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Interaction in the construction process—System effects for a joinery-products supplier

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Abstract

Research Questions: How is the supply-chain relation between a joinery-products supplier and the construction process arranged, and what deficiencies can be seen from a supply-chain and information-management perspective? If there are deficiencies in the supply chain, what are their causes, and what possible improvements can be made?

Purpose: To contribute to the understanding of the interactions present in the construction system and their effects on the make-to-order/engineer-to-order joinery-products supplier.

Findings: Supply-chain management and information management are two areas that work poorly and cause numerous knowledge-disconnection effects. The main reasons for undesirable consequences in the process are: (1) information needs are not met; (2) competence is lacking; (3) there is a lack of activity in the gathering and mediation of information; (4) inventory buffers break the flow of value-creating activities.

Limitations: The study is limited to contributing knowledge from a single case in the north of Sweden about the effects of the present interaction level in the construction system. The main discussion is limited to the interaction between a joinery-products supplier and the construction process.

Implications: The academic implication is to contribute to the theoretical generalization for the area of construction-related joinery-products supply. The implication for industry is to gain information that will help to improve interaction and develop better production strategies.

Value for practitioners: The value for practitioners is the indication that more interaction between suppliers, originators and adjacent processes is needed. Standardized routines for interaction and more active information exchange are needed in order to decrease inventory buffers and increase value-creating activities.

Keywords: Construction, Joinery products, Secondary wood-products manufacturing, Information management, Supply-chain management

Paper type: Case Study

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Introduction

Interaction in construction involves a process in which individuals or organizations through their actions affect each other in terms of managing communication and collaboration. The traditional construction process is mainly project-based and characterized by one-of-a-kind set-ups (Vrijhoef and Koskela 2005) in which the unique characteristics come from the production set-up, site and temporary organizations (Höök and Stehn 2008). The traditional construction process is characterized by being of a fragmented nature with loosely coupled actors who only take part in some of the phases of the process (Anheim 2001). Since construction projects are often complex and involve many different actors, the communication is both comprehensive and complex (Cigén 2003). According to Cigén (2003), the main reason for interaction in the traditional construction process is the coordination of efforts and the implementation of time planning. The communication focuses on detailed questions of a problem-solving character and with a short time focus. Another significant reason for communication is to transfer information and documentation, often to inform other actors about changes, mistakes and delays. Due to the fragmented nature of the construction process, the information flow is also fragmented. Thus the communication process suffers from a meagre information flow between various actors in the process.

Construction companies work in a culture of hiding experiences and information instead of sharing them. This culture works against effective development (Polesie *et al.* 2009). For instance, Santos *et al.* (2002) claim that companies often fail to implement and maintain standardized practices due to a lack of teamwork. On the other hand, Holst (2004) states that the sharing, creation and use of knowledge across traditional boundaries is becoming more and more common. This trend, with boundary-crossing groups, is a result of the organizations being challenged to be functional in an increasingly networked and globalized world.

Supplying the construction industry with highly value-added one-of-a-kind wood products is the major business strategy of the make-to-order/engineer-to-order (MTO/ETO) joinery-products supplier studied in this case. Here make–to-order refers to new customizable products being made to order to suit specific needs. Engineer-to-order refers to not-already-defined products being engineered to fit specific needs. Further on in this text, the MTO/ETO joinery-products supplier is referred to as a joinery-products supplier. The joinery-products supplier offers products like entrances, glass partitions, doors, windows, furniture, cabinet fittings, special fittings and stairs. Supplying construction involves interactions and information flows between various actors in the construction process that define the fully customized product from the supplier. In this interaction and information interchange, mismatches occur that affect the performance of the construction system and the supplier.

In construction-related research as well as in forest-products research, MTO/ETO joinery-products manufacturing and its peculiarities in supplying construction seem limited. In the case of this study a supply process of a stair railing is studied. There are earlier examples of studies on the supply-chain management in construction (SCMC) area focusing on pre-engineered metal building manufacturing, electrical switchgear, elevators and aluminium windows (Akel *et al.* 2001; Elfving *et al.* 2002; Azambuja and Formoso 2003; Fontanini and Picchi 2004; Arbulu and Tommelein 2002). In 2010 Melo and Alves presented a work on supply chains and prefabricated wooden doors, concluding that information deficiencies and a lack of integration in the system can take away the benefits of prefabrication of joinery products. Furthermore the authors conclude that a lack of trust and preconditions leads to longer lead times.

With this background, the following research questions are addressed in this study:

- How is the supply-chain relation between a joinery-products supplier and the construction process arranged, and what deficiencies can be seen from a supply-chain and information-management perspective?
- If there are deficiencies in the supply chain, what are their causes, and what possible improvements can be made?

The study was conducted from a systems perspective, meaning that the focus is on the entire process from design to assembled product. However the scope is mainly from the joinery-products supplier's view. The study emphasizes the interaction between a joinery-products supplier and the construction process. The purpose is to contribute to the understanding of the relations and contacts between the construction process and the joinery-products supplier. The study was conducted in an ongoing on-site construction project in 2009, and the information derives from this specific studied case. The study is limited to contributing knowledge from a single case about the effects of the present interaction level in the construction system. The main discussion will be of consequence for the interaction between joinery-products suppliers and the construction process.

