UNDERSTANDING COLLABORATION: INDUSTRIAL DESIGN VERSUS CONSTRUCTABILITY REVIEW

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ABSTRACT: Constructability review is frequently mentioned as solutions to industry-wide problems of improving design efficiency and reducing construction errors. Despite numerous attempts to conduct constructability review, few practical implementations can be found in construction industry today. Inspired by the efforts of industrial researchers in investigating the collaborative aspects of integrated industrial design, the collaboration aspects in constructability review process (CRP) should be well addressed in order to fulfill the promises of constructability review. The study presented in this paper attempts to gain a better understanding of the collaborative process among parties from different disciplines in CRP. Insights and knowledge learned from highly integrated industrial design are transferred to constructability review domain to gain better understanding of the collaborative interfaces, and the barriers and enablers that influence the creation of shared understanding among different parties. This paper also formulates a method for empirical study of the collaborative aspects in CRP. Future work is to conduct case studies on industrial CRP with the developed method.

KEYWORDS: collaboration, enablers, barriers, interface, constructability review process, empirical study.

1 INTRODUCTION

Constructability review is frequently mentioned as solutions to industry-wide problems of improving design efficiency and reducing construction errors. Despite numerous attempts to conduct constructability review, few practical implementations of CRP can be found in construction industry today. Nowadays, both industrial practitioners and researchers have investigated the organizational and collaborative aspects of integrated industrial design. Constructability review demands effective multi-disciplinary collaboration and shares common features with integrated industrial design. The promises of constructability review remain unfulfilled, and both researchers and practitioners have not yet put much effort into the collaborative aspects of constructability review process (CRP). This makes that the involved parties are not able to create shared understanding about the design they are reviewing. Shared understanding about designs is important because it influences the quality of the end result of the design process (Valkenburg, 2000). The aim of this study is to gain a better understanding of collaborative aspects of parties from different disciplines involved in CRP. The purpose is to facilitate the knowledge transfer from industrial collaborative design into CRP for improvement.

In order to show what kind of collaborative processes this paper compares, Section 2 discussed the main characteristics of CRP and Section 3 presented the collaborative aspects of industrial design process (e.g., the way different parties are involved in the different stages of the industrial design process). Section 4 focused on the factors (enablers and barriers) that influence the creation of shared understanding among parties from different disciplines in CRP, and examined the collaborative interfaces between parties in CRP. Section 5 formulated a method of empirical study to create knowledge on the factors that influence the creation of shared understanding.

2 CONSTRUCTABILITY REVIEW PROCESS

Constructability is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives ("Constructability" 1986). Constructability review process (CRP) formally review projects and address constructability issues which usually occur at the design stage. Such multidisciplinary reviews intend to improve the constructability of projects as well as the design. CRP typically involves various parties such as planners, designers, engineers, constructors, suppliers, sub-contractors, etc.

Previous research has addressed various aspects of constructability and primarily sought to understand the elements in a CRP, and the optimal way to implement a

CRP. For example, Fischer and Tatum (1997) developed models to classify constructability knowledge. Navon et al. (2000) developed methods to automat the process of constructability reviews. Surveys were conducted to better understand the CRP, and to quantify the advantages obtained from constructability reviews (Anderson et al. 1999; Uhlik and Lores 1998). O'Connor and Miller (1994) identified four major types of barriers involved in CRP: cultural, procedural, awareness, and incentive barriers. Cultural barriers are caused by company tradition, inflexible attitudes, frozen mind-sets, or other ingrained paradigms within the organization. Procedural barriers result from established methods or practices considered "set in stone," or by a lack of interest in trying new ideas or suggestions that might force revision or changes to standard operating procedures. Awareness barriers include those arising from a lack of understanding of the goals, concepts, methods, and benefits of constructability, or a lack of comprehension of the application of these items to organizational practices. Incentive barriers are caused because no motivation or inducement for constructability implementation is present (O'Connor and Miller 1994). The focus of the study presented in this paper is on the collaborative aspects between parties from different disciplines involved in CRP.

