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Investigation of the supply chain of prefabricated wooden doors

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Abstract

Research Hypotheses: H1: fabricators are in a better environment to perform certain tasks and deliver better products that can be quickly installed on site. H2: off-site prefabricated doors have short lead times for fabrication and on-site installation and present fewer problems during installation when compared to traditional doors.

Purpose: to investigate how information and materials flow in a supply chain.

Research Design: a preliminary study followed by two in-depth case studies.

Findings: Wooden doors presented problems related to the installation and final product quality regardless of the type of project. Some advantages of prefabricated elements were lost due lack of trust between contractors and suppliers, lack of consideration of preconditions necessary for successful site installation, and lack of standardization and tolerance management resulted in suboptimal solutions during the installation phase.

Limitations: findings are based on a small number of case studies in companies in the city of Fortaleza (Brazil).

Implications: the findings support the need for the development of trust and more open communication among participants of a supply chain, and integrated solutions. They also point out some of the costs incurred by companies when these are not in place.

Value for practitioners: 1. Lack of open communication and low levels of trust amongst the supply chain members result in significant waste (e.g. rework, wasted time, unnecessary handling, unnecessary use of resources) and diminished value to the client. 2. Pay special attention to the interfaces between prefabricated elements and other parts of the project; review traditional means and methods to fully take advantage of prefabrication.

Keywords: Supply chain, pre-fabrication, wooden doors.

Paper type: Case Study.

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Introduction

Supply chain management in construction (SCMC) is still considered an 'emerging area of practice', is still in its infancy and has been slowly adopted by construction companies (Akintoye et al. 2000, O'Brien et al. 2009). SCMC seeks to adapt supply chain management practices originated in the manufacturing environment to the distribution of small quantities of resources to multiple and often geographically dispersed projects (O'Brien et al. 2009).

Construction supply chains (CSCs) differ in many ways from their manufacturing counterparts. The structure of CSCs is fragmented, information flows across companies are slow and little information is shared between the companies, adversarial practices are rather frequent, and there is a need for standardization and tolerance management across the CSCs (Azambuja and O'Brien 2009).

Azambuja and O'Brien (2009) emphasize the need for better SCMC given that owners cannot fully achieve project goals without relying on efficient contractors and suppliers working on their projects. Owners are viewed as champions that can lead change in construction as they can reap many benefits from SCMC (Saad et al. 2002). Contractors tend to be more inclined to have agreements with owners, who provide them with business; however, contractors tend to treat their own suppliers more like employees and subcontractors that they can hire and fire as they please (Akintoye et al. 2000). This behavior may be due to the competitive environment in the industry and the lack of trust among contractors and suppliers. Frequently, practitioners see the SCMC in construction as a means to improve the operational performance of their organizations instead of a way to fundamentally rethink the way they do business and interact with other actors in the industry (Green et al. 2005).

In order to investigate how information and materials flow in a supply chain and the relationships among its actors, research was carried out to investigate the supply chain of wooden doors. This supply chain was chosen due to the omnipresence of wooden doors in the place in which the research was carried out, i.e., Northeast Brazil, and because the product and its supply chain were deemed troublesome by previous research projects developed by the lab (GERCON) the authors were affiliated with.

SCMC Research

SCMC Researchers have covered different engineering specialties and multiple operational aspects of the relationship between companies in the industry (Saad et al. 2002, Azambuja and Formoso 2003, Alves 2005, Kim and Bae 2009). Examples of studies related to supply chains of specific materials include: pipe supports (Arbulu and Tommelein 2002), elevators (Azambuja 2002), rebar (Polat and Ballard 2003), aluminium windows (2004), HVAC ductwork (Alves 2005), to name a few. Others have highlighted the theoretical aspects of SCMC (Vrijhoef and Koskela 2000, London and Kenley 2001, Azambuja and O'Brien 2009).

