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BIM-based collaboration across organizational and disciplinary boundaries through knotworking

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Abstract

Knotworking is introduced as a new idea and an emerging practice for enhancing collaboration across organizational and team boundaries in BIM-based building projects. Knotworking refers to co-located 'knots' that are organized on a temporary basis to solve a specific task, a problem or an open question requiring multi-disciplinary expertise in a building project. The idea of knotworking was adopted and re-interpreted from elsewhere in a research and development program in the Finnish construction industry and experimented with in the early design of a school building. The aim of this study is to examine how the fragmentation of design and construction work could be reduced through knotworking in building projects. The methodology of the study is based on developmental and interventionist approaches in activity theory (Engeström 2014; Miettinen et al. 2013), according to which the developmental processes are carefully followed, analyzed and documented. Complex problems such as "waiting" and "decision-making" motivated the practitioners to experiment with knotworking in the program. The experimentation required thorough prior preparation in the development of knotworking. The new knotworking concept, using the best existing technology, enabled the creation of 15–20 energy solutions and cost calculations for five architect scenarios in a two-day knotworking workshop. The method was further tested in three other cases during the program, and it was presented to relevant stakeholders at several events.

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Keywords: activity theory; BIM-based building design; disciplinary boundaries; knotworking; multi-organizational collaboration; temporary teams.

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1. Introduction

Knotworking is introduced here as a new idea and an emerging practice for enhancing collaboration across organizational and team boundaries in BIM-based building projects. In knotworking, co-located 'knots' are organized on a temporary basis to solve a specific task, a problem or an open question requiring multi-disciplinary expertise in a building project. The stakeholders, specialists and experts required for conducting the task are invited to participate in a 'knot'. These 'knots' last usually one or two days, and several knots can be arranged during a project. After the task is accomplished, the 'knot' dissolves. The idea of knotworking was re-interpreted from previous health care projects (Engeström 2008) and adopted to a development program in the Finnish construction industry (Kerosuo et al. 2013). In this program, knotworking was experimented with in the early design of a public school, the object of which was to provide design alternatives for the client's decision-making. The new knotworking concept, used in conjunction with the best existing technology, enabled the creation of 15–20 energy solutions to five architect scenarios in a two-day knotworking workshop. Cost analyses were also provided for selected energy solutions in the workshop.

The purpose of knotworking is to address the problems caused by the fragmentation of design and construction work in a multi-project environment. The fragmentation arises from the spatially and temporally distributed character of the industry, with actors from different organizations working together in an adversarial context (Bresnen and Marshall 2000). The fragmentation of the industry is deeply rooted in professional practices and bodies of knowledge (Choccio et al. 2011; Dossick and Neff 2010). Practitioners are continuously balancing between the overall project goals in temporary teams and their obligations to their company goals and contracts and their pursuit of financial success (Dossick and Neff 2011). The implications of fragmentation manifest as quality problems, time and cost overruns, and extensive uses of resources to improve the defects resulting from poor performance (Baiden et al. 2006; Choccio et al. 2011).

The implementation of building information modeling (BIM) is expected to improve the collaboration in project teams (e.g., Eastman et al. 2011). Some studies show, however, that the problems of working together in design and construction teams have not decreased with the adoption of BIM (Volk et al. 2014). Fragmentation is still one of the main obstacles in the industry that has to be solved locally in each building project. Although BIM technologies enable tighter links between project participants, they remain organizationally divided (Dossick and Neff 2010).

The uses of different team integration mechanisms are also attempts to decrease the effects of fragmentation in design and construction teams. Construction project teams exist within their organizationally defined boundaries, and the degree of their integration varies according to the adopted team practices and procurement approaches (Baiden et al. 2006). Our aim is to explore how the fragmentation of design and construction work could be diminished through knotworking in temporary and multi-disciplinary teams. An experiment in knotworking in the early design of a public school is provided as an example. Firstly, we examine the challenges and gaps connected to the fragmentation of work in the previous literature of temporary teams. Secondly, we introduce knotworking by presenting its activity-theoretically based principles (Engeström 2008). Thirdly, we describe the methodology, the methods and the data of the study. Next, we provide our findings. After that, we discuss the advantages and challenges of knotworking on the basis of our findings, and finally, we make some conclusions on the possibilities of decreasing the fragmentation of work through knotworking in multi-disciplinary design and construction teams.

