KNOTWORKING – A NOVEL BIM-BASED COLLABORATION PRACTICE IN BUILDING DESIGN PROJECTS

Hannele Kerosuo[1], Tarja Mäki[2], Jenni Korpela[3]

[1] Docent, PhD, Institute of Behavioral Sciences, CRADLE, University of Helsinki
[2] Project Manager, Institute of Behavioral Sciences, CRADLE, University of Helsinki
[2] Researcher, Institute of Behavioral Sciences, CRADLE, University of Helsinki

Correspond to hannele.kerosuo@helsinki.fi

ABSTRACT: Knotworking represents a distributed collaborative expertise in pursuit of a task that is organized among designers from different design disciplines. Construction processes involve phases and tasks that cannot be solved in one organization only, as integration of expert knowledge from various sources is needed. Through knotworking, groups of people, tasks and tools are set to work intensively for a short period of time to solve a problem or accomplish a task. Knotworking requires intensive collaboration across organizational boundaries and hierarchies. The practice of knotworking has been developed and applied in the development of healthcare organizations, libraries and school-university relationships, but it has not previously been applied in the construction industry. In this paper, we describe the concept of knotworking and the findings of a case study that we completed in the Finnish construction industry. We will also compare the similarities and differences of the Big Room and knotworking in terms of participants, duration, target, space/infrastructure, benefits and challenges. Finally, we present some suggestions for further research and experimentation on knotworking in construction projects.

Keywords: Knotworking; design; collaboration; Building Information Modeling, Big Room, construction project

1. INTRODUCTION

The complexity of modern day construction projects has increased the need for more intensive collaborative relationships between designers than before. Collaboration is considered one of the critical factors affecting quality and preventing delays in the timetable for the design in a construction project [5]. Yet still, single designers often focus on tasks without sufficient integration into other designers' tasks in design processes [22, 4].

The adoption of the principles of lean construction (LC) developed in the 1990s [17, 2, 1, 18] has been an attempt to address some of the major shortcomings in the construction industry. LC refers to the adaption of the concepts and principles of the Toyota Production System (TPS) to construction, in which the relevant lean construction principles, tools and related practices were taken into use in construction [23]. The main principles of the LC approach are "just-in-time delivery" involving the reduction of waste, the provision of added value to the customer and continuous improvement in the flow of work completed by one team and handed over to the next team. A construction process organized in this way has been "achieved only by collaborative planning of all participants for each part of the work" [19].

LC is often used in parallel with building information modeling (BIM) in successful construction projects [19, 14]. Sacks and his colleagues [23] report on the high number of interactions between lean construction and the use of virtual modeling tools in present day construction. The implementation of 3D tools such as BIM is expected to improve the collaboration between designers by providing a smoother process for the entire project team [e.g. 5, 19]. According to Eastman and his colleagues [5], the use of BIM promises to enhance coordination among participating designers and contractors and reduce errors in the construction process. Conflicts between different designs and constructability problems can be identified and solved already during the design phase. The development of standards such as IFC (Industrial Foundation Classes) has enabled the exchange of technological information between different partners and made interoperability between their contributions possible.

Integrated Project Delivery methods (IPD) have been developed along with the development of BIM use to ensure collaboration. IPD is a project delivery approach that integrates "people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction" [13, p. 20]. IPD is claimed to build trust and common goals rather than competitive relationships between team members. Instead of each team member only aiming at maximizing their individual goals, team members also see the benefits of working on common goals [5].

Organizing "Big Rooms" is one application of IPD that has been created in large health care projects in the US [14]. In a Big Room, designers work side by side in the same place in order to share information with each other in a better way than working separately in different design offices. According to Khanzode and Reed, the goal of a Big Room is to create a work environment where the latency of decision-making can be reduced with intensive collaborative work. Working in a Big Room is more economical, because the design work can be coordinated effectively in the same space. Designers do not have to wait for postings to see what other designers are doing and they can get the information they need in their design work right away by asking a colleague sitting in the same room. Thus, the overall time is also shortened in the design phase [14, p. 193].

