Skill-driven Optimization of the Housing Industry

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Abstract

Despite its historical maturity, the housing industry suffers from the typical problems of immature production: low productivity caused by complex fabrication processes requiring high skill. This problem, caused by the low repetitiveness of construction projects, can be overcome by adopting adequate process modeling techniques. These techniques require changing the focus of the building models from objects to processes and relations, thus increasing the construction efficiency. To substantiate this point first a broader vision of the future of the housing industry is presented, highlighting the areas where research is needed and likely to emerge either from non-construction disciplines or from the construction research community. Second, the concepts of construction algebra and taxonomy of construction methods are introduced. The suggested path, that envisions extensive use of virtual reality and force boosters, also has the potential of attracting many young people to the profession by creating an information-rich and physically friendly work environment.

Keywords: Construction methods, project models, construction algebra.

Introduction

According to the theory of operations management, the production process is dependent upon the maturity of the produced product. As a product matures, its production process becomes less complex and fabrication becomes more efficient (Hayes and Wheelwright 1979, Wacker 1996). Standardization, modularization, and various process and product modeling techniques have been used to increase the productivity of industrial operations. All these techniques work well for mature production processes, where there is no variation in material flow, technology, labor and production scale (Abernathy and Townsend 1995). Such production processes are optimized for maximizing profit. The production cost decreases with the time the product has been on the market. While the PC market offers perhaps the most recent example for this statement, the first example was set by Ford, who introduced mass production for its Model T in 1913 and quickly improved the speed of chassis assembly from 728 minutes to 93 minutes (Ford 2001), at the same time doubling wages and reducing the cost of the cars from $850 in 1908 to $99 in 1914 (Gross 1996).

From one point of view, the construction industry resembles the car manufacturing industry of 1913: fragmented, with specialty teams moving from one product to another. Unfortunately, compared to the manufacturing industry, construction has made only modest gains in

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productivity improvement and reduction of time to market. . It is arguable that the reason the construction industry did not follow the example of automobile manufacturing is that homebuyers want choice of size, style, location, amenities, and color, and are unlikely to embrace the "you can have it in any color as long as it's black" concept of Model T. Diversity and customization seem to be the main requirement for residential homes. This may also be the reason manufactured homes have not achieved their anticipated popularity.

High–volume production allows the manufacturers to fine-tune the operations and increase efficiency by analyzing each aspect of the real production. Product and process modeling techniques allow doing the same using virtual reality (Rooks 1998). However, the capabilities of current modeling programs are limited to the scenarios and products imagined by the designers and do not benefit from the participation of all the collective intelligence of the people on the assembly lines. Even with the participation of many people in the process, the chances of achieving an optimal solution are only fair (Walsh et al. 2002).

Current product/process optimization methods do not respond well to the needs of low-volume (or immature) products, such as buildings. While great progress has been achieved in the area of "design for X" (where X can be manufacture, assembly, disassembly, recyclability, maintainability, etc.) (Kuo et al. 2001), the current design methods rely heavily on the experience of the designer in optimizing the design for achieving "X". A suitable optimization process should provide automatic methods for changing both the product and the process to achieve optimization goals such as production time, cost or required labor skill, and should be based on mathematically sound principles. Simple adaptation of principles of design for X is impractical for construction.

A Vision for the Housing Industry

Table 1 presents the long-term vision of the author for the future of residential construction. The scenario described in Table 1 would provide substantial productivity improvements and mimic assembly-line processes even for unique building projects. The table presents each construction phase, the envisioned status it can achieve, the current technological state of the art, and the parties interested working toward the envisioned status.