Theory

Traditionally manufacturing can be described as a value-adding process (Bröte 2002) in which raw materials are transformed into finished products that the company sells (Jackson 2000). Koskela (1992) compares the conceptual basis of conventional construction and the new lean production philosophy. The conventional production philosophy of conversion of input to output is restricted to looking at production as a set of operations that are controlled operation by operation and improved periodically. Lean also takes into consideration the process flow with respect to waste and customer value. Thus lean adds the dimension of the interaction between the operations in the production. Koskela (1992) finds that the construction industry is truly conversion-oriented, as previously observed in manufacturing. Because of that, construction is unable to control the amount of non value-adding activities (waste) and even less able to manage continuous improvements. Value-stream mapping (VSM), presented by Rother and Shook (2003), is a method used in analyses of the value adding in supply chains in construction. For example, Arbulu and Tommelein (2002) show through VSM that the waiting time (inventory buffers) is a significant contributor to the lead time in the analysed supply chain. Vrijhoef *et al.* (2001) contend that a major part of the inefficiency and problems in construction is related to supply-chain problems, as shown in Figure 1.

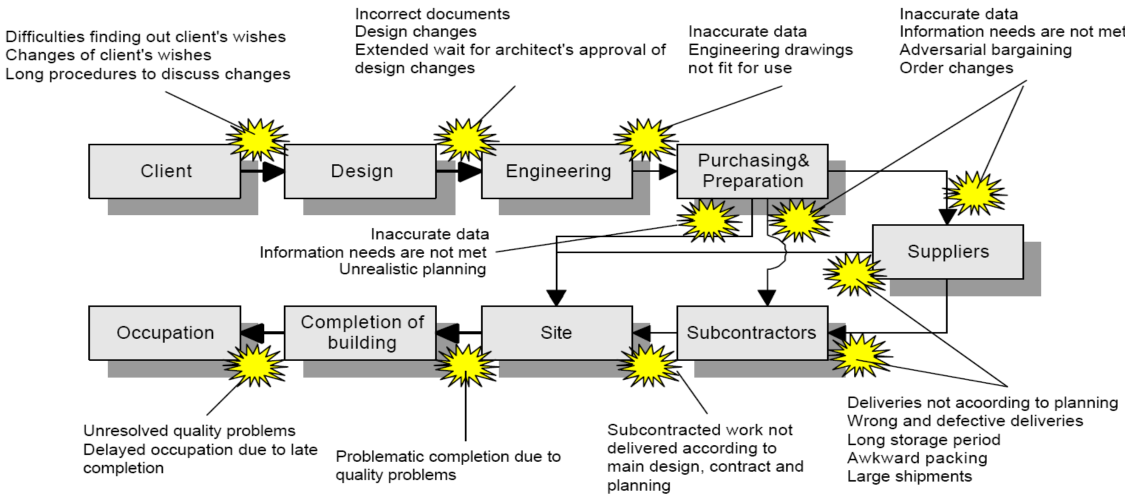

Figure 1: Generic problems in the construction process (Vrijhoef *et al.* 2001). Reproduced by permission of R. Vrijhoef.

Traditionally, supply in construction is controlled as a series of individual activities rather than being viewed as an integrated value-generating flow, as in supply-chain management (SCM). SCM issues are typically related to information and communication problems through the phases and contributors in construction. SCM is closely related to the supply model used in lean production.

There is evidence of benefits for practitioners from close relationships in supply chains that together focus on adding value to a process faster than adding cost (Lamming 1996). When the focus on value and cost accumulation through cross-organizational boundaries is limited in construction, the development of the interaction interface between the actors in the construction supply chain is still inadequate (Polat and Ballard 2003).

Vrijhoef (1998) finds that problems occurring in the supply chain are mostly caused by other actors or part processes in the earlier stages of the supply chain. Pollat and Ballard (2010) find that problems for the entire value chain start as early as the design phase. According to Koskela (1992) attempts to develop the construction process are hampered by traditional design, production and organizational concepts and by the peculiarities of construction. The one-of-a-kind nature of projects, site production, temporary multi-organizations injecting new members into the construction interaction chain and regulatory intervention are known peculiarities of construction. Problems caused by these peculiarities are a lack of feedback cycles where the culture is to hide information and experience, flow configuration difficulties where the different part processes are not well suited to each other, variability problems caused by a low level of standardizations, problems in the communication of knowledge across organizational boundaries and a lack of accumulating improvement in processes. These peculiarities affect the studied cases when conducted in a traditional way. As early as 1992 Koskela asserted that by implementing structural solutions, such as minimizing the one-off content of projects, the on-site content of material flows and the temporary organization interfaces, the effects of the peculiarities of construction can be avoided or at least minimized.

Improvement across the conventional organizational boundaries can be stimulated by long-term relationships or partnerships between actors in the construction process. Thus one minimizes the work of finding routines for cooperation and interaction with new members and can focus on improving the routines for interaction. For this task there is a need to reconceptualize construction as flows and change the way of thinking. According to Azambuja and Formoso (2003) there are cooperation problems—a lack of coordination and integration between agents—in the construction process. For example Bildsten *et al.* (2010) suggest that value-driven purchasing is better than market-driven purchasing. According to Lessing (2006) increased productivity depends on how well a company succeeds in changing focus from unique projects to continuous processes.

