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Knotworking and the visibilization of learning in building design

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Abstract

Purpose – This paper aims to study the visibilization of learning in the context of developing a new collaborative practice, knotworking, in building design. The case under study describes the process of learning from the initiation of knotworking to its experimentation. The implementation of new building information modeling tools acted as an impetus for this development.

Design/methodology/approach – The research is based on activity-theoretically oriented ethnographic research. The four analytical steps created by Engeström (1999) for analyzing the expansive visibilization of learning are applied in the analysis.

Findings – The envisioning of the idea of knotworking involved the first and the second steps of visibilization. First, a flowchart made the ideal process of design visible and triggered a discussion on the problems and requirements emerging in the project members' work. Second, an idea for a new type of collaboration was introduced as a solution to these problems and requirements. Planning the knotworking experiment and explicating the associated design instruments involved the third step of expansive visibilization. The fourth step of visibilization took place during the experiment of knotworking in a design project.

Practical implications – Two other knotworking projects have already been conducted, and plans have been made to commercialize knotworking in building design. New technical tools have been developed for energy calculation and the comparison of alternative design requirements.

Social implications – Knotworking can improve the collaboration between designers with positive implications on the quality of a building design process.

Originality/value – Development and learning are studied as a longitudinal process in the construction industry.

Keywords Development, Collaboration, Building design, Cultural-historical activity theory, Expansive learning, Knotworking

Paper type Research paper

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Introduction

Knotworking refers to the "tying, untying and retying of separate threads of activity" (Engeström *et al.*, 1999, p. 346). Thus, the combination of actors constantly changes according to the requirements of the task, which includes improvisation instead of fixed rules or procedures and has no single actor with fixed authority (Engeström, 2008). Knotworking has been articulated in activity-theoretical projects (Engeström *et al.*, 1999; 2003) with the aim of improving the care of patients with multiple health problems in Finland. In these projects, medical experts utilized their specialized knowledge to solve problems identified in the organization of the care provision. The idea of knotworking has been applied in other studies of inter-organizational collaboration in settings such as the defense sector (Blackler and McDonald, 2000), city planning (Kangasoja, 2002), school–university relations (Fenwick, 2006), the construction industry (Bishop *et al.*, 2009) and libraries (Engeström *et al.*, 2012).

We will study the development of knotworking in inter-organizational and inter-professional collaboration in Finnish building design. Today's building design requires multiple experts whose specialist knowledge needs to be integrated to fulfill the demands of quality, sustainability and cost-effectiveness. The implementation of 3D tools such as building information modeling (BIM) is expected to improve the integration of expertise between designers (Hardin, 2009). BIM represents a simulation consisting of 3D models with links to all of the required information needed in the planning, construction and operation of buildings (Kymmell, 2008, p. 28). Proponents of BIM attest that the integration of information can be controlled technologically in a digital format between experts (Hardin, 2009; Succar, 2009). However, the development of social processes of collaboration is also needed. Knots enable the crossing of organizational and expert boundaries that easily prevent collaboration between designers representing different design disciplines (Dossick and Neff, 2010).

From the perspective of learning, the development of knotworking represents a lengthy process involving the participation of different occupational groups and stakeholders. The ongoing mix of contributors brings about discontinuity and destabilizes the knowledge, practices and relationships in the normal regulation of inter-organizational collaboration (Blackler and McDonald, 2000; Fenwick, 2006). As a consequence, actors have to struggle to make sense of unfamiliar situations when dilemmas, tensions and context-bound contradictions are found in the activity. Expansive transitions of a new type of collaboration can emerge when the actors solve the problems, tensions and contradictions in their activity (Engeström, 2001).

In our case, learning is related to the development of the "new" BIM-based collaboration, i.e. knotworking in early project design. The case here describes the process of knotworking from its adoption to its experimentation in building design. Learning and knowledge sharing usually take place in an informal and *ad hoc* manner during the accomplishment of the work itself in the construction industry (Bishop *et al.*, 2009). How to make the learning visible becomes a problem that needs to be solved in practical research.

The context of the study is the Finnish Built Environment Process Re-engineering (PRE) program[1] and its Model Nova work package www.rym.fi/en/, in which representatives of nine industrial partners together with researchers from two research institutes have developed new procedures and business models for the real estate and construction sectors. In this program, the use of BIM is examined from different

standpoints. The current study of knotworking is a part of a larger study carried out by the CRADLE research group[2] in which the researchers focus on BIM use during different phases of a building process by applying qualitative research methods and ethnography.