This study focused on the relationships between two tiers of the supply chain for wooden doors, namely, the construction site and its immediate supplier and the interactions between them. Therefore, the discussion that follows emphasizes on relationships between supply chain actors and common challenges identified by SCMC scholars in previous research projects.

Azambuja and Formoso (2003) studied the supply chain of elevators and conducted a critical analysis of the processes necessary to deliver this product. Amongst the main problems encountered figured the lack of communication between actors, the lack of standardization, interferences between the installation of elevators and other site processes, and rework. Their research called for greater integration between suppliers and site management, improvement of information exchange between the site management and suppliers, and better planning of the flows of workers and materials at the construction site to name just a few.

Alves (2005) studied decisions related to buffering and batching practices in the HVAC ductwork supply chain and found that changes in installation schedules and the lack of information exchange between site and suppliers caused inventories to accumulate at the site and at the suppliers' yard. Batching practices caused accumulation of inventories and large capacity buffers were maintained to deal with uncertain demand and variations in schedules. These practices result in more money spent on rework, when changes in design are made after parts are fabricated, and on keeping extra resources at hand to deal with variations (i.e., overhead related to maintaining facilities, workers, and equipment to respond to unpredictable site needs).

In order to make costs of supply chain decisions visible, Kim and Bae (2009) have used activity-based costing to identify and quantify the main drivers for supply chain costs. They suggest that an organization should understand their own cost drivers as well as those of their suppliers to define which cost drivers are wasteful and should be eliminated.

Vrijhoef and Koskela (2000) suggested that the management of CSC and their design should be based on four roles SCMC can assume. The first role focuses on the immediate interface between the construction site and the supply chain. The second focuses on the entire supply chain that provides resources to a construction site, but not on the site itself. The third role focuses on transferring activities from the construction site to the supply chain, e.g., pre-fabrication initiatives. Finally, the fourth role suggests that the entire supply chain and the construction site should be managed in an integrated fashion.

The cases presented in this paper focus on the third role, discussed by Vrijhoef and Koskela, which suggests that activities should be performed by suppliers, outside of the project site, as they are in a more stable and controlled environment than that found in the construction sites. However, for this role to work it is paramount that the supplier and the construction site management be mindful of issues related to prefabrication, standardization, and tolerance management as discussed in the next item.

Pre-fabrication, Standardization & Tolerance Management in SCMC

The literature on prefabrication emphasizes that the production of products and systems off-site in safer and more controlled environments yield better productivity rates for projects and ultimately results in better product quality, reduction in material waste and final costs (Gibb 1999). Prefabrication allows for reduction in the lead time to perform site activities, as parts can be assembled while other activities are performed on site. The product or system can be pre-assembled before all of its predecessor activities are finished on site, e.g., a precast concrete structure can be prefabricated while the site crews are working on the foundations, resulting in shorter lead times.

Potential cost savings can also be achieved due to shorter construction times, more efficient use of site equipment to support activities that can only be performed on site, and fewer construction workers on site, to name just a few. Quality and predictability in terms of meeting standards are also said to increase as assembly activities are performed in a more controlled environment ahead of time, allowing enough time for inspection and correction if needed (Gibb 1999). However, Pasquire et al. (2005) observed that much of the cost data to evaluate the different advantages suggested by Gibb (1999), and needed to perform an accurate evaluation of prefabricated elements, are not tracked by construction companies.

In addition to a careful analysis of the costs and benefits associated with prefabrication, other factors should be observed such as the adequacy of the project to use prefabricated components, the use of standard sizes for various components (prefabricated or not), the consideration of prefabricated elements early in the design phase, and an understanding of how prefabricated pieces and/or modules can be taken into account for installation, maintenance, and repair (Pasquire and Connolly 2003). And last but not least, the level of tolerance management to be achieved and proper specification regarding required tolerances and installation must be taken into account to assure that parts can be properly put together as originally envisioned.