Research methods and empirical results

To understand the interaction in the studied process, the case was evaluated from a systems perspective. The study focuses on interpreting and understanding the interaction practices and processes of the actors involved in the case. The study was carried out as a case analysis with a hermeneutic qualitative approach with the purpose of enhancing the knowledge of how the information and interaction between different actors appear and what practices apply. Case analyses are appropriate when the research problem requires understanding of complex phenomena that are not controllable by the researcher (Yin 2003). Data were collected through semi-structured interviews, meaning that an interview guide was developed prior to the interviews, but questions outside the guide were also asked during the interviews. This was in order to enhance the understanding of the process and the interactions. According to Bell (2000) the structured interview strictly follows a guide, the semi-structured interview follows the guide but the interviewer can ask questions outside the guide and the unstructured interview can bear more of a resemblance to a conversation about an area of interest. Beyond the interviews with the involved actors, project documents were used, such as contracts, drawings, organization charts and cost estimates, to verify and to understand more about the interactions and the process. Observations were also conducted on the building site. Lucko and Rojas (2010) suggest that to establish validity, at least face validity, it is useful for the construction industry to use semi-structured interviews. The interviews were semi-structured, and the study was built on 18 interviews, each of which was recorded and supported with detailed notes. The observations were documented in pictures and notes. The documentation regarding the studied case was copied and filed. Each interview, document and observation produced data, but it is the combined results of the interviews, documents and observations that generate the significant contribution to the analysis. Yin (2008) discusses triangulation as a method for validation; in short triangulation means that the studied object is looked at from different angles. In this case we chose to use interviews as one way and documentation and observation as a second way, and used three researchers to look at the same material, ending up with the same conclusions, to build up the internal validation through triangulation. The study aims to contribute to the theoretical generalization in the construction area. Accordingly, the study is not a far-reaching study over time and can at its best give a momentary picture of the reality that applied at the time of the interviews, the documents and the observations, as well as a reconstruction of the development up to that point. The respondents were chosen for their specific knowledge and position to provide relevant information about the process.

The studied joinery-products supplier is an association of a production company and a sales company. The sales process in the traditional construction process means that the customers send out quotation requests to possible subcontractors in two cases: (1) when the contractor is calculating for a possible project and is supposed to make a quote for a future proprietor in the early stages of the product determination stage; (2) when the customer has received a project from the future proprietor, i.e. in the late stages of the product determination. This procedure in the construction process means that a project is processed twice before a contract is signed between the customer and the studied organization. The quotation requests are often guided by quite detailed and complex regulations. Apart from the regulations, there are often varying degrees of detailed definitions and specific demands that are open to interpretations from both sides.

The studied case builds on the experiences of a manufacturer of joinery products supplying an ETO wood product to an on-site construction production of a new office building. The process began with a quotation request for a twelve-floor continuous stair railing in solid wood, with some complexity prior to production (Figure 2). The complexity involved verification of the as-built geometry of the stairs and corresponding 3D modelling necessary to control the numerically controlled machinery in manufacturing. Already small deviations between drawings and as-built would sum up to a substantial error if not accounted for by the joinery manufacturer.

The joinery-products supplier is an association of a production company and a sales company. The construction project is represented by the client, architect, constructor, construction coordinator and construction contractor. The construction contractor is the buyer who is ordering the products from the joinery-products manufacturing organization.

Figure 2: ETO product in the studied case

The construction process interviews

Client

The client, KJ, expressed that a key to the experienced success in the project is to use organizations that are not slim on personnel, as both the construction contractor and the client organization. Communication during the project was through a centralized database with a web interface making the information remotely accessible. Email and personal meetings are also considered important communication channels improving the interaction. Making subcontractors and suppliers contribute the solutions early in the process also stimulates interaction. KJ stated that they have come a long way with the web-based project sites, though outside suppliers have not had access nor asked for it. Further optimization of information management is seen as an important component.

High-quality interaction is valuable and it's important to come in early in the process to achieve interaction.

To avoid a situation in which the general contractor exploits its dominant position in the negotiation with suppliers, the client applied a coordinated general contract for the project in this particular case. The client thus procured some of the subcontractors that were to be coordinated by the construction contractor.

Architect

According to the architects, JF, FB and JB, the main role for the architect is to interpret the client needs and translate these needs into an expression. In this process, the need for cooperation is great between the customer and the architect. It is also important that this contact has the right process timing. JF sees the direct contact between actors in the process as important for the knowledge distribution in a project, in order to fill in the details for, for example, the suppliers. JF stated that the prescribing can be detailed on visible parts of the product while other parts are mostly left to the supplier to solve. In the overall project, JF, FB and JB concluded that cooperation was built through close dialogue between the actors in the process. A problem was that not all the actors have initiated and participated in the cooperation, for example the joinery-products supplier in the studied case.

The project of the stair railing supplier was ambitious but it was done without dialogue.

There were shortcomings in the relations between the consultants and also between other actors in the construction process. Still, the overall project is seen as a good example with well-managed interactions. JF and JB do not see effective alternative tools for interaction that surpass dialogue. The interaction outside the dialogue is the communication of layouts and visualizations. This interaction is mainly managed digitally. JF believes that each part process, for example different design areas like electricity or HVAC, needs self-control with a system focus and calls for an individual or a function that focuses on smoothing the interaction between various actors in the process. The main areas for development in the construction process, as seen by JF, FB and JB, are openness, cooperation and feedback-developing actions and tools supporting interaction.