The historical and institutional setting of knotworking examined in this paper differs from the knotworking described at the beginning of the introduction (Engeström *et al.*, 1999; 2003). Bishop *et al.* (2009) characterize the construction industry as a setting ruled by institutional conflict and even hostility in which actors are easily driven apart instead of being pulled together. On the other hand, the multi-project partnership arrangements taking place in this industry can support the repeated arrangement of improvised knots through the continued collaboration of the contractors. A project-based work context is also an ideal location for a coordinative center for working. Although the case examined in this article is located in the AEC industry (in the architecture, engineering and construction industry), it was carried out in a developmental context. As the development of the industry was the main purpose of the activity, the experiment may have had more freedom to act in relation to the competitive culture of the industry.

Our research task is threefold: first, we examine the envisioning of knotworking in the project group; second, we study the planning of the knotworking experiment and the explication of the associated design instruments in a series of planning meetings; and third, we analyze the content, procedure and results of the knotworking experiment. In carrying out the research tasks, we will focus especially on which dimensions of collaboration are made visible during the process of learning.

The activity-theoretical approach and the main concepts of the study

The theoretical approach of the paper is based on the cultural-historical activity theory initiated by Vygotsky and Leont'ev and developed further by Engeström. In activity theory, human activity is understood as mediated by an object, instruments (i.e. signs and tools) and a community, including that community's rules and division of labor. An object of activity is material as well as ideal, and given and projected (Engeström, 2001). The motive of an activity is formed when human needs meet the material object. The level of an activity is distinct from the actions and automatic operations that realize it. An activity is object-oriented, and different activities are distinguished from each other by their objects. Actions are carried out by subjects and connected to a collective object through goals and operations directed by the circumstances and tools at hand. Activities are not stable entities but open to changes that emerge as tensions and contradictions in and between the elements of an activity system. The activity-theoretically derived concepts of "mediation", "object", "instruments", "activity", "action" and "expansive learning" are used as resources in the analysis.

The choice of the activity-theoretical approach was natural in this study because the industrial partners and researchers used the concept of an activity system to connect the dispersed relations of the subjects, tools, objects, communities, rules and the division of labor of the participants involved in knotworking. The overall object of the design activity was emphasized during the process when the participants regulated their actions according to the frame of the overall design object instead of only according to the perspectives of their disciplines. The role of new 3D tools was also critical in our case during the knotworking experiment.

The visibilization of work activity is often studied as the linear or socio-spatial dimensions of work (Engeström, 1999). The linear approach refers to processes of workflows that are often visualized as flowcharts (as was also the case in our study), whereas the socio-spatial approaches focus on the situational aspects of work. According to Engeström, the problems of the linear approaches relate to the lack of a horizontal dimension of work that emerges in parallel tasks and actions. The socio-spatial dimension of work is often made visible in detailed ethnographies of work situations, but successful descriptions of the drivers of the action are lacking.

The social aspects of work are often tacit in construction and often only become explicit when some aspect of work is changing. For instance, the prevailing structures and practices of work seem to become explicit when they are altered during the use of new digital tools (Harty and Whyte, 2010; Dossick and Neff, 2010). However, the developmental dimension of change emerging during the use of new tools often remains implicit at work and in its studies. Following Engeström, linear and socio-spatial visibilization can be seen in a broader developmental perspective. The developmental visibilization of learning enables the study of learning as a longitudinal and potentially expansive process.

Expansive learning focuses on qualitative transformations of work and enables the visibilization of learning during the process of development (Engeström, 1999). Expansive learning highlights developmental contradictions, tensions and multi-voicedness as energizers of collaborative object construction and learning. It takes place when a group of people (i.e. subjects) engages in a process of analyzing contradictions and creating solutions for them. The solutions to the contradictions are often new models of an activity that can be experimented with, implemented and disseminated. Contradictions between the old, familiar activity and the new model of an activity usually emerge during the process of experimentation with and implementation of the new model. The dissemination of a new activity for its part causes contradictions between the renewed activity and other activities in the network of activity systems.