Milberg and Tommelein (2003) highlight that tolerances are not measured and therefore not managed in construction projects. In fact, tolerances are dealt with on as-needed basis and contractors use tacit knowledge to devise one-time solutions. Milberg and Tommelein (2003) indicate some reasons why construction practitioners do not pay enough attention to tolerance management, i.e., lack of data regarding geometric variation of construction processes; lack of definition regarding who manages tolerances, leaving final decisions and rework to the skilled workforce installing products on site; difficulty in visualizing and describing geometric variations and their accumulation.

Milberg (2007) emphasizes that the lack of tolerance management results in field changes, lack of standardization, use of non-standard connections and fillers, and ultimately in failure to meet project specifications, rework, and poor quality. Therefore, for prefabrication initiatives to be successful the parties involved in the process should be mindful of their requirements for fabrication and installation, which should be properly shared and assured on the supplier plant and at the construction site.

Value Stream Mapping and SCMC

Value Stream Mapping (VSM) uses a series of predefined symbols to track the flow of materials and information throughout the value stream necessary to acquire resources and information all the way to delivering a product or service to the client. The value stream comprises both value adding and non-value adding tasks to deliver a product to the client, and the use of VSM helps in understanding how these activities are related to one another and the resources they use (Rother and Shook 2003).

In construction, VSM has also been used to study supply chains and production systems and how they should be reconfigured to improve their performance. Arbulu and Tommelein (2002) have used a variation of VSM to investigate the supply chain of pipe supports and how the designers and fabricators interact to deliver this product. Causes for the long lead time and the low share of processing time (~4%), when compared to the total lead time, were related to batch and queue practices as well as rework.

Alves et al. (2005) used VSM to study the make-to-order environment of a sheet metal ductwork fabrication shop. Alves et al. pointed to several requirements and adaptations that need to be made when using VSM to study construction-related materials and processes. Along the same lines, Yu et al. (2009) adapted the VSM to study the construction of houses and devise better ways to organize a production system to deliver this product. By using VSM and Lean practices to design a future state, Yu et al. reported a 27-day decrease in the lead time of the process (65.5 to 38.5 workdays) and an increase in value adding time (from 17% to 26%), which reveals the potential for improvements that can be achieved when the value stream is made visible.

The use of VSM promotes transparency, and allows researchers and practitioners to visualize the flows of materials and information exchanged by supply chain's actors. VSM also produces a blueprint to document the current state of processes and their performance, and provides a basis for future improvements by indicating where kaizen (i.e., incremental change) initiatives should be carried out (Rother and Shook 2003).

Research method

The supply chain investigated was chosen based on previous research projects carried out by the research group GERCON in Fortaleza/Brazil. Previous research projects developed by the authors highlighted that wooden windows and doors had been identified by construction firms of large low-income housing projects as products which caused many problems to their projects. The low quality of the material delivered resulted in rework, schedule delays, and products delivered with diminished value to the final user. While wooden doors are used in all types of buildings in Fortaleza, wooden windows are mostly used for low-income housing projects. Therefore, the authors focused this study on wooden doors and their supply chain, and more specifically on pre-fabricated doors, which have all of its components pre-assembled by the supplier.

The research was carried out in two phases in projects in the city of Fortaleza:

- **preliminary study** about wooden doors and windows used in low-income housing projects;
- **in-depth case studies** in a residential and in a commercial construction project and visits to a supplier's fabrication shop.

In both phases, VSMs were created to investigate the flow of information and materials between the suppliers and the construction site. However, the VSMs are not presented in this paper due to space limitations. A detailed discussion of the VSMs can be found in Melo (2010).

The preliminary study helped the researchers to gain a better understanding of the phenomena to be studied and to properly design the second phase of the research. Case studies were chosen as the research strategy for this project because they allow researchers to observe real life phenomena in their actual context (Yin 1994). However, case studies have limitations in terms of their generalization in that they are context specific and can be used for analytical and not statistical generalization.

The validity of the research was addressed by the use of different approaches to test the findings as suggested by Yin (1994). The construct validity was assessed through the use of the literature review and previous findings to compare and contrast the current research findings and how they relate to other studies and to build a chain of evidence.

The internal validity addresses causality and how different factors interwoven to produce a result. For construction management researchers this is a challenge as factors interact in real life scenarios in an uncontrolled and, at times, unpredictable way (Lucko and Rojas 2009). This research tried to address the internal validity approach through the use of multiple sources of evidence (i.e., interviews, video and photo records, document analysis, direct observation) to build causal relationships and allow for triangulation (cross-analysis of data from multiple sources). The use of direct observation allowed the collection of data which revealed what people actually did instead of what they said they did, whereas the interviews with open-ended questions provided specific details and clarified questions about the processes observed (Proverbs and Gameson 2008).

The external validity (representativeness) was established by the definition of the scope of the study, in the preliminary study, and the two case studies carried out in the second phase. Finally, the reliability of this research was addressed by the full documentation of steps and data collected by the researchers.

Based on the literature review and the previous research projects developed by the authors, two working hypotheses were formulated:

> *H1: Fabricators are in a better environment to perform certain tasks and deliver better products that can be quickly installed on site, as the product is delivered pre-assembled by the fabricator.*
>
> *H2: Off-site pre-fabricated doors have shorter lead times for fabrication and on-site installation and present fewer problems when compared to traditional wooden doors used in low-income housing projects.*

Study of the supply chain of prefabricated wooden doors

This section is organized in two main parts, which comprise the two phases of this research: preliminary study (PS1) and case studies (CS1 and CS2). It describes the data collected in each of the phases and the resulting conclusions.

Phase I- Preliminary Study (PS1)

The preliminary study was carried out in a low-income housing project comprising 1,057 houses (44m^2 each) and 750 apartment units (48m^2 each) as well as the infra-structure for the project (i.e., school, health care center, community center, urbanization, police station, and wastewater treatment station) with a total budget of R$32M (~ US$ 17.8M). This project (PS1) was funded by a Brazilian bank owned by the federal government. The study was carried out between the months of November and December 2008. The authors investigated the main problems indicated in previous studies regarding the quality of materials and their impact on the project.

The focus of this study comprised the wooden doors and windows, which had been considered problematic as pointed out by previous studies carried out by GERCON researchers in low-income housing projects. The project used batten doors (Figure 1a) with four ledges and windows (Figure 1b), which were fabricated out of the batten doors and cut in two pieces, had two ledges.

(a)  **(b)** 

Figure 1: (a) Batten door used in PS1; (b) Window used in PS1

The wooden windows and doors supplied to PS1 were provided by a company that used to acquire materials from other suppliers and resell them to construction companies in Fortaleza. The supplier would buy the wooden elements from other regions of Brazil and transport them to a yard in Fortaleza, from there the material used to be distributed to construction projects. The construction company had a list with contacts for nine different suppliers for this project. At the time of the study 3 different suppliers had been used. The products used to be inspected upon delivery and characteristics such as height, width, and plumb were checked for windows and doors.

The preliminary study confirmed the problems already indicated in previous studies carried out by the researchers at GERCON: the wood had cracks, the elements were neither aligned and levelled nor had uniform measurements, the wood still had water in it or was not adequate to be sold (some pieces were deemed too green), the wood had not received adequate treatment (e.g., pest and humidity control), some doors and windows had more than one type of wood in a same element. However, the products would end up at the construction site and ultimately installed at the houses and apartments because of the low level of detail and rigor of the specifications as outlined by the governmental institution in charge of managing the resources for PS1. In addition to that, an imbalance between supply and demand, i.e., many low-income projects being built at the same time in the city due to available government funding for these projects, had put construction companies in disadvantage when searching for these materials.

This study verified anecdotal evidence provided by inspectors and project managers in low-income housing projects. Poorly defined product specifications of the materials in low-income housing projects allied with the low quality of the product supplied resulted in rework, lower quality of the housing units, and excessive handling at PS1. The excessive handling and rework walked hand in hand as workers had to adjust doors and windows to fit the openings, i.e., multiple measurements, cuts and trims had to be performed before the installation could proceed. Also, the wood had not been adequately treated to lose its natural humidity before it was sold, and during the time it was stored at the site and after installation, it kept loosing water and having its physical and mechanical properties altered. This caused other problems as doors and windows already installed would shrink and leave cracks and small openings all over the housing units.