Engineer

The engineer, KH, described the main role of the engineer as being to convert the architect's expression into construction drawings. This work is performed in cooperation mainly with the client and the construction contractor. The level of engineering in the details varies; the engineer does not have competence in every type of product, and therefore some things are left for the supplier to solve. According to KH, the main interaction with other contractors occurs in planning and construction meetings. The problem according to KH is that there are many actors involved, and they do not all think of commenting on or sharing information.

> *Cooperation and coordination between the actors in construction is important, but maybe the most important coordination is between consultants in the design.*

KH says that there should be coordination meetings earlier in the process. A problem with meetings is that all have to be present at one location. Therefore, KH calls for better communication forms.

Construction coordinator

The client organization hired an external contractor, EJ, to interact between the construction contractor and the design originators (e.g. architects, engineers, HVAC engineers). A responsibility was the coordination of all the questions raised for the originators from the contractors. This role is considered important, and the idea of this process is to assure correction feedback to design documents and two-way information transfer between the design of all the technology disciplines and construction. In practice, EJ's role evolved to coordinate design changes and the interaction between contractors and suppliers in the process and these were not defined in the role at the beginning. EJ's role also involved enhancing communication and decreasing the time from questions to answers. In the case there was a focus on choosing the best solution rather than the cheapest. EJ stated that the culture is open for cooperation, but there are given rules to follow in standardized contract regulations. There also seem to be culture-bound obstacles to initiating contact in some areas of the industry.

> *Weak interaction and lack of feedback result in meagre solutions.*

EJ sees the optimal construction process as one in which all the design is completed before the start of construction. This seems to be hard to achieve when there are obvious lacks in the coordination between contractors in the design, leading to problems with, for example, interference in design and meagre solutions. More time and interaction in design would be needed before the start of construction.

Construction contractor

The construction contractor, HR, finds that the project was successful, but had some interaction mismatches and design conflicts.

> *The industry has become more professional, but there is still a long way to perfection.*

The main problem areas were in drawings, a lack of coordination between actors and competence. HR reported that the production was largely conducted by following drawings, and in some cases the ability to read drawings was poor. Most of the communications on design concerned problem solving. HR calls for more dialogue and cooperation, better design, better coordination and competence development. According to HR construction is about logistics, and there are large gains to be made from finding the right individual for each task. Accordingly there must be a standardized procedure for information transfer, and all the actors must be users of that standardized procedure.

The joinery-products supplier

Sales

The sales division is organized to serve the MTO and ETO product strategy. The seller, CH, says that the desired position is relationship marketing allowing the manufacturer to interact with design in the construction project. The majority of orders come from the construction contractor. If the supplier is involved with the design, it is more seldom exposed to competition in the purchase.

> *Regarding interaction with construction, there's generally no or little dialogue between entrepreneurs in the preparatory stage.*

In the assembly phase, subcontractors meet at the construction site and coordinate with each other. In the studied case, there was no interaction with adjacent processes, causing a need to conform to the given conditions, such as improperly positioned railing anchors in the stair. CH says that the main information carrier produced by sales is the contract and accompanying documentation that are delivered to the joinery producer. The contract initiates the process for the producer. The contract handover is performed together with a contract review that informs the producer about the project. The major issue from the sales perspective is how to obtain a faster and more accurate calculation basis in order to make competitive and profitable quotes.

The studied case had an element of uncertainty resulting in production errors affecting the production cost and flow for the assembly. CH stated that some of the errors could have been avoided with better process control.

Sales calculation

The sales calculator, JH, uses customer-supplied information to estimate the cost of the product. Depending on the product complexity, there is an interaction with the producer. Despite previous experience with special projects, the character of the studied project was seen as complicated regarding ensuring the as-built geometry of the object and the 3D modelling needed. The quotation request sent from the customer consisted of drawings that showed a plan and an elevation, but no actual details. Drawings are seldom mediated in Computer Aided Design (CAD)formats. It is customary in the construction industry not to define in detail and to leave design parts to the supplier to solve. Despite the lack of information, no architect contact was initiated. Errors in the 3-D modelling carried out by the joinery producer were not detected, and control of the producers' modelling is not a responsibility of the sales calculator in the current interface between the sales company and the producer. JH reported that the producer has that responsibility. The errors gave incorrect product deliveries that affected the assembly.

With a totally new product, the development cost is difficult to cover in a single project.

More difficult projects are strategically important since they often generate orders for other products as well. According to JH, the use of 3-D modelling could be useful in automating the generation of useful assembly information, which normally is not done. The assembly is considered to have performed well and contributed to developing the product from the assembly perspective. The conceptual idea of the product attachment is considered to have worked almost flawlessly—only minor adjustments were required on-site.

Production

CF and PW, in production, claimed that the production preprocessing in this project was a challenging 3-D modelling task conducted under time pressure that required new modelling knowledge. PW realized that they needed more modelling competence and that the manner in which sales and production were to support each other in such a case was not defined.

Sales calculates the project, and they hold the information.

The magnitude of the project was not fully grasped when the project was estimated, and key problems in the modelling and production method were underrated. The initiation of the project at the producer was late due to a late order. The need for new manufacturing methods required more man-hours than estimated. Machine limitations were not accounted for in the estimate, and no supporting systems were available to automate such information. Modelling errors were made that could have been avoided through better interaction with sales. Interaction with construction was limited, and no interaction with the architects was initiated. Interaction with assembly was a continuous and iterative process, developing both manufacturing and assembly processes. The main information carrier was the contract and its drawings. CF and PW see information and information transfer as a topic for improvement in the organization. Currently no standardization is used to assure the quality of information. How manufacturing and assembly interaction and information exchange will perform is a from-time-to-time developing model. Assembly needs information to understand the assignment, but what information and from whom needs to be defined in every specific case.