In the case focused on here, learning the new type of collaboration was intertwined with its development. The developmental context of learning differed from a stable work situation, as the participants struggled between the familiar and the new, emerging design activities (Blackler and McDonald, 2000). The creation of the new kind of collaboration required the familiar ways of collaboration to become visible to the collaborative partners during the process of development. The participants involved in the configuration of knotworking were working outside their established organizational practices, and they needed to negotiate the nature of their tasks. Collaboration therefore occurred as tasks were recognized and analyzed as well as during the processes of responding to them (Edwards and Kinti, 2010, p. 126).

Data and methods of the study

The idea of knotworking for building design was created during a seminar on the Model Nova work package in 2012. Three planning meetings related to a knotworking experiment followed the seminar during the spring of 2012. The actual case chosen for the project represented an early design phase of a school community center in mid-Finland. During the process, the knotworking type of collaboration was adapted to building design to provide alternative plans for a client's decision-making with the help of new information technology (BIM). The experiment was carried out in May 2012. The

structure, procedure and the number of participants are included in the presentation of the findings. The participation of the actors was voluntary in all phases of the development of and experiment of knotworking. The city authorities and representatives of the school and town joined the experiment through negotiation and enrollment.

The methodology of developmental ethnography (Kerosuo, 2006) guided the research on the emerging forms of design collaboration in this study. The present authors conducted the fieldwork and gathered the data through participant observation. They observed the process of knotworking from the introduction of the idea to the end of its experimentation phase. As the authors are partners in the research program, access to the scene of action was naturally granted to study the transformation of work during the implementation of 3D technology in practice. However, the degree and quality of their participation during the process alternated in the different events and situations from being "an active participant, more or less in equal terms with other participants" to being a "professional stranger" or an "observing participant" whose main interest is to study the specific setting (Alvesson, 2009, p. 159). As active participants, the researchers identified the problems and challenges of current design practices and conducted initiatives and interventions as equals to the industrial members of the endeavor. During the planning and realization period of the knotworking experiment, the current authors were assigned to be facilitators as well as observers in the process.

The data of the study include the audio-recordings of one working group's meetings and general discussion presenting the group's work during the seminar (altogether 9 hours 30 minutes), the audio-recordings of three planning meetings (altogether 6 hours and 30 minutes) and the audio- and video-recordings of the knotworking experiment (altogether 20 hours). Photographs, project documents and the researchers' notes were also included in the analysis of the data. Ethical principles and good scientific practice according to the Finnish Advisory Board of Research Ethics have been applied in the study.

The analysis of the data started with listening to the audio-recordings and watching the video-recordings. Content memos were created of the audio-recordings of the seminar and the video-recordings of the knotworking experiment. The planning meetings were transcribed verbatim. The four analytical steps created by Engeström (1999) for analyzing the expansive visibilization are applied as analytical tools in the analysis. According to Engeström, *the first visibilization step* involves making the disturbances and innovation visible and analyzable to the practitioners and researchers. The idea of *the second visibilization step* is to engage the practitioners and researchers in an analysis that connects seemingly random incidents with contradictions in the activity system. *The third visibilization step* relates to the actual design of new actions and associated artifacts. *The fourth visibilization step* concerns the implementation of the designed new actions and the intended and unintended consequences of the implementation.

The findings of the analysis are rendered in a case narrative documenting the events of the developmental process in temporal order. The plot of the ethnographic description is divided into phases of envisioning the idea, planning the experiment and carrying out the experiment of knotworking in a two-day session.

Envisioning knotworking for the collaboration of design experts

The Model Nova project group created the context for the initiation of knotworking during an intensive seminar in 2012. The aim of the three-day seminar was to develop a BIM-based collaborative process to be implemented from the initial planning of the project to the end of the warranty period of the building. Three different sub-groups worked on the topics of decision-making, the ideal process of collaboration and value creation during the seminar. Altogether 33 participants from different organizations represented the property owners, project consultancy, architectural and structural design, MEP (mechanical, electricity and plumbing) design, information modeling, contractors and researchers. The program of the seminar consisted of joint sessions and group work. The group had already worked together for more than one year with the aim of producing a novel business model and an operating culture for the built environment that would exploit BIM.

The idea of knotworking was envisioned in the sub-group focusing on the development of the project collaboration between different design partners. Two researchers from another research institute facilitated and documented the seminar, whereas the first author of this paper assumed the role of an observing participant. The first and the second phases of visibilization were realized during the phase of envisioning the knotworking. