann and Fischer emphasized the knowledge transfer to engineer or non-construction managers during the construction planning. This application is quite useful because efficient communication is the key factor of successful construction. However, identifying appropriate construction methods and preparing feasible construction schedules are the most important concerns of the planner. The application of VP technology should thus assist the planner to identify suitable construction methods and prepare construction schedules.

This paper presents a case study of applying virtual prototyping technology to a real life construction project. It identifies the need of virtual prototyping technology and presents a new profession which is named process modeler. The role of the process modeler in the project procurement process is discussed. Skill set for the process modeler is defined. The paper concludes that the virtual prototyping technology can remove the bottleneck of the construction industry. As VP technology requires designers to modularize design into BIM (Building Information Management) models which are 3D models with information for performance evaluation of the models, this encourages standardization and prefabrication. Prefabrication indirectly introduces a production line into the construction industry. VP can realistically simulate construction processes and effectively capture design and construction knowledge which can be re-used in future projects. In addition, VP provides the platform for practitioners to 'try before build' the project.

2. Process modeler as a new employment classification

The Construction Virtual Prototyping Laboratory (CVPL) at The Hong Kong Polytechnic University has applied VP technology to several real construction projects in Hong Kong. VP technology enables contractors to "construct the building many times" in the computer. All sorts of scenarios can be previewed and potential problems identified in advance in this simulation process. The simulation process performs such tasks as production, transportation, handling and assembly of different construction components, including all the associated operational processes. All the variables affecting the construction processes, such as site layout, plant locations, rate of machinery operation, quantities of resources, etc., can be considered in order to evaluate the feasibility of the proposed construction methods and sequences, and to explore possible solutions and improvements to the methodology prior to actual work beginning.

However, the VP technology is unfamiliar to contractors. Contractors expected but doubted the VP application on their projects in the beginning. General contractors and their planners often have little idea about how construction VP can help them. Some regard VP technology as only animation tools that better represent their planning ideas. Although the new technology is useful to construction planning and project management, the misunderstanding of planners can be a major impediment for the adoption of the VP technology in the industry. In order to demonstrate the usefulness of the technology, researchers of the Construction Virtual Prototyping Lab at The Hong Kong Polytechnic University have worked very closely with contractors of several real life projects in Hong Kong. In fact, for each project, a researcher has been seconded to the site office to assist the planning and project monitoring process.

Due to the fact that neither the design team nor the construction team has the capacity to apply the virtual prototyping technology, researchers of the Construction Virtual Prototyping Lab act as the process modeler to connect the design and construction teams. The process modeler accepts the BIM model from the designer, and