Assembly calculation

OH, the assembly project manager, plans and calculates the on-site assembly of the products and interacts with the assembly contractor, construction contractor, sales and the producers to find a manufacturing method that facilitates assembly.

By working closer, probably much of the present assembly trouble could have been avoided.

That is where 3-D modelling errors caused disruption and extra cost in the assembly of the stair railing—errors that OH considers could have been avoided by interacting with the sales company with respect to the 3D modelling, but neither part initiated such interaction. Production preprocessing was considered late at the start, resulting in late material orders and late material deliveries. That, along with modelling problems, delayed the production and the deliveries to the assembly crew. Except for the errors, the assembly was considered as running smoothly. OH said that difficult one-of-a-kind projects like this are considered difficult to run profitably the first time, though they might generate orders for other products in the same construction project and show off production skills. In those projects, the order-supplied information, mainly drawings, seldom held all the necessary information for production. Interaction with the prescribing parties is generally needed, but in the current project, architect interaction was never initiated.

Assembly

The assembly was performed by a subcontractor interacting with the producer to find assembly methods and product solutions. On-site test assemblies were performed in the presence of producer and sales representatives. The test assemblies were seen as successful, and the assembly methods were developed from that test. The stair was not constructed with consideration of the anchoring of the joinery product to the stair, resulting in more time-consuming assembly.

The project has been a long journey.

Problems in the assembly were: (1) at the start, no written instructions for assembly were available; (2) problems discovered early on were still present when the assembly phase was embarked upon; (3) incorrectly manufactured components arrived at the assembly causing staff to wait in an idle state and delays in material supply. Late in the process, reference heights from the 3-D model were given to assembly, allowing easier product positioning on-site. One reason for these problems is seen to be an effect of the producer being late in starting the project. As the delivery dates were fixed, the problems increased the pressure on assembly, requiring overtime work.

Analysis and discussion

The objective was to study interaction in the supply chain in supplying an ETO joinery product to the construction process. The study was conducted from a systems perspective, emphasizing the interaction between the joinery-products supplier and the construction process. The analysis was based on interviews, on observation and also on documentation regarding the process.

The gathered information illustrates that the main negative effects are caused by the following factors: (1) information needs are not met; (2) competence is lacking; (3) there is a lack of activity in the gathering and mediation of information; (4) inventory buffers break the flow of value-creating activities. Putting the studied case in the generic perspective presented by Vrijhoef *et al.* (2001), the main factors result in the following consequences:

- Inaccurate data transfer or lack of data transfer
- On-site solutions without information feedback
- The physical distance from the construction site influences the amount of information received due to a loss of informal information channels on-site
- The distance from the construction site also influences the ease of on-site controls of adjacent environments
- Known problems are not solved because of undefined areas of responsibility
- Uncertainties both in production methods and in technical solutions
- Errors and delays, such as incorrect deliveries to assembly
- Lack of feedback except in cases where problems have arisen
- Disturbances in the process flow
- Information inventory buffers; for example, twenty-seven weeks elapsed from the supplier quote to the construction contractor's order.

In Figure 3, the studied case is illustrated with value-chain interaction problems affecting the supplier pointed out with stars. In the studied case, the relation was between the construction contractor and the joinery-products supplier. Most often, the supplier sales efforts were towards the construction contractor. Through this procedure, the construction contractor could easily disconnect the supplier from those accountable for the design. This disconnection affected the transparency of information negatively, and even worse, customer demands were filtered through yet another link in the value chain. In the studied case the information in the project database was not accessible to the joinery-products supplier. The supplier witnessed that in general, drawings were seldom mediated as CAD files, which limited information and caused duplicate work to be conducted.