3 CHARACTERISTICS OF INDUSTRIAL DESIGN PROCESS (IDP)

Industrial design projects are nowadays performed in multidisciplinary design teams. This means that, all disciplines involved in the IDP, are ideally involved from the beginning until the end. Figure 1 shows the IDP. The different tones of the team members around the table 1 represent their discipline. The three different tables represent different phases of the design process. (Different disciplines, such as, Market research, Sales and Quality Control can also be involved in the team.)

Figure 1 also shows that Marketing, R&D and Production are involved from the 'definition of the market need' (or 'definition of new technology') until the final product has been developed. This is important since most decisions concerning the design of the new product are taken in the first phases of the design process. If production for example is not taken into account in the early phases, the problems that occur in the final product that are related to production issues can only be solved cosmetically.

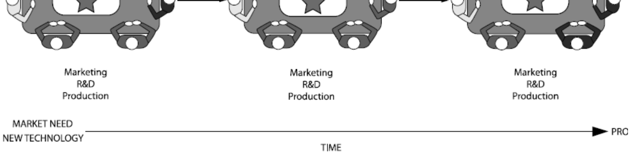

Figure 1. The collaborative industrial design process (Kleinsmann 2006).

In order to facilitate IDP, companies use Stage Gate Models that describe the activities that need to be performed in order to develop the new product (Cooper 1988). However, these prescriptive Stage Gate models implicate an undisturbed flow of activities during IDP, which differs greatly from practice. This is because (in addition to cooperative aspects), collaborative aspects play an important role in IDP.

Collaboration between disciplines in an IDP process is difficult and delicate since the actors have different knowledge bases and they represent the design they are making differently (Buciarelli, 1996). Additionally, they communicate in different jargon about the product to be designed. The different team members also represent a different department within the company. Therefore, they have different responsibilities that result in different interests. The mutual interests of the different team members are often in conflict.

All the aspects mentioned cause team members difficulties to create shared understanding about the design they are making. Valkenburg (2000) showed that the creation of shared understanding influences the quality of the end result, which shows the importance of the collaborative aspects of the IDP. Furthermore, interviews with several managers of IDP have revealed that multidisciplinary design teams have to deal with collaboration problems on a daily base.

Kleinsmann (2006) defined the collaborative design process as:

Collaborative design is the process in which actors from different disciplines share their knowledge about both the design process and the design content. They do that in order to create shared understanding on both aspects, to be able to integrate and explore their knowledge and to achieve the larger common objective: the new product to be designed.

This definition of collaborative design shows that the main aspects in the collaboration process are:

- knowledge creation and integration between actors from different disciplines
- communication between the actors about both the design content and the design process
- the creation of shared understanding about the subjects communicated

Knowledge creation and integration are the goal of the collaborative design process. If actors are not able to create and integrate knowledge, then they will not be able to design a new product. The actors involved in the design project share and create knowledge through design communication. The actors communicate orally and through the use of textual documents. Additionally, drawings and prototypes play an important role in supporting content related design communication. The quality of the design communication depends on the process of creating shared understanding. Therefore, it is necessary to create insight into the process of creating shared understanding between actors involved in a collaborative design project. There is not much literature on collaborative design as it is defined here. However there is research done on the three main aspects of collaborative design. For a complete literature review on these aspects of collaborative design see: Kleinsmann, 2006 pp. 29-71.

4 COLLABRATIVE ASPECTS IN CONSTRUCTABILITY REVIEW PROCESSES

Since the process of creating shared understanding influences the quality of the end product, it is important to know what factors influence the creation of shared understanding. Kleinsmann (2006; 2007) investigated these factors and their mutual relationship. This section shows how the factors found in the research of Kleinsmann can be applied to the CRP process. O' Connor and Miller (1994) also found some additional factors that are also applied to the CRP process.

4.1 *Enablers and barriers in CRP*

This section discussed the influence of the factors on the creation of shared understanding in CRP. Knowing these factors is the first step towards implications towards improving CRP. These factors will either support or hamper the creation of shared understanding. Factors that support the creation of shared understanding are called *enablers* and factors that hamper the creation of shared understanding are *barriers*. The construction industry needs to be aware of these common barriers and work to mitigate their effects. The work presented in this section allows corporate and project level constructability review program managers to determine which of the common barriers they should expect to encounter.