In addition to that, a lack of regulations and strict requirements defined by the government and construction associations encouraged suppliers to provide low quality products without the fear of getting punished or running out of work as they consistently delivered bad products. That reveals the importance of industry-wide initiatives to promote the quality of products and fair trade among companies in CSCs.

Phase II - Case Study 1

The case study 1 (CS1) was carried out in a commercial project with a total constructed area of 26.771 m^2, which included 170 commercial offices. The study started after the first author contacted the project engineer and discussed the goals of this research project and obtained his permission to carry out the study at that project. The company was NBR ISO 9001:2000 certified[4].

The project engineer also provided the contact of the supplier of the prefabricated wooden doors used in the project. The supplier was contacted and allowed the first author to observe the entire fabrication process at the supplier's plant. The plant was located about 27 Km from the project site and supplied wood parts for construction projects including doors, windows, and gates. The 13-year old company had never supplied prefabricated doors, and CS1 was the first project to buy this product from it.

The supplier was contracted to provide the project with 160 prefabricated doors, and this was the batch size considered in this study during the months of August to December of 2009. In addition to delivering prefabricated doors at the construction site, the supplier was also contracted to install the doors at the project.

The wood used to produce the prefab doors was obtained from the Northern region of Brazil (Amazon region) about 1,500 Km from Fortaleza. Therefore, due to accessibility issues the harvesting of the wood and its transportation to Fortaleza were not investigated. The wood travelled by truck for about six days from the source to the supplier's plant and, once it was at the plant, the wood was stored in dryers for about 18 days until it reached an acceptable humidity level before fabrication started. The 160 doors were fabricated in a single dimension 60 cm x 210 cm x 3.5 cm, and it was the first time the supplier produced prefabricated doors. Once the doors were fabricated, workers would open spaces for the door hinges and latches. The next steps were sanding and preparing the doors to be painted. After that, the doors were framed, received the doors hinges and latches, and were packaged for transportation to the construction site. The door knob and the trim were installed at the construction site.

Analysis of the Fabrication Process

The total lead time, from the wood arrival at the supplier's plant to delivery, was about 105 days. Out of 105 days, about 61 days were used to process the wood and fabricate the batch of 160 doors. The total lead time includes a 23-day delay during which the supplier waited for the availability of a worker, designated by the general contractor, to observe the operations related to gluing the faces to the core of the door.

The project manager for CS1 alleged that it was the first time they had ordered materials from this supplier and that in previous projects he had had many problems

[4] NBR ISO 9001:2000 is the Brazilian version, or adaptation, of the ISO 9001:2000. They follow the same standards of the ISO documents and are published by the Brazilian Association of Technical Standards (Associação Brasileira de Normas Técnicas - ABNT)

associated with the low quality of the core of the doors (which cannot be seen and inspected after the doors are ready). He mentioned that clients would complain about the performance of the doors, problems related to the core, during the use phase. Therefore, he wanted this worker to assure the supplier was using the contractually specified material to fill the core of the doors. The worker visually inspected the process at the supplier's plant for two days, and signed on each door after the operation was completed, to assure the doors had the specified materials in their core.

The project manager lack of trust in the supplier resulted in an additional time to deliver the product, generation of work in process at the supplier's plant as the doors could not proceed through the fabrication process, and affected other orders being fabricated during the same period. By the time the doors reached the painting sector, the workers were busy with other orders. The order for CS1 was fractioned in five parts and delivered in separate days. Another delay was added to the time to process the doors when the general contractor failed to supply the door hinges, knobs, and latches to the supplier. The doors sat for 21 days waiting for these components.