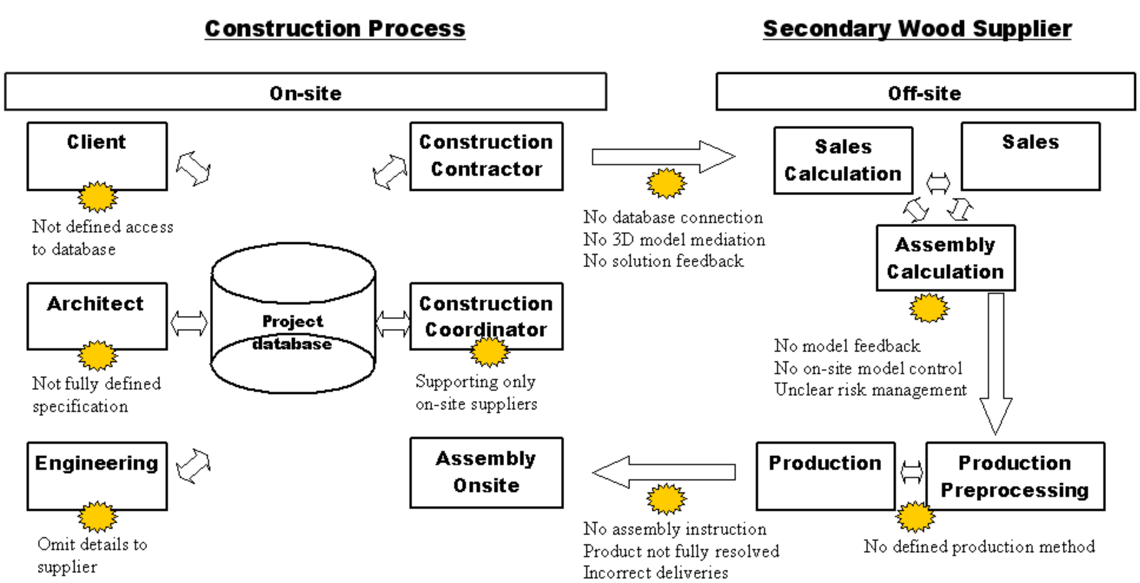

Figure 3: The customer and supplier information flow

Information needs

The manufacturing of products not fully defined by a prescriber to a fixed price is a peculiarity of this system. Originators deliberately left out undefined details for the supplier to solve, while at the same time, the supplier claimed that they produced according to defined specifications. The originators saw the suppliers as the product experts while the supplier saw the originators as the design experts. This undefined responsibility created a need for the supplier to interpret mediated information and can cause a value loss of the product.

In this case we can see disconnection effects at different levels in the process, one being the supplier's risk management when pricing. Responding to quotation requests involves estimating production costs and market prices when pricing the product. At this stage, the product is seldom fully defined by the originators at the level of detail needed for production. Estimation work is not chargeable, so the resolution of the estimation work tends to be limited. Thus the detailed product solution and production method are not made until the client's order is received.

This behaviour results in a need for a supplier-originator interaction that is not a standardized routine in the present supplier procurement model. Further, the joinery-products supplier confronts a number of product- and method-developing issues that need to be solved for every specific order. In this case, for example, the question of how to connect the corners of the stair railing to allow dimensional changes due to air humidity variations of the indoor climate needed to be answered. The culture in construction is for each party to optimize its own process, without proper routines for how and what information is needed for the next or adjacent partial process. The culture of ad hoc problem solving minimizes reflection on the desired state in a situation in favour of solving the situation at hand. Therefore, no root analysis is carried out, and the problem is likely to recur. What can be found is that there is no defined responsibility for keeping the focus on the systems perspective. Therefore, when processes are adjacent and should have an exchange of information, this is not always accomplished due to the lack of a systems perspective. The studied case shows an example of adjacent processes without information exchange, e.g. when the construction contractor cast the stair, cast-in anchor points were made for a railing but with a lack of information on where to position these anchor points. This inaccurate positioning of the anchor points resulted in extensively increased assembly time for the joinery-products supplier when the anchor points did not fit the prescribed product solution.

Competence

Most MTO/ETO joinery-products suppliers in Sweden are small-to-medium-sized organizations. As seen in the studied case the companies are high in craftsmen's skills, but low in engineering competence, and are not organized to participate in the construction design process.

The supplier displayed an inability to estimate accurately complex work not previously performed, and the production planning was further disrupted by repeating 3-D modelling already performed by the originators, causing delays and disturbances in the process.

A major part of the internal and assembly problems could have been avoided through exchange of the 3D model: information that was available, but was not shared. This is an example of the culture in the construction process that does not encourage work with standardized routines for interaction in cases such as this. One effect of this culture is that organizations need to have competencies in areas that they should not actually need to have. The information produced by these competencies should already be present this late in the process. At the same time, the competence of the originators needs support in the form of knowledge of product-specific effects and production effects of the chosen solution. The uncertainties in the supplied drawings and methods in the project together with the lack of risk management generate high risks in the price setting since the production costs cannot be fully known. In the studied case, for example, the production cost differed substantially from the calculated production cost.

Information mediation

In the studied case there was a competent client and future proprietor with skills within the construction area. The project was arranged with a web-based information platform for the actors involved in the project. Still, there were actors who were not invited to this platform, for example, the supplier in the studied case. On the other hand, the supplier did not seem to try to connect to the existing information. One reason for this behaviour is that the contractor/supplier relation culture does not encourage that practice, and the supplier was simply unaware of this information platform praxis. As a result of this disconnection, the joinery-products supplier managed engineering work (3D modelling of the stair) already performed by the originators, and with a lack of competence in some parts affecting the overall result.

Non-value adding

In Figure 4, a rough value-stream map of the total process shows the project lead time and the presence of inventory buffers that resulted in a major time span between the design and the ETO joinery production (data supplied by the client, joinery sales and joinery production and through observations). The time span between the preliminary quotation request and the product order was 96 weeks (27 of these weeks were between the quote and the order). During this time span, the major focus and efforts were invested in the business transaction rather than value adding to the product. When the final product design was left to the supplier to manage, this time span limited the supplier's possibilities to interact with the client due to the narrow time (24 weeks) to design, produce, deliver and assemble the 109 wooden elements of the ETO product.