The analysis of the current technological state of the art, as revealed in Table 1, shows that, from a research point of view, the critical problem is the use of a "macro" representation of the activities. Even in the most advanced representations to date (Fischer and Aalami 1996, Akinci et al. 2002, Guo 2002), activities (resources, actors, and constraints) cannot be broken down into operations, access-denies or other types of hindrances. Today the hindrances are considered only at the whole-activity or macro level and do not account for the skill level of the workers, thus the existing construction project models do not contain all the information required for optimizing the construction delivery process. A model that would allow the optimization of the construction delivery process will have to be able to: (1) represent and (2) reason about each task of each activity and the skills required to perform those tasks.

Representation of construction tasks. A method to break down unequivocally any construction activity into tasks, sub-tasks and movements has been developed in combination with modeling and measuring the skills required by each activity (Oztemir 2003). This method allows selecting the appropriate worker for a particular task. However, while the method does allow a complete representation of all the tasks, a taxonomy of construction methods is yet to be developed for this level of representation. Such a taxonomy will allow formalizing the search for an appropriate construction method in the presence of given labor skills. The taxonomy will also allow the evaluation of new construction methods and even discovering new methods that may be appropriate for the available skill pool and new equipment such as the force boosters described in Table 1.

Reasoning about construction tasks. Independent progress has been reported in two areas pertinent to reasoning about construction tasks: (a) definition of a construction work space ontology for activities (Akinci et al. 2002) and (b) constraint-based modeling of the construction objects (Nassar et al. 2003). A third, missing component, called here "construction algebra" is needed to allow reasoning about construction tasks. Such reasoning will allow automation of operations sequencing and will form the base for optimization of construction processes. The construction algebra contains a minimal set of relations that are enough to describe all the relationships between objects and tasks, as well as the rules to operate with those rules. One known complex problem that will be brought up by the construction algebra is automatic path planning.

Optimization of construction processes. Once the detailed tasks can be generated in concordance with the available skills and construction methods and automatically aggregated into activities, the whole construction process can be optimized for time, cost or safety. Due to the complexity of the problem this optimization is not a trivial task. Multi-project optimization and resource allocation will probably be a computationally challenging, but not impossible problem.

Conclusion

In addition to the potential of reducing the cost and time of production and increasing the safety of construction operations, the proposed approach will offer a way of detecting new construction methods, appropriate to the particular skills the available work force may have. With the addition of virtual reality and force boosters construction may become again a profession of choice for most of the people entering the workforce.

Table 1. Home-building scenario — a long-term vision for the housing industry

PHASE	***CURRENT STATUS***	***INTERSTED PARTIES***
1. Floor-plan selection and design		
Building material superstores will have "virtual home" rooms where customers can immerge in virtual homes they select from a catalog. Changes can be made to these projects by moving building elements (stairs, walls, doors, windows,) fixtures and appliances, and selecting colors/finishes. The customer may choose to use the services of an architect during the selection.	Superstores limit 3D models to kitchens, displayed on 17" monitors. Whole house models, including construction objects and lists of materials exist (IAI 2003), but are not linked to the manufacturing process. Immerging virtual reality rooms are commercially available (Fakespace 2003) but for construction they exist only in academic environments (Penn State 2003, Virginia Tech 2003).	Construction Project Modeling community (academia + software developers)
Walking through the virtual building will be a real walk in an empty room, with virtual reality goggles and gloves.	Force-feedback gloves (Immersion Corporation 2003) and virtual reality glasses (iO Display Systems 2002) are readily available	Computer science, Gaming Industry,
Force boosters (see phase 5 below) can be used to restrict the movement through virtual walls and mimic stair climbing.	Limited to haptic gloves. Extra skeletal force boosters reportedly under development for military purposes.	Construction + Robotics + Gaming, combat research.
2. Selection of Building System		
After making the decisions on the details of the home, the customer will be asked to choose the way he/she proffers to build the building: with own hands, subcontract most of the work, or hire a general contractor.	Project models are contract-independent. Building technology is not represented with the project model. VR models have been used to help human experts in selecting the appropriate building methods since the 1980-s (Heng 2003).	CIC, Construction Project Modeling community. **See text**.
Depending on the choice of the customer and local conditions and regulations,	Code and regulation checking is actively researched (Han 1998). It is the opinion of the author that a viable solution will be found only when the codes and regulations will be performance-based (Wiezel 1996).	CIB-W60, Building performance research groups, NIST.