2. The challenges and gaps identified in the previous literature on temporary teams

Temporary teams function under constraints of high uncertainty and interdependence during a limited time. The functionality of the teams is dependent on their members' sets of diverse skills and knowledge sets. Goodman and Goodman (1976, 494) define temporary teams as constituted of "a set of diversely skilled people working together on a complex task over a limited period of time." Temporary teams are not separated from their contexts but function in their firm- and industry-based environments.

Gaps in the previous literature on temporary organizations and teams include the effects of the limited time of their existence, the functioning of the teams, the nature of the tasks and the characteristics of the contexts under which the teams are operating (Bakker 2010). The effects of limitations on time concern the processes, functioning, behavior and performance of temporary teams. Temporary teams are oriented by the demands of a situation, and they do not anticipate future interactions with each other beyond their imminent deadline (Saunders and Ahuda 2006). According to Bakker (2010), empirical research is lacking on the assessment of the task orientation demanded by a situation versus future-oriented relationship building in temporary teams.

The functioning of the temporary teams depends on their capability to resolve the issues of vulnerability and risks during their limited existence. Teams are vulnerable in the sense that their members must constantly interrelate with one another in order to meet their goals. The trust between the members has to be created swiftly in temporary teams (Meyerson et al. 1996). The issue of trust has already been addressed, but studies on the conditions under which interaction and co-ordination take place in temporary teams are still needed (Bakker 2010). Further research is also needed to chart the implications of multiple team memberships and the actors' embeddedness in multiple temporary organizations.

Temporary teams are often involved in conducting complex tasks (Meyerson et al. 1996). The complexity of the tasks has been examined in different fields of activity, but a more fine-grained picture of the tasks is needed in future research (Bakker 2010). From the perspective of this study it is interesting to understand the nature of the routines of temporary teams working on complex tasks. When team members are conducting routine or repetitive tasks, they know what to do beforehand (Lundin and Söderholm 1995, 441), but the situation can change when routines change.

Temporary teams do not exist in a vacuum but are connected with the environment in which they function. The relationship of temporary teams and their contexts has been examined on the level of firms and wider social contexts, such as on the level of industries (Bakker 2010). Challenges and gaps uncovered in previous studies involve topics such as learning from one project to another and the impact of a team's embeddedness in wider contexts. Although the importance of the exterior context has been highlighted in many studies, further research is needed on the conflicting loyalties of project participants towards the project versus their ongoing activities in their firm of origin (Bakker 2010).

3. The activity-theoretically based principles of knotworking

Knots can be considered temporary teams because of their changing memberships and the limited time of their existence. However, they differ from the definitions of temporary teams above in terms of their theoretical basis in cultural historical activity theory (also shortened to activity theory) (Engeström 2015, 2001). Engeström (2008) has defined the principles of the general idea of knotworking by adopting and re-interpreting the basic concepts of the activity-theoretical approach. The first principle of knotworking is the object orientation of an activity. In its activity-theoretical meaning, the object of a knot not only refers to its materiality but also to its motive or the purpose reflected in its material existence. According to Leont'ev (1978, 54), an entity becomes an object of activity when human needs and material-cognitive formations of the world meet. "[O]bjects/motives give directionality, purpose, and meaning to the collective activity" (Engeström 2008, 204). In contrast to task orientation (Goodman and Goodman 1976), an object of knotworking cannot be reduced to a single task or an item that can be acted upon, but it can be constituted of interconnected, often complex tasks (Engeström 2008, 66).

The second principle of knotworking is related to the concept of mediation in human actions and activity. According to Vygotsky's (1978) concept of voluntary action, human beings can regulate their actions by sign and tool mediation. Leont'ev (1978) extended the concept of mediation to involve social forms of activity such as the division of labor, community and rules. This means that a change of activity takes place through processes of re-mediation and socialization (Engeström 2001). For instance, the adoption of BIM could accelerate the process of re-mediation in building processes. But only few studies examine tool mediation in the construction industry, although research on tools and technologies is currently urgently needed (i.e., Whyte et al. 2008; Dossick and Neff 2011).

The third principle of knotworking concerns the mutual constitution of actions and activity. Leont'ev (1978) made a distinction between a collective object-oriented activity and goal-oriented individual and group actions and their components, which are automated operations. The literature on temporary teams usually focuses on the issues taking place on the levels of teams or organizations (Bakker 2010). Instead of having clear divisions, the levels of an activity are co-constituted. However, the analytical distinction between different levels is useful for studies on the development of an activity, for instance, the development of a new kind of activity through future-oriented planning and visioning.