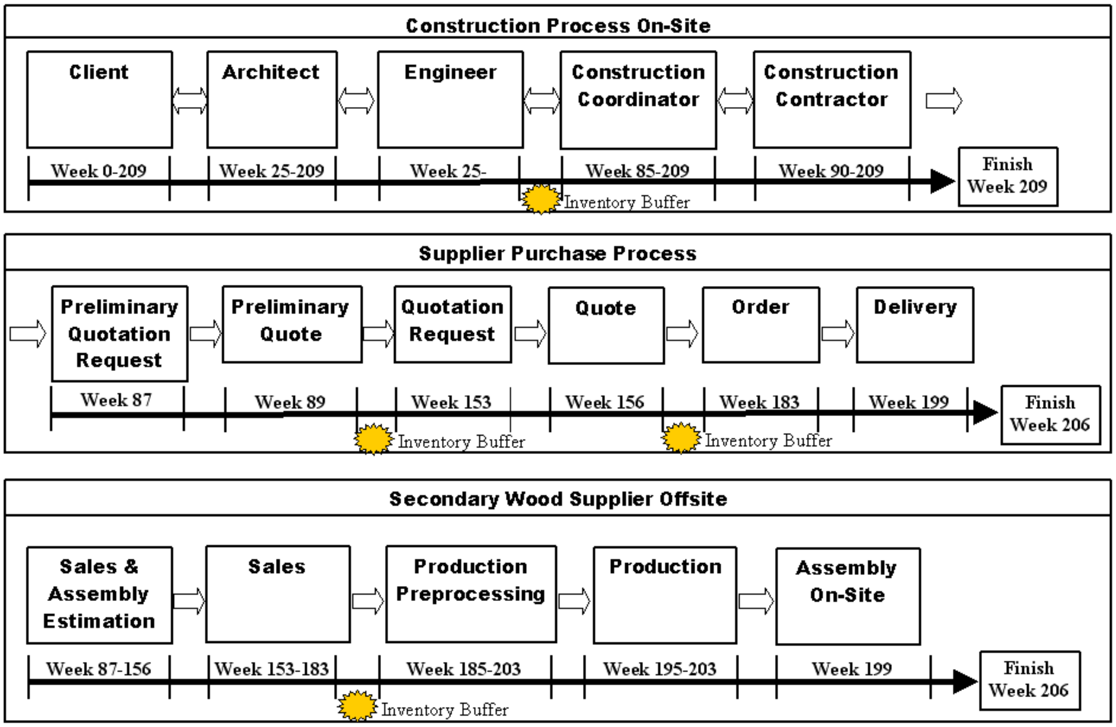

Figure 4: Timeline of the total process

The production of this ETO product involves a minimum of inventory buffers of finished goods. As soon as the first batch of finished good is produced, it is sent to the assembly personnel at the construction site for final testing and assembly if correct. If the assembly shows that the product and its design are correct the production continues with small batches that are shipped to the assembly continuously.

If looking at the total process there are inventory buffers of finished goods of information present before the actual production starts. Examples of this information are the prescribing documents of the originator, preliminary quotation request, preliminary quote, quotation request, quote and order that are stored in inventory buffers. Prescribing documents are produced early in the process and are used both in the business transaction of the ETO wood product as well as in the production preprocessing, though there is no real reviewing of the prescribing documents for the ETO wood product until the production preprocessing. The time between the preliminary quote and quotation request, and between the quote and the order, are the inventory buffers with the highest impact. After the order has been placed it is stored in an inventory buffer until the supplier can fit the order in to the production.

As seen in the study of the case, the procurement involves extensive work on estimating for the joinery-products supplier. The model for procurement also involves competition for suppliers. Thus the work of estimating costs is undertaken by several competitors in every project. There is no culture of long-term relations in the supply of joinery products. Unlike the general contractor, suppliers have a double quotation process.

The cost of making unsuccessful quotations must be covered by orders that successfully go to completion, and this tends to increase the general price level.

Summary

These findings connect to experiences found in other case studies of the supply chain in construction, e.g. Elfving *et al*. (2002) and Melo and Alves (2010), in which a lack of system view, lack of knowledge of dependencies, lack of trust, lack of consideration of preconditions etc. are a hindrance to significant improvement of the SCMC. As we see the best solution of a different model for procurement of the supplier integrating with originators would be desirable in construction. A starting point for a supply chain model in the MTO/ETO joinery products supplier would be the co-makership model between contractor and supplier as described by Vrijhoef (1998). Such a model would avoid the procurement in every single construction project and the focus could be on adding value faster than costs through joint efforts and winnings.

However the current business culture in construction is a hindrance to the joinery-products supplier already joining the construction process in the design phase. Therefore one suggestion would be to improve the standardization of the interfaces between the actors in the construction value chain.

Conclusions

As shown in this study, interaction is interfered with by poorly defined interfaces and a lack of standardizations and inventory buffers are distancing the actors in the value chain from each other. One solution to the problems that occurred could be to agree on the supplier interfaces with the contractor organization, but also with the architect and the client. This calls for different behaviour in construction towards the suppliers, and more integration of contractors and suppliers is needed to progress towards a model in which all the parties strive towards a common goal.

The case findings show that supply-chain management and information management are two main areas that work poorly, causing numerous knowledge disconnection effects for an ETO joinery-products supplier in construction. From a systems perspective, the most harmful reasons are:

(1) Information needs are not met;

(2) Competence is lacking;

(3) There is lack of activity in the gathering and mediation of information;

(4) Inventory buffers break the flow of value-creating activities.

In this case gains could have been obtained by:

- More interaction between supplier, originators and adjacent processes
- More standardized routines for interaction
- Higher activity in searching for and mediation of information
- Decreasing system-dependent inventory buffers and using time for value-creating activities

We therefore suggest improving the standardization of the interfaces between the actors in the construction value chain, starting with the most adjacent downstream actor (customer) in the value chain. This would lead to an improved information flow in the value chain. Our future work will continue with the MTO/ETO joinery-products supplier perspective in relation to improving internal processes in terms of lean values and information flow. Supporting the process with as-is 3D measurements and efficient mediation of that information is part of that research.