Analysis of the Installation Process

The lead time to complete the installation of 160 doors was 32 days. One day after the first batch of 40 doors arrived at the site, the supplier's workers in charge of the installation met with the quality manager, the safety manager, and the project's foreman and equally distributed the batch in four floors. The installation process started the following day on the first floor, which was a model (prototype) for the services, and then proceed from the upper-most floor down.

(a)  **(b)**  **(c)** 

Figure 2: (a) Door frame permanently fixed; (b) Door is removed and frame remains fixed; (c) After the voids are filled with mortar the door is installed again.

During the installation phase, the supplier's workers positioned the door in the opening, made adjustments to align and level the door and permanently fixed the door to the walls (Figure 2a). After this task was completed, the general contractor's workers would remove the door from the fixed frame (!!!) and fill in the voids around the door with mortar (Figures 2b and 2c). This operation was carried out to avoid damages or spilling mortar on the door. The prefabricated door was disassembled and then reassembled again increasing the installation lead time.

To make matters worse, the water present in the mortar infiltrated inside the door frame and increased its volume. This caused a reduction in the door opening (there was not enough space to close the doors), damaged the door (the ones that were closed due to the action of winds inside of the building got damaged), and added one more delay to the conclusion of the installation. Finally, the trim could not be added to finish the door frame because workers had to wait for the mortar to dry out so that the trim could be precisely installed. The problems caused by the mortar (the need to disassemble the door, the expansion of the frame, and the delay) could have been prevented should the general contractor have used expansive foam to fill in the voids around the door frame.

Phase II – Case Study 2

The case study 2 (CS2) was carried out during the months of November and December of 2009 in a 22-store residential project. By the time the researcher started the study, 70% of the prefabricated doors had already been installed. The supplier of prefabricated doors was located in a different state about 3,300 Km from the project site; therefore, the fabrication process was not part of case study 2. A total of 410 prefabricated doors were ordered for this project; the doors were delivered to CS2 in two batches. The supplier was in charge of the fabrication and transportation of the product to the project site, and the general contractor was in charge of the installation.

The 29-year old company that supplied the doors for CS2 was NBR ISO 9001:2000 certified and was part of a national program to improve the performance of the supply chain of internal wooden doors (PSQ-PIM). The supplier complied with European and Brazilian standards for the products it provided.

Analysis of the Installation Process

(a) **(b)**

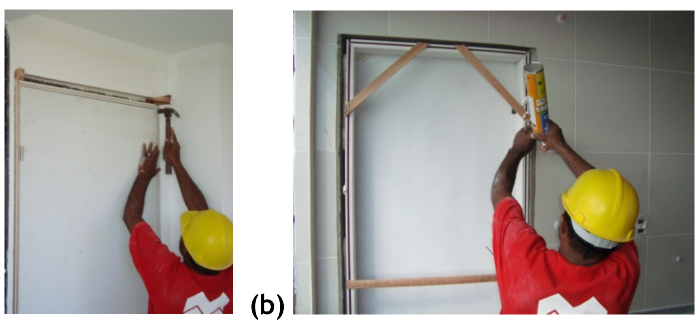

Figure 3: (a) Door is positioned and adjustments are made; (b) Door frame is permanently fixed.

The installation of prefab doors in CS2 was carried out in three phases: the frame with the door was positioned in the opening and adjustments were made to align and level out the door (Figure 3a); next, the door was permanently fixed to the walls with expansive foam (Figure 3b); finally, the trim was added. A journeyman and a support worker installed the doors in the rooms and bathrooms of CS2.

The study carried out at CS2 revealed the differences in tolerances and precision of the measures encountered in brick walls and drywalls which use gypsum boards. The drywalls had more precise dimensions, as the boards are part of a prefab system which is assembled on site, and were put next to each other without the addition of filling between the parts. The bricks supplied by the local industry do not have very strict dimensional standards and the amount of mortar placed between bricks is not controlled. Therefore, brick walls presented, more often than drywalls, dimensions that differed from the ones indicated in the plans and specifications for CS2.