In order to create more insight into the nature of the barriers and enablers in CRP, these factors are categorized into three levels: party-level, project-level, and corporate-level. Barriers on the party level deal with direct collaboration between two parties executing a design task. Parties from different disciplines have different interests and responsibilities because of their different design tasks. Parties also have different project approaches while performing their tasks. This will influence their collaboration process. An example of a barrier on the party level is that the constructor does not know how to interpret information from the architect. He does not know exactly for which purpose a shore should be erected. This example shows that there is no shared understanding between the constructor and the architect. The constructor is not able to properly fulfill his own task because he does not have the information he needs. An example of an enabler on the party level is that the architect is capable of explaining the application of the shore to the constructor. A list of party-level factors involved in CRP is identified in Table 1. The second level is the project level. Barriers on the project level deal with project-specific factors, such as planning, monitoring, budget, and project organization. An example of barriers on the project level is the low efficiency of information processing (e.g., it is unclear what information is needed). An example of enablers on the project level is the active use of the Minutes of Meeting. A list of project-level factors involved in CRP is identified in Table 2. The third level is the corporate-level. Barriers on the corporate level deal with how the involved parties organize their CRP and how they apply its resources. An example of a barrier on the corporate level is that in the middle of CRP, problems are not solved adequately because certain mechanical engineers are removed to new projects and no longer dedicated to the CRP. This indirectly hampered the achievement of shared understanding. An example of an enabler on the corporate level is that at the beginning of the CRP, relevant parties from different disciplines are put together in a team. This multidisciplinary team takes all requirements from the different departments into account early on in the project. A list of corporate-level factors involved in CRP is identified in Table 3.

Table 1. Identification of Party-level Factors in CRP

Factors	Discussions
The ability to identify constructability issues	The parties involved might be strong in identifying constructability issues, or might fail in searching our problems.
The experience of parties	The enablers within this factor deal with the experience that parties have with the other parties' regular tasks. The barriers are lack of experience of other parties (e.g., lack of construction experience in designers).
The applicable knowledge of a party	e.g., the designer's partial understanding of construction requirements
The ability of parties to make a transformation of knowledge	It concerns the knowledge exchange between different disciplines. Since parties of different disciplines use different knowledge, a transformation of knowledge is always needed. The parties need to transform both the content of the knowledge and the representation of the knowledge. In both cases, the barriers within this party deal with the translation of design or construction specification into knowledge that other relevant parties (architects/engineers/constructors) can use during their own respective tasks.
The view of a party on the CRP	• The view on CRP benefits (e.g., the resistance of the owners to formal constructability approaches because of the highly visible extra cost to projects) • The view of a party on the process to follow (e.g., perception of increased liability and reluctance of genuine commitment) • The view of a party on the knowledge to be shared (e.g., reluctance of field personnel to offer preconstruction advice)
The empathy of the party about the interest of a task	This factor deals with the understanding of the content and interest of one's task. In addition, it is about to what extend a party is able to interrelate his tasks to other (interrelated) tasks. The barriers within this factor deal with: parties do not fulfill a task that is required because they are not aware of the interest of the task or they underestimate a task or, parties perform a task and do not inform other parties, since they do not know that the information is important for the other party. An enabler might be that if a party knows the context of his task, he has more empathy for other tasks just outside the direct scope of his own task.
The view on team-building	Lack of mutual respect between designers and constructors, e.g., unreceptive to contractor innovation.
The ability of parties to make use of different communication methods	Poor communication skills
The equality of the language used between the parties	It concerns the different jargon that the parties use (both in words as well as in drawings).
Personality and corporate cultural	e.g., diverging goals between designers and constructors

Table 2. Identification of Project-level Factors in CRP.