References

Akel, N., Tommelein, I., Boyers J., Walsh, K., Hershauer, J, (2001) "Considerations for Streamlining a Vertically Integrated Company: A Case Study". *IGLC 9*, Singapore. International Group for Lean Construction.

Anheim, F. (2001) *Entreprenörens lärande: drivkrafter för lärande i och mellan projekt*. Luleå University of Technology.

Arbulu, R.J. and Tommelein, I.D. (2002) "Value Stream Analysis of Construction Supply Chains: Case Study on Pipe Supports Used in Power Plants". *IGLC 10*, Gramado, Brazil. International Group for Lean Construction.

Azambuja, M.M.B. and Formoso, C.T. (2003) "Guidelines for the Improvement of Design, Procurement and Installation of Elevators Using Supply Chain Management Concepts". *IGLC 11*, Blacksburg, USA. International Group for Lean Construction.

Bell, Judith (2000) *Introduktion till forskningsmetodik*. 3rd edition, Studentlitteratur, Lund.

Bildsten, Louise, Björnfot, Anders and Sandberg, Erik (2010) "Value-driven vs Market-driven Purchasing of Kitchen Cabinets". *IGLC 18*, Haifa, Israel.

Bröte, Staffan (2002) *Towards Market Driven Manufacturing Systems Design*. Linköping Studies in Science and Technology. Dissertations, 0345-7524; 734. Dep. of Management and Economics, Univ., Linköping.

Cigén, Sunna (2003) "Materialleverantören i byggprocessen: en studie av kommunikationen mellan träkomponentleverantören och byggprocessens övriga aktörer". Lic, Luleå University of Technology.

Elfving, Jan, Tommelein, Iris D. and Ballard, Glenn (2002) "Reducing Lead Time for Electrical Switchgear". IGLC 10, Gramado, Brazil. International Group for Lean Construction.

Fontanini, P.S. and Picchi, F.A. (2004) "Value Stream Macro Mapping – A Case Study of Aluminum Windows for Construction Supply Chain'. *IGLC 12*, Elsinore, Denmark. International Group for Lean Construction.

Holst, M. (2004) *Knowledge Work Across Boundaries—Inquiring into the Processes of Creating a Shared Context*. Licentiate thesis, Luleå University of Technology, Sweden. http://epubl. luth. se/1402-1757/2004/66/index. html (accessed January 4, 2005).

Höök, Matilda and Stehn, Lars (2008) "Lean Principles in Industrialized Housing Production: The Need for a Cultural Change". *Lean Construction Journal*, 20-33.

Jackson, Mats (2000) *An Analysis of Flexible and Reconfigurable Production Systems: An Approach to a Holistic Method for the Development of Flexibility and Reconfigurability*. Linköping Studies in Science and Technology. Dissertations, 0345-7524; 640. Linköping University, Linköping.

Koskela, Lauri (1992) *Application of the New Production Philosophy to Construction*. Center for Integrated Facility Engineering, Stanford University, Inglaterra.

Lamming, R. (1996) "Squaring Lean Supply with Supply Chain Management". *International Journal of Operations and Production Management,* 16, 183-96.

Lessing, Jerker (2006) *Industrialised House-Building: Concept and Processes*. Department of Construction Sciences, Lund University, Lund.

Lucko, G. and Rojas, E. (2010) "Research Validation: Challenges and Opportunities in the Construction Domain". *Journal of Construction Engineering and Management,* 136 (1), 127.

Melo, Reymard Sávio S. de and Alves, Thais da C.L. (2010) "Investigation of the Supply Chain of Prefabricated Wooden Doors". *Lean Construction Journal,* 30-42.

Polat, G., Ballard, G. (2003), "Construction supply chains: Turkish supply chain configurations for cut and bent rebar" IGLC 11, Virginia USA, International Group for Lean Construction.

Polesie, P., Frödell, M. and Josephson, P.-E. (2009) "Implementing Standardisation in Medium-Sized Construction Firms: Facilitating Site Managers' Feeling of Freedom through a Bottom-up Approach". *IGLC 17,* Taiwan. International Group for Lean Construction, 317-26.

Rother, Mike and Shook, John (2003) *Learning to See: Value-Stream Mapping to Create Value and Eliminate Muda*. Lean Enterprise Institute, Brookline, MA.

Santos, Aguinaldo, Formoso, Carlos Torres and Tookey, J.E. (2002) "Expanding the Meaning of Standardisation within Construction Processes". *The TQM Magazine,* 14 (1), 25-33.

Vrijhoef, Ruben (1998) *Co-makership in Construction: Towards Construction Supply Chain Management*. MSc, Delft University of Technology.

Vrijhoef, Ruben and Koskela, Lauri (2005) "Revisiting the Three Peculiarities of Production in Construction". *IGLC-13,* Sydney, Australia. International Group for Lean Construction.

Vrijhoef, Ruben, Koskela, Lauri and Howell, Greg (2001) "Understanding Construction Supply Chains: An Alternative Interpretation". *IGLC 9,* Singapore. International Group for Lean Construction.

Yin, R. (2003) *Case Study Research: Design and Methods,* 3rd edition , Sage Publications, Thousand Oaks.