These differences in actual dimensions for the walls and openings resulted in extra activities to complete the installation of doors. Workers had to trim the frame when the opening was too small, and adjust the frame when the opening was too large. This problem could have been avoided if the general contractor had inspected the walls, when they were completed and received, and detected the problem early on so that it would have not propagated throughout the building. The needs of the prefabricated doors were not adequately translated, and made explicit, to those erecting the walls.

During the procurement phase, a representative of the supplier visited the construction site and measured the openings executed in the first floor of CS2. The representative tried to be proactive and gather as-built data, which was supposed to represent the capability of the construction processes in place. The representative assumed that the general contractor would assure that the other floors would follow the same standards. The standard measurements could have been assured with the use of a metallic frame with the precise dimensions for the openings. The metallic frame would be positioned at the designated area for the opening and the workers would build the walls around it, removing the frame once the wall was done.

Conclusions

This study was carried out based on two working hypotheses, as indicated below. What follows is a discussion on whether or not the working hypotheses were verified.

> *H1: Fabricators are in a better environment to perform certain tasks and deliver better products that can be quickly installed on site, as the product is delivered pre-assembled by the fabricator.*

Analysis of research data revealed that even if suppliers are in a more controlled environment and are able to deliver better products, than those assembled on site, that does not assure that prefabricated products are quickly installed and result in better quality for the final client. For prefabrication and preassembly to work as planned it is necessary that construction sites observe the requirements for their successful installation and operation, otherwise the benefits are lost or can only be 'potentially' achieved. The studies carried out in CS1 and CS2 revealed myriad problems that resulted because the use of prefab doors was not properly conceived and integrated with their surrounding materials and systems.

> *H2: Off-site pre-fabricated doors have shorter lead times for fabrication and on-site installation and present fewer problems during installation than traditional doors.*

Evidence from the case studies suggest that the lead times for site delivery and installation of prefab doors will not be reduced unless suppliers and contractors trust each other and make sure that the preconditions to use prefabricated elements are met. Problems during the installation phase will not go away unless companies using prefab elements understand that these require a higher level of precision during the execution of predecessor tasks.

The study presented in this paper corroborates previous research findings which suggest that prefabrication is a strategy that has to be carefully implemented for its benefits to be fully achieved. Some preconditions for its implementation are: careful analysis of the requirements to be met by previous tasks, reliable exchange of information and materials between supplier and contractors, and integration of the prefabricated element with the surrounding systems, to name a few.

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References

Akintoye, A., McIntosh, G., Fitzgerald, E. (2000). "A survey of supply chain collaboration and management in the UK construction industry", *European Journal of Purchasing & Supply Management*, 6, 159-168

Alves, T.C.L., Tommelein, I.D., Ballard, G. (2005) "Value Stream Mapping for Make-to-Order Products in a Job Shop Environment." *Proc. Construction Research Conf.: Broadening Perspectives*, ASCE, 5-7 April, San Diego, CA, USA.

Alves, T.C.L. (2005). *Buffering Practices in HVAC Ductwork Supply Chains.* Ph.D. Dissertation – Civil and Environmental Engrg., University of California, Berkeley.

Arbulu, J.R. and Tomelein, I.D. (2002). "Value. stream analysis of construction supply chains: case. study on pipe supports used in power plants." *Proceedings IGLC-10*, Gramado, Brasil.

Azambuja, M.B.M. and Formoso, C.T. (2003) "Guidelines for the Improvement of Design, Procurement and Installation of Elevators Using Supply Chain Management Concepts" *Proceedings IGLC-11*, Blacksburg, Virginia, USA. 14pp

Azambuja, M. and O'Brien, W.J. (2009). "Construction Supply Chain Modelling: Issues and Perspectives." *Construction Supply Chain Management Handbook*, O'Brien, W.J., Formoso, C.T., Vrijhoef, R, and London, K.A. (editors). 2-1 – 2-31

Fernie, S.and Thorpe, A. (2007) "Exploring change in construction: supply chain management." Engineering, Construction and Architectural Mgmt, 14(4), 319-333

Fontanini, P.S. (2004) *Mentalidade enxuta no fluxo de suprimentos da construção civil: aplicação de macro-mapeamento na cadeia de fornecedores de esquadrias de alumínio*. Dissertação. Faculdade de Engenharia Civil, Arquitetura e Urbanismo, Universidade Estadual de Campinas, 275pp.