Factors	Discussions
Physical barriers	Geographically distant parties have to arrange time and transport for face-to-face constructability review meetings.
Incentives and rewards	As an encouragement for CRP, parties usually get paid extra for doing work outside of the scope of their assignment.
The efficiency of information processing	It concerns the information exchange between parties. The important barriers are: • the status of the documents are not sufficient • it is unclear what information is needed • there are iterations due to mistakes • there are too few meetings for processing information • in meetings sometimes not the most important issues are discussed • appointments are made orally and can not be found on paper Enablers are: • the early involvement of relevant parties • the active approach of party toward the other party • the availability of efficient information management systems • the active use of the Minutes of Meeting
The quality of project documentation	• ongoing changes in the documents • incomplete documents • it is unclear how to deal with certain documents • different versions of the same document • unclear structure of the document
Availability of formal management processes	Enablers will be an on-site CRP program manager to coordinate the entire formal process.
The division of labor	E.g., there is a lack of manpower at the beginning of CRP, due to another uncompleted project. Furthermore, the corporate does not have enough manpower to do all CRP activities.
Project controllability	• The controllability of project budget, e.g., reluctance to invest additional money and/or effort in CRP • The controllability of design changes • The controllability of project quality

4.2 *Interfaces: the relationship between the barriers and enablers*

This section shows the individual factors that influenced the creation of shared understanding. This section shows that these factors occur not isolated. Some of them are interrelated to each other. According to Smulders (2006), an interaction pattern between parties is an interface if two (groups of) parties work to a large extent separately, yet share a common boundary. As a result of this common boundary, they must interact with each other. One (group of) party (s) needs to share their knowledge with each other in order to share and create the knowledge necessary. Each interface involved in CRP actually consists of barriers and enablers on more than one level (party, project, and corporate). Therefore, the enablers and barriers within each interface can be identified and analyzed. In addition, the identification of interfaces could allow revealing:

- the knowledge that the parties have to share and create within the interface
- the communication processes between the actors
- the relationship between the barriers and enablers within each interface

Table 3. Identification of Corporate-level Factors in CRP.

Factors	Discussions
The organization of resources	At the start of the CRP, the "right" resources (personnel) needed to be allocated to the project. Many parties might go to other projects in the middle of CRP, resulting in discontinuity of key project team personnel.
The organization of the CRP team	A well organized multidisciplinary team from the beginning of CRP in which the important disciplines are involved from the project start until the end of the project is critical. For instance, the designers have never been involved in the construction phase, therefore, they are not used to giving their input in other stages along the life cycle of project.
Organizational responsibilities	Designer might not be willing to be involved in aspects outside the scope of their own work. They only want to be involved in a particular task when this is formally arranged. This is partly due to the complexity of a design project. For example, a design team has to design a bridge for high-speed train. This is a complex project all on its own. However, it is just a piece of the design of the entire high-speed train trajectory. Therefore, there exist many interdependencies on different levels inside and outside the project team and outside the corporate. For the engineers, it is difficult to foresee the consequence of getting involved in a task outside their direct scope. The necessary paperwork of this design project also intensifies this. Furthermore, the designer team has to be actively been involved in integrating aspects that are just outside the scope of their own task into their design.

There are interfaces with their own constructability review team and there are interfaces with the outside world. Therefore, two major types of interfaces are identified below:

- The interface with the outside world: examples are the interface between CRP team and owners or government representative. In interfaces with the outside world, there is sometimes a formal relationship between the CRP team and the other party. At other times, the CRP team needs to gain knowledge of the parties in the outside world because these parties are the future final end users of the constructed facility. In all situations, the relationship in the interface can best be described as a relationship between a customer and a supplier.
- The interface between parties inside CRP teams: examples are the interface between designers and constructors, the interface between designers and suppliers, the interface between constructors and subcontractors, the interface between the design team and the suppliers, etc.

5 METHOD OF EMPIRICAL STUDY FOR CRP

In this section, a research method is presented to study the collaborative aspects of CRP. This method is based to a large extent on the learning history method as developed by Roth and Kleiner (2000) and applied by Kleinsmann (2006). Figure 2 shows the research method.

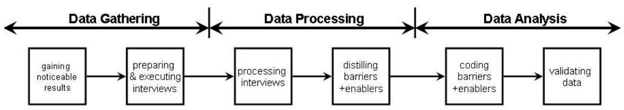

Figure 2. Research method for empirical study of CRP (adapted from Kleinsmann 2006).

The research method consists of three phases: data gathering, data processing and data analysis. The activities which need to be executed in the different phases are described in the squares of Figure 2.