the system selects the OPTIMAL building technology.	**Does not exist. Needs research.** Current representations of building technologies use a “macro” representation of the activities. Activities (resources, actors, constraints) are the lowest level of the representation (Fischer and Aalami 1996). Activities cannot be broken-down into operations. Access-denies or other types of hindrances are not considered. The existing construction project models do not contain the information required for optimizing the construction delivery process. Representation of connection constrains has been implemented for maintaining detail consistency (Nassar et al. 2003). No consideration to the skills required for various degrees of assemblability was given.	Computer Integrated in Construction (CIC) research groups, computer science. **See text.**
3. Preparation of project documents		
The system generates a list of materials, a building sequence,	Theoretically solved. Implementations lack enough detail in building modeling for complete fabrication. Sequencing solved only at activity level (Akinci et al. 2002) (not at operation level)	CAD research, IAI
prepares the contracting documents and	Dependent on technology, list of materials and activities. Document preparation itself is trivial.	
transfers the plans to the local authorities for approval.	Implemented.	
4. Off-site fabrication		
When the customer places the order for the building, the chosen model is automatically sent to robotized pre-production. During this phase all the components are pre-cut, drilled, tagged (bar-code or RF) and, to some extent, pre-assembled,	Not implemented commercially. Dependent on representation of building technologies. Robotization problems solved for specific materials (Navon 1998). Bar-coding solved (ADCIC 2003)	**See text.**
then packed and loaded in reverse order (last first) on a trailer. A wearable computer, containing a CD with the 3D project model and video assembly instructions, is added to the package. The actual fabrication, packaging, and shipping is coordinated with the building schedule.	Trivial once the previous phases are solved.	

(Table continues on next page)

5. On-site assembly		
A spatial positioning system,	Exists. XYZ position of LED-s can be tracked on construction site at 25 Hz, with the accuracy of 1/200,000 of the distance to laser transmitters (Trimble 2003).	
immerging virtual-reality kits and	See phase 1. Need further development. First attempts reported in 1995 by Feiner & Webster (1995)	
"*force boosters*" can be rented and installed on site for the duration of the construction.	Not developed yet for construction. Expected to be a spin-off of military research.	CII
When connected to the wearable computer, the spatial positioning system, together with the virtual-reality kit, allow seeing the building in the planned phase (say frames assembled on floor, before rising), and the real status of the building. The two images will overlap when the construction phase is completed.	Achieved indoors for small systems (Webster 1996). Outdoors systems achievable using spatial positioning systems such as The Spectra LaserStation (Trimble 2003), eye movement control systems (SR Research Ltd. 2003), and I-glasses (iO Display Systems 2002)	
The system presents to the construction worker the activity to be performed,	Schedule linked 3 D models are readily available. Need for "reality check" in schedule updating.	
helps find the required components	Bar-coding available. Other systems are developed (ADCIC 2003)	
and can present a video describing the operation to be performed (such a fastening).	Exists.	
If necessary, the construction worker may wear a "force booster." Force boosters are wearable devices with actuators, capable of handling heavier loads and reaching farther than humans.	Do not exist. Need research. Expected problems: control, balance, weight and size, safety. Research can be started only after human skills are understood.	
Automated Inspection using GPS and Pattern Recognition. Generation of Accurate 3D As-Builts.	Does not exist. Needs research. Independent from the rest of development. Not critical to implementation of the whole system.	
6. After completion		
Delivery of the computer with the building controls, the functions of the building, and the **maintenance** schedule of the building. The model will be updated to reflect the accurate as-built.	Do not exist. Need research. Independent from the rest of development. Not critical to implementation of the whole system.	

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