Gibb, A.G.F. (1999). *Off-Site Fabrication: Prefabrication, Pre-assembly and Modularization*. John Wiley & Sons, Inc.: New York, NY. 262pp.

Green, S. D., Fernie, S., and Weller, S. (2005) "Making sense of supply chain management: a comparative study of aerospace and construction." *Construction Management and Economics*, 2(6), p. 579-593

Kim, Y. and Bae, J. (2009) "Supply chain costs analysis using activity-based costing: case study in rebar supply." *Proceedings IGLC-17*, Taipei, Taiwan, 113-126

London,K. and Kenley, R.A. (2001). "An industrial organization economic supply chain approach for the construction industry: a review." *Construction Management and Economics*, 19, 777–788

Lucko, G. and Rojas, E.M. (2009) "Reseach Validation in the construction domain." Proceedings of the Construction Research Congress, Seattle: ASCE, 1449-1458

Melo, R.S.S. (2010). *Estudo da cadeia de suprimento de portas prontas de Madeira*. Master thesis, Civil Engrg: Structures and Construction, Federal University of Ceará (in Portuguese: Study of the Supply Chain of Prefabricated Wooden Doors)

Milberg, C. and Tommelein, I.D. (2003). "Application of Tolerance Analysis and Allocation in Work Structuring: Partition Wall Case." *Proceedings IGLC-11*, Blacksburg, Virginia, USA, 13pp

Milberg, C. (2007). "Tolerance Considerations in Work Structuring." *Proceedings IGLC-15*, East Lansing, Michigan, USA, 233-243

O'Brien, W.J., Formoso, C.T., Vrijhoef, R, and London, K.A. (editors) (2009) *Construction Supply Chain Management Handbook*. 1st Ed. CRC Press, 2008.

Pasquire, C., Gibb, A.G.F., and Blismas, N., (2005). "What Should You Really Measure if You Want to Compare Prefabrication with Traditional Construction?"*Proceedings IGLC-13*, Sydney, Australia, 481-491

Pasquire, C. L. and Connoly, G. E. (2003) "Design for manufacture and assembly." *Proceedings IGLC-11*, Blacksburg, Virginia, USA, 11pp

Polat, G. and Ballard, G. (2003) "Construction Supply Chains: Turkish Supply-Chain Configurations for Cut and Bent Rebar." *Proceedings IGLC-11*, Blacksburg, Virginia

Proverbs, D. and Gameson, R. (2008) "Case study research." Knight, A., Ruddock, L. (eds) *Advanced Research Methods in the Built Environment*. Oxford: Wiley-Blackwell

Rother, M. and Shook, J. (2003). *Learning to see*. The Lean Enterprise Institute, Cambridge, MA. Version 1.3., June 2003

Saad, M., Jones, M., and James, P. (2002). "A review of the progress towards the adoption of supply chain management (SCM) relationships in construction." *European Journal of Purchasing & Supply Management*, 8, 173–183

Vrijhoef, R. and Koskela, L. (2000). "The Four roles of supply chain management in construction." *European J. of Purchasing & Supply Mgmt.*, 6, 169-178

Yin, R. K. (1994) .*Case Study Research: Design and Methods*. 2nd Ed. Applied Social Research Methods Series. 5. Sage Publications: Thousand Oaks. 171pp

Yu, H., Tweed, T., Al-Hussein, M., and Nasseri, R. (2009). "Development of Lean Model for House Construction Using Value Stream Mapping." *Journal of Construction Engineering and Management,* 135(8), 782-790