As a collaboration practice in construction projects, the Big Room is best suited for large projects involving such a large amount of work that designers can be employed in one project full time. Some construction projects are customarily smaller in Finland, so designers may work for several projects simultaneously. Thus, full-time commitment to a Big Room collaboration in a single project may be difficult.

Since the implementation of Big Room collaboration in Finland is challenging, a new type of collaboration practice has been developed and is currently under experimentation within a Built Environment Process Re-engineering (PRE) research program, which is part of the Strategic Centre for Science, Technology and Innovation of Built Environment Innovations RYM Oy. In this paper, this Finnish application of a Big Room collaboration aiming at improving collaboration between designers is called *knotworking.* The basic idea bears similarity to the Big Room: designers gather, in a planned or spontaneous manner, to work together in the same space. Differing from the Big Room, the collaboration in the same space is limited to critical, pre-agreed phases in the design process that will most benefit from the collaboration. Designers engage in this collaboration for a few days at a time; after this each designer is free to resume working on their respective projects in their own offices.

In this study we report the findings of a Finnish case study. How did the collaborative design work proceed during the knotworking sessions? What were the temporal steps of the design work? What was the division between independent and collaborative work during the knotworking sessions? What were the challenges and benefits of knotworking identified in the case?

We begin by describing the concept, the theoretical background and the previous development of knotworking. After that we present a case in which knotworking was applied in an early design phase of a construction project. This is followed by the presentation of our findings. In the discussion we compare knotworking and the Big Room, and finally we conclude with suggestions for further research.

2. KNOTWORKING AS AN EMERGENT TYPE OF COLLABORATION IN CONSTRUCTION

Construction processes involve phases and tasks that cannot be solved in a single organization, as integration of expert knowledge from various sources is needed. Knotworking is an alternative way of organizing work in processes that require intensive collaboration between subjects. In knotworking, groups of people, tasks and tools are set to work intensively for a relatively short period of time to solve a problem or accomplish a task. When the problem or a task is solved, the knot dissolves [8].

The concept of knotworking was created in the research and development of health care conducted in the Center for Research on Activity, Development and Learning (CRADLE) at the University of Helsinki [8, 10, 6, 7]. After its initiation it has been adopted to various projects internationally in educational and social sciences [e.g., 3, 12, 16].

The development of knotworking has taken place in the context of co-configuration, which represents emerging historical types of work, organization and production [24]. The characteristics of co-configuration are integrated product and/or service combinations, continuous relationships and mutual exchanges between customers, producers and products and/or service combinations, the customization of products and/or services over a lengthy period of time, and multiple collaborative producers operating in networks within and between organizations [6, p. 12).

The idea of knotworking is based on cultural-historical activity theory (CHAT) [9]. According to CHAT, human activity is object oriented and mediated by signs and tools. The concept of an object includes the purposeful target or goal of an activity that gives sense and meaning to an activity. For instance, knotworking differs from teamwork in that the continuity is connected to the objects of activity instead of team members [11]. Another thing worth noticing is that a tool does not refer to an artifact only but also to its various functionalities created during the genealogy of its use [20]. Furthermore, the adoption of new tools such as BIM causes changes in the object, including to the tasks of individual subjects and groups. However, the object of an activity is not given in a new situation but requires collective effort, problem solving and construction together in a community, in its rules and division of labor [21]. In this situation, a change of an activity generates and requires a new type of collaborating.

The main characteristics of knotworking involve ident ifying the phases of a project that requires knotworki ng and finding the right experts to accomplish the ta sk at hand. The task at hand usually involves proble m solving, but the solution is not necessarily simple. It requires a search for the cause of or reason for th e emergence of the problem. This means that particip ants are required to engage in the pursuit of assets a cross their organizational and disciplinary boundaries. Although knotworking is carried out as transient, intensive collaboration, it is not the same as having a meeting. Instead of merely coordinating their collaboration or exchanging initial data about it, designers assemble to create, e.g., necessary design solutions.

3. CASE – KNOTWORKING IN EARLY DESIGN PHASE OF A CONSTRUCTION PROJECT

Our research focused on the implementation of knotworking in drawing up early phase designs for a construction project. The early phase designs concerned a school community center located in Central Finland.

The knotworking intervention was prepared, with the help of researchers, by the designers and construction professionals responsible for the early phase designs. The designers determined themselves what type of initial data and pre-planning the knotworking intervention would require, and to a large degree also took care of producing these data before the intervention. Before engaging in actual knotworking, the participants met five times in total to plan the formation of knotworking groups, the requirements for the initial data, timetables, working methods, the necessary tools, objectives to be set for the design work, assessment tools for the design solutions, and the collaboration with the client and the end users.

In a two-day knotworking session, due to the large number of participants, it was decided that the group be divided into two. The knotworking groups consisted of designers from different disciplines, cost analysts, building information modeling experts, structural engineers and contractors' representatives. Both groups had similar expertise, but the participants in group 1 had been more actively involved in the preparation work for the knotworking intervention and knew each other better. The participants in group 2 did not know each other very well and had been less involved in the preparation work. Both groups had access to the same initial data, such as the initial options for the models produced by an architect, the client's requirements and the end users' wishes for the school community center. During the knotworking intervention, the groups worked on slightly different assignments in the facilities of different companies.

The assignment for both groups consisted on the one hand of producing design solutions that would first correspond to the client's requirements and to the wishes of the end users, and second, fulfill the requirements in the rules and regulations. On the other hand, the assignment was to analyze the newly created solutions from the point of view of costs, indoor temperature and consumption of energy to allow comparisons to be made between the different solutions suggested. In addition, the two groups created presentations of their solutions to be used as introductory material for the client and the users' representatives directly after the knotworking intervention was over.

The assignment for group 1 was to produce different design solutions for a new building of a school community center. The assignment for group 2 was to produce design solutions for the integration of a historically valuable building into the designed school community center. The options for the designs were 1) to create solutions in which all the functions and facilities would be located in the old, preserved building, or 2) solutions in which the functions and facilities would partly be in the old building and partly in the new one to be built next to it.

While working on the assignments, the groups were able to discuss issues with representatives of the client by phone. Also, the two groups could communicate by phone or email. The groups were allocated one afternoon and one morning to engage in the actual knotworking. The results were presented to the client's and the users' representatives on the afternoon of the second day.

The researchers observed the preparation for knotworking and the actual knotworking in both groups. They audio and video recorded the events, and additionally, made notes of their observations. The data of this paper consists of these recorded data. The data will be later transcribed for further analysis.

4. FINDINGS

How did the collaborative design work proceed during the knotworking sessions?

Both groups began working by first orienting themselves and then by jointly crystallizing their goal. Group 1, which had been active already in the preparation phase, was able to begin the actual design work a half an hour into the session. Instead, group 2 spent nearly two hours discussing what the focus was and what initial data were available for the design work. The problems were that one of the designers had not brought along sufficient tools and that one of the participants was opposed to the overly tight timetable.

"It cannot be done that quickly, it (costing) takes several hours."

In both groups, one of the group members was elected the leader of knotworking. The tasks of the leader included seeing to the timetable and ensuring that each member was doing the right tasks during the right phase. The leader also participated in the actual design work to a certain extent. In group 1, the role of the leader mainly consisted of seeing to the timetables and simultaneously developing the presentation of the final outcomes.

After the initial orientation session, both groups engaged in independent work and collaborative work. At first, each participant engaged in their own design or analysis work individually or in pairs. Once the work on a phase had reached a certain level, the group members interrupted what they had been working on and gathered together to go through and comment on each other's models, calculations of costs or analyses. At this point, the model, calculation of costs, etc. would be projected onto a wall to allow everyone to join in the discussion. Similarly to a traditional design process, the design work proceeded with the architect completing his model first. After this, other designers were able to start their design work or energy and cost calculations. Simultaneously, the architect was working on the next accommodation schedule.

Roughly half of the time was spent engaged in independent work and half engaged in collaborative evaluation and development of the outcome. The temporal phases and the division of time into independent and collaborative work are depicted in Figure 1.

Time	Phase: Group 1, day 1
30 min	Set up, deciding how to continue
1 h 30 min	Modeling
1 h 40 min	Presenting 2nd version
2 h 10 min	Modeling
2 h 30 min	Energy calculations of the first version
3 h 50 min	Modeling
4 h 30 min	Combining results, making a decision about 3rd version
5 h 30 min	Solving the problem of high temperatures
5 h 40 min	Presenting the results

Time	Phase: Group 2, day 1
30 min	Setting the target, delegating tasks
1h 20 min	Defining the premises of design and chosing the alternatives
2 h	Modeling
2 h 25 min	Presenting the first version
2 h 35 min	Checking the costs
3 h 30 min	Modeling of the next version
3 h 45 min	Checking the energy calc.
4 h	Presenting the next v.
4 h 45 min	Modeling continues

Time	Phase: Group 1, day 2
20 min	Set up, presenting 3rd version
1 h 20 min	Modeling, combining results
2 h 20 min	Preparing presentations
2 h 50 min	Checking results

Time	Phase: Group 2, day 2
40 min	Set up, deciding how to continue
1 h 30 min	Working
1 h 50 min	Checking the costs
2 h 00 min	Preparing presentations
2 h 10 min	Checking the costs
2 h 35 min	Preparing presentations

Collaborative work
Individual work
Preparing presentations

Figure 1 The division between independent and collaborative work during the knotworking sessions.

What were the benefits of knotworking and the challenges of knotworking to be further developed?

Certain *problems related to technical and data-transferring issues* arose. Transferring data directly from the model to the costing software or the energy analysis programs did not work. Instead, the cost accountant had to enter figures manually from a printed document into the costing program. Also, the person in charge of energy analyses had to draw up new accommodation schedules for the energy analyses. In addition to this, further problems were caused by the use of different types of space and their itemization and classification in different software programs. Also, the group would have needed a web-enabled data transfer method and a printer connected to the workstations. Files had to be transferred using memory sticks. Later, the groups began utilizing a Drop box service between the knotworking groups. This had not been agreed on at the beginning of the project, so issues related to how to use the service caused some confusion.

Different *challenges connected to the initial data and client collaboration* arose during the knotworking. As the design progressed, new issues emerged, and it became necessary to discuss these issues with the client. The client was able to be reached by phone and email, but due to the client's busy schedule, the replies at times were too late to be utilized in the design work.

The *schedule* for the knotworking was deemed too tight. On the one hand, the participants stated that working together made them put more effort into it and pick up the pace of their work. On the other hand, they acknowledged that the efficiency of *working required good preparation beforehand* and also, e.g., that everyone was aware of how to work as a group, how programs used by others worked, and what kind of data a cost accountant needs.

Another challenge faced was that knotworking *requires solid expertise in one's own job*. Also, it requires a positive outlook towards teamwork and an atmosphere of openness to others' opinions and the freedom to express them.

One participant stated during the feedback discussion that while it is interesting to work intensively in a group, it is *tough* and would be too demanding to continue as a full-time practice. The group agreed that a series of knotworking sessions would probably be most efficient: at times a group would assemble to work on a joint design object, and at other times the group would dissolve and get back to the traditional individual work in their own offices, and again later resume working in collaboration.

All in all, the participants thought that the pilot was a success and that collaborative design is the direction towards which to develop forms of design work. However, this *requires more learning about and development of the knotworking model.* The participants regarded the opportunity to learn from other's work as an advantage of knotworking.

> *"It was great to see what someone else was doing; one could quickly get a hang of the goals and needs of others working on it."*

All the designers were present at the same time, so the *information between the designers flowed* quickly, and each designer's competence in doing the work fed into that of others. For example, costs were evaluated together, allowing each expert to assess from their respective point of view the possible costs involved in a renovation project, for example.

During knotworking, the two groups, which worked for approximately eight hours each, produced and analyzed altogether six alternative solutions for implementing the project. It can thus be said that knotworking was very productive, and despite the short duration, the groups succeeded in their work well. It would have taken several days or weeks to accomplish this result following the traditional, individual form of working.

5. DISCUSSION

According to Khanzode et al. [15], the first phase of the Big Room coordination process is "getting the technical logistics right." The aim is to align the basic principles as to how, in what format and where the data will be stored. This enables an efficient distribution of electronic models and ensures that knowledge is available and useable by everybody.

At the preparation phase of the knotworking pilot, the participants discussed the technical demands it makes, such as which equipment or software will be needed and how the data are to be transferred. The responsibility for seeing to these preparatory tasks was divided between the different parties. The level of accuracy in the design work was fairly high, so no separate modeling instructions needed to be drawn up.

During the next phase of the Big Room, which Khanzode and Reed [15] (2008) describe as the "Kick off the coordination process," the difficult technical details arising from the previous phase are analyzed. To start off the knotworking day, working methods (e.g., how to transfer files, how the knotworking proceeds) were reviewed first with both groups, and later on in each group separately.

Khanzode et al. [15] present a detailed list of the order of design tasks for the next phase of the Big Room: "Establish the sequence of coordination." When following this list, the design work will proceed smoothly. In knotworking, the participants first agreed on, and later as the work progressed, specified the order of design tasks. They worked in overlapping phases in such a way that while an energy simulation engineer and cost accountant worked on the first model, the architect was drafting the next one. Overlapping design tasks in this way allowed everyone to work efficiently on the design.

The next phase in the Big Room involving "Manage handoffs between designers and detailers" was disregarded in knotworking due to the short duration of the planning session. Also, the scope of the planning session only concerned the planning of the start-up phase. In table 1, the similarities and differences between the Big Room and knotworking are summarized in terms of participants, duration, target, space/infrastructure, benefits and challenges.

Table 1 Comparison between Big Room and knot

	Big Room	**Knotworking**
Participants	Architects, engineers, general contractors and construction managers, but also design consultants, major trade subcontractors, and representatives of owners and end users including facilities managers, major tenants	The expertise needed varies in every knotworking session, often architects, engineers and construction managers
Duration	Troughout the construction project, permanent	2-3 days at time, temporary
Target	Designs of the construction project	Decided previously in a spontaneous critical designing phase
Space/Infra-structures	Stationary, fixed	Transient
Benefits	Working together in the same place Collaboration A good understanding of the costs, the ability to decrease costs	Information between the designers flowed quickly Very productive Learn from each other, the possibility to take part in multiple projects if needed
Challenges	Requires a full-time presence Requires a cultural shift, determination and the right attitude from participants	Problems related to technical and data-transferring issues because of the temporary infrastructure Requires good preparation beforehand Requires solid expertise and a positive view of team work Challenges connected to the initial data and client collaboration Tight schedule

6. CONCLUSIONS AND FURTHER STUDIES

New ways of organizing collaboration are needed in today's construction projects, which involve phases and tasks that cannot be solved in a single organization. The Big Room and knotworking represent potential candidates for IPD to support collaboration. In this study, we have described the idea and a concept of knotworking together with its theoretical background and previous developments. We have also presented how knotworking proceeded in an early phase of a design in a construction project. Furthermore, we have compared the similarities and differences of the Big Room and knotworking in terms of participants, duration, target, space/infrastructure, benefits and challenges.

The challenges of knotworking involved problems related to technical and data-transferring issues because of the temporary infrastructure of the knotworking space and the need for good preparation beforehand, the solid expertise of the participants and a positive view of teamwork. There were also challenges connected to the initial data and client collaboration. Furthermore, the tight schedule was a challenge. The benefits of knotworking related to the instant exchange of information between designers, the productivity of the work and its outcomes, and the possibility to learn from each other in a multidisciplinary team.

Knotworking requires, however, further research and development to become a finalized concept and practice. First of all, the essential phases of the research project requiring knotworking must be defined. Second, knotworking was introduced as a concept of collaboration suitable for smaller projects in which a designer works for several projects simultaneously. Therefore, whether a list of the essential elements of a coordination process can be created in knotworking in the same way as the Big Room needs to be studied. Importantly, knotworking represents a local approach that is able to be customized according to its use.

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