During data gathering, gaining noticeable results is the first activity. These noticeable results are gathered during CRP meetings. The noticeable results function as input for the preparation of the interviews and the desk research. The noticeable results also influence what team members are asked to be interviewed, since it is important to interview those team members that were most involved in the noticeable results. Both the selection of the key figures to interview and the set up of the interviews are results of this preparation. The last activity of the data-gathering phase is the actual execution of the interviews and the desk research.

In the data processing phase, the interviews are processed and jointly told tales are constructed. Jointly told tales are the combination of the transcribed interviews as well as the interpretations made by the researchers. The barriers and enablers for the creation of shared understanding are distilled from the jointly told tales.

The data analysis phase comprises both the coding and validating the barriers and enablers. The coding of the barriers and enablers according to the three levels (as proposed earlier in this paper) provides insight into the kind of factors that influence the creation of shared understanding. The coherent stories of the parties, combined with the observations (executed by a researcher) enable the finding of the relationships between the barriers and enablers.

6 DISCUSSION

The next example shows how future CRP processes could be improved by the Learning history method in an IDP project. This example was transformed from an example from industrial design engineering into a CRP problem. This section shows the value of the research method proposed in this paper. It would be interesting if we can apply the method proposed in realistic CRP in the future. Imagine the following situation:

"A mechanical constructor got an assignment to build the hydraulic piping for drainage. In the list of specifications, he saw the maximum amount of space he could use for the hydraulic piping. From his experience, he knew that he was not able to put all of the components he needed in that space. The program manager told him that the drainage designer came up with this design and specification. The constructor asked the drainage designer if he could change this design. The designer told him that this was the maximum amount of space the constructor could use. The designer explained himself with design intention and design requirements. Although the designer tried to explain his point of view clearly, the constructor did not understand. By using drawings of drainage design, the constructor tried to explain to the designer the impossibility of getting all the functionality into such a small space. The designer did not understand what the constructor was talking about. They ended the discussion with the knowledge that there was a space problem. Yet, they were not able to negotiate with one another in a productive way in order to solve the problem."

A CRP program manager who faces the problem can use the method presented in this paper to recognize the underlying causes of the collaboration problem that occurs on the party level. The main problem here is that the designer and the constructor are both incapable of transferring their knowledge to one another. The major interface lies between the designer and the constructor if this process is regarded as CRP. Looking at the collaborative mechanisms of this interface, a program manager should be aware of the fact that this design issue can lead to construction and maintenance problems. In order to manage this, a program manager should help the designer and constructor transferring their knowledge to one another. He should function as a boundary spanner between the two parties. If the transition of knowledge is made and both parties have learned some of the language of the other, then both the designer and constructor can together solve the design problem. Furthermore, a program manager should be flexible with the planning of this aspect. He should be aware that this design task may influence the critical path of the entire project delivery. In order to control this, a program manager should also monitor he progress and possible problems.

This method can help program manager to recognize and distill the factors (enablers and barriers) and collaborative mechanism within his CRP team. The program manager should actively observe his own team during their regular meetings. He should take notes about the most important issues concerning communication about the design content. During the regular face-to-face meetings (design problems or changes) with the separate parties, he can use his notes as input for discussing the collaborative aspects with the parties. This form of storytelling will provide the program manager with knowledge about the collaborative aspects of this CRP. The program manager should also learn to distill the barriers and enablers from these conversations. Dependent on the kind of barriers and enablers he has found, he can then decide if he needs to intervene to fix some collaborative problems.

7 CONCLUSIONS AND FUTURE WORK

This paper investigated the factors that influence the creation of shared understanding among experts from different specialty services in construability reviews. These factors are categorized into three levels: party-level, project-level, and corporate-level. Barriers on the party level deal with direct collaboration between two parties executing a design task. Barriers on the project level deal with project-specific factors, such as planning, monitoring, budget, and project organization. Barriers on the corporate level deal with how the involved parties organize their CRP and how they apply its resources. This paper also formulates a method to implement empirical study of the collaborative aspects involved in a specific constructability review process. This method is based on the identification of factors (enablers and barriers) at each interface (e.g., interface between designers and constructors) that exists in a CRP. Future work will use the findings of this paper and the presented method to implement case studies from existing CRP in construction industry. The results from the case study will be used to reflect the method and conclusion can be made accordingly.

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