The fourth principle of knotworking directs us to study contradictions as sources of change. Contradictions represent historically accumulated tensions between opposing forces in an activity (Engeström 2001). Contradictions are not explicitly discussed in Bakker's (2010) extensive review on temporary teams. Yet the discussion on participants' conflicting loyalties towards the project versus their membership in their own organizations suggests that such tensions may still exist. The issue of change is another topic that, according to Bakker, is not discussed in previous research. The study of technological change would presumably be urgently needed in the construction industry. The development of technologies and the organization of their use have different temporal dynamics (Perez 2002). The full deployment of new technologies such as BIM requires changes in various collaborative practices and in the conduction of routine tasks.

The fifth principle of knotworking concerns the different historical layers of an activity and their emergence in actions and operations. The fourth and fifth characteristics of knotworking are intertwined because contradictions emerge as systemic tensions embedded in and between historically layered and embedded human activities. The prevailing routine tasks and ways of working inherited from different historical periods of construction work can be being performed as new types of work simultaneously emerge. The development of knotworking is connected to a new historical type of work called co-configuration (Engeström 2008). The characteristics of co-configuration involve integrated product and/or service combinations in continuous relationships and the mutual exchanges of different players and customers. Multiple producers operating in networks within and between organizations customize products and/or services over a lengthy period of time.

4. The methodology, the methods and the data of the study

The idea of knotworking for BIM-based building projects was created during a seminar organized by the Model Nova work package in the Business Project Re-engineering (PRE) program (Kerosuo et al. 2013). Two meetings with the potential client and four planning meetings related to the knotworking experiment followed the seminar during the spring of 2012. The idea was experimented with in an early design phase of a school building in central Finland in May of 2012. The aim was to provide alternative plans to support the client's decision-making early in the design. A variety of representatives of the client, users, contractors, architects, structural designers, mechanical and plumbing planners, energy specialists, BIM experts as well as the researchers participated in all the phases in the development of knotworking. The participation of the actors was voluntary in all phases.

The methodology of the study is based on developmental and interventionist approaches in activity theory, according to which the developmental processes are carefully followed and documented (Engeström 2014; Miettinen et al. 2013). The collaborative use of BIM through knotworking is an open-ended process and under construction. A methodology is needed that allows the problems, conditions and progression in its development to be examined and clarified. The method of the data collection followed the ethnographic principles of participant observation (Hammersley and Atkinson 1983) during the entire process of the adoption, planning, experimentation and introduction of knotworking in the construction industry. The present author together with her colleagues[1] conducted the fieldwork and gathered the data throughout the process. The researchers' participation in the PRE program as partners naturally granted access to the locations of the activity. However, the degree and the quality of the researchers' participation varied in different events and situations, from being active participants as co-developers/facilitators in the Model Nova seminar and knotworking experiment to being observers of the knotworking workshops and co-presenters of knotworking to the industry stakeholders. The data includes approximately forty-two hours of audio- and video-recordings as well as project documents and researchers' notes.

The method of analysis focuses on 'critical events', which are critical phases of the process of developing knotworking. The phases of developmental research (Engeström 2014, 253) are used to make sense of and guide the analysis of the critical transitions in the study. The critical transitions are (1) the new object of collaboration

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[1] PhD students Teemu Lehtinen and Anne Kokkonen from Aalto University together with the author collected the data at the Model Nova seminar. Project Manager Tarja Mäki and Jenni Korpela, M.Sc. (Eng.), from the University of Helsinki together with the author collected the other data.

motivated by the problems of waiting and decision-making, (2) knotworking presented as an idea of collaboration to be experimented with, (3) the re-configuration of tools and practices for the knotworking experiment, (4) the decreasing of the fragmentation of design work across organizational boundaries in the knotworking workshop, and (5) knotworking introduced as a new BIM-based collaboration method in the construction industry.

5. Findings of the study

5.1. The new object of collaboration motivated by the problems of waiting and decision-making

The effects of limitations on time for temporary teams have been described as multiple and complex (Bakker 2010). The purpose of knotworking is to compress the process of design to fit the time scheduled for it in a building project. Instead of a sequential chain of different meetings, the experts and specialists form a knot to work on objects of activity requiring intensive collaboration across organizational and disciplinary boundaries.

The emerging object of design and construction was motivated by a discussion related to the problems of waiting and decision-making in design and construction projects. The discussion took place in a small group session in a seminar organized by the Model Nova work package in February 2012. The complex and intertwined nature of the problems made their solution difficult. Everyone was doing their tasks, but the problem was that they had to wait for others to be ready before they could start doing their own tasks.

Because the problems seemed to extend over the entire design and construction process, a small group of participants began to plan a BIM-based process that would build on a new concept of collaboration. Waiting for colleagues from different design disciplines to complete their tasks was a general problem that had become urgent in recent BIM-based projects. The problem was related to the misalignment of different design tasks and the lack of an overall object and shared goals in the design activity. The problem was also connected to the wait for the client’s decisions in the building projects. The idea of knotworking, initiated by a researcher, started an effective process of ideation, during which the new collaboration practice was created as a solution to the problems.

5.2. Knotworking presented as an idea of collaboration to be experimented with

The HVAC designer presented the idea of knotworking to the other participants of the Model Nova seminar. The Model Nova work package was able to organize a knotworking workshop in which designers worked together for one or two days in order to test the idea of knotworking in a real case. The case that the HVAC designer suggested was a school project. The goal of the workshop would be to produce design alternatives for the client’s decision-making early in the design process. The HVAC designer envisioned the idea of knotworking in the following way.

HVAC Designer: “Instead of having meetings in which they are waiting for the decisions, the experts and specialists form a knot for making decisions. A knot may last from one to three days. The goal of the first knot is to produce a requirement model, and at least the user, architect, energy specialist and life-cycle specialist would need to be present. An HVAC designer and cost calculation specialist would also be present depending on the task. The final outcome of the alternative knot will include target prices, life-cycle costs and perhaps e-figures, schedules, goals etc. As an outcome, the knot provides essential information in an agreed format. The development of tools is required to achieve these [results] during the knot. After the knot, when, for example, the requirement model has been produced, a committee evaluates the results and selects one or two of the alternative solutions or asks the knot to start from the beginning if it is not satisfied [with the outcome]. (…) What is totally different compared to the present model is that only certain closed targets are defined at the beginning of the process (...). As a result, the outcome may be quite different from what was initially imagined” (February 1, 2012).

5.3. The re-configuration of tools and practices for the knotworking experiment

Members of the Model Nova work package decided to test the idea of knotworking in the design of the school. The city planning office representing the client agreed to engage in the experimentation. The participating firms assigned an interdisciplinary group to the experiment. The group of experts and specialists from different firms, companies and universities represented contracting, architecture, different design disciplines and research. Some members of the group had already participated in the ideation of knotworking in the Model Nova seminar, but others were newly invited to join the experiment. The task of the group was to plan and prepare to carry out the experiment. The planning and preparation emerged as a process of re-mediation during which the purpose and goals of the workshop were clarified, tools were selected, their use was re-configured, and the action plan for the workshop was created.

Four preparatory meetings were organized during the spring of 2012. A list from previous design projects was used for the definition and collection of the basic information. The interoperability of different software was ensured for the workshop. The technical process involved architectural design, the visualization of architectural solutions, energy design, and the calculation of the building costs. The architect's design was based on the space program and the mass model that would be used for the creation of technical designs and cost calculations. The energy design contained the requirement model of HVAC-E designs and energy simulations. The calculation of building costs was based on the listing of spaces from the architect's space model. The technical values and models were combined with performance indicators to enable the calculation of the building's life-cycle costs. The definition of the terms and indicators was also necessary in order to verify that everyone understood them in the same way.

The schedule and the proceedings of the knotworking workshop were described in the action plan. Researchers acted as facilitators of the planning meetings and the knotworking workshop. They also interviewed the client and the users of the school building in order to chart their needs. Besides the needs related to the school, both the client and the users emphasized various community uses of the building after school hours.

5.4. Decreasing the fragmentation of design work across organizational and disciplinary boundaries in the knotworking workshop

The two-day knotworking experiment was organized on May 2012. The workshop started in a session for discussing the aims and schedule of the two-day experiment. The different parties explained their starting points and presented the tools that would be used in the experiment. The city planner introduced the plans of the school building. The community members inquired about the available heating solutions for the building and provided information about the village. After the session the architects and designers started to work on their assignments.

The knotworking workshop is one solution to the contradiction between fragmentation and integration in temporary teams. The idea of a "swing"[2] explicates the logic of collaboration in the design process. A swing started with an architect delivering his model to the design engineers and the cost calculation expert. The design engineers prepared energy solutions, and the cost calculation expert provided calculations of the building costs for selected energy solutions. The architect worked on the second architectural design in parallel with the design engineers and cost calculation expert, who were working on the first architect's model and related tasks. After each swing, the architect, design engineers and cost calculation expert discussed the analyses and calculations together and improved the designs and calculations if necessary. They also decided together how to proceed with the designs and calculations after each swing. The information-modeling expert included in the group worked on a template for presenting the design solutions to the client and the users.

A feedback session was organized for the architects' and designers' presentations of the alternative designs and calculations to the client and the users at the end of the second day. The workshop was considered successful, and despite the short time, the quality of work was considered good. The users and the client participated in the session by raising questions and commenting on the alternative design solutions. The users asked for clarifications related to their use of the building (the size of the gymnasium, space for theater performances, etc.). The client was interested in the evening use of the building as well as the heating solutions. The client and user involvement was, however, low in the knotworking experiment and requires further development in different phases of the building process.

The practitioners and researchers evaluated the workshop after the feedback session. Conflicting loyalties as effects of multiple memberships were not observed in the multi-disciplinary group. The participants considered knotworking an opportunity to receive immediate feedback from others to open questions. Knotworking was

[2] Dr. Jiri Hietanen presented the idea of a "swing" (*pyöräytys* in Finnish) in the seminar of February 2012.

effective for learning to understand the goals, information needs and working methods of other disciplines. However, problems arose in the data transfer between the architectural model, energy simulation and cost calculation. The cost calculation methods and tools also required further improvement. Although the schedule of the workshop was assessed as being tight, the designers and experts working together enabled accelerating the pace of the work.

5.5. Knotworking introduced as a new BIM-based collaboration method in the construction industry

The method of knotworking was introduced as one of the key results of the PRE program in the industry. Knotworking is described as a flexible collaboration method for mastering unstable objects and fragmented processes in construction. It speeded up the decision-making and enabled the different parties to commit themselves to the achievement of a common goal. The method was tested in three other cases during the program, and it was presented to relevant stakeholders in several events. Key participants profiled themselves as promoters and pioneers of the new practice when they were presenting the achievements of the experiment. The participants from these companies have become independent developers of knotworking.

6. Discussion

In this section, we discuss the advantages and challenges of knotworking related to the issues of time, 'knots', the nature of the tasks and the relation of a knot to its larger context. The efficient use of time during selected periods through co-located working seems to be an advantage of knotworking for making an overall project more effective and finished in a shorter time. According to the participants of the knotworking, achieving the same results as the ones in the knotworking experiment would have taken two to three weeks. However, no other calculations regarding the costs and effectiveness of knotworking have been made; more cases are needed to accomplish these calculations.

The assignment of the right experts is an ordinary problem in design and construction projects (e.g., Bakker 2010). The same problem concerns the knots. It was easy to recruit participants to the knotworking experiment because the participants of the Model Nova work package were experts in their field or able to recruit new ones. Finding suitable experts may be a challenge in future knots because their 'rightness' depends on the task of the knot, and the 'right' experts may not be assigned to the project group.

The nature of task complexity is often brought up as a challenging feature of temporary teams (Meyerson et al. 1996; Bakker 2010). In our study, the tasks themselves were not necessarily complex, but they were intertwined in a complex way during the design process. The participants co-created the idea of a "swing" to solve this problem for early design collaboration. The new logic of collaboration embedded in the idea also supported the solution of open questions not easily solved in BIM-based projects (see for comparison Dossick and Neff 2011).

The larger context of knotworking and the aspects of the changes caused by the digitalization of work were not analyzed in this study. The digitalization of work related to the adoption of BIM in the construction industry is still an urgently needed research topic. Many challenges related to the structuring of work and collaboration as well as work practices need to be solved in order for BIM to be an effective tool in the industry.

7. Conclusion: Knotworking as a possible method for decreasing the fragmentation of work in temporary teams

The challenges related to the fragmentation of multi-disciplinary collaboration in design and construction teams can be improved through knotworking. The transformation of the idea of knotworking into practice demanded experimentation and careful planning of the tools and procedures in our study. The concept of an alternative knot became gradually "defined" during the planning and presenting of the knotworking experiment and its results to the relevant audiences. The participants started to develop their own versions of knotworking as part of their service palette. However, the organization of a new kind of knots in other phases of the design and construction process is still open and requires continuous development.

The object of activity is important in the process of knotworking because the process of object formation is connected to the motives, purpose and goals of the design and construction activity. A lack of common goals hinders the effective performance of both temporary teams and knots. Simultaneous membership in a knot and a firm or a company may also restrict the effective performance in a knot. However, there is no general recipe for solving the tension; it needs to be solved locally in each building project. As a consequence, employees are not only the providers of project outcomes, but they also become planners for multi-disciplinary collaboration in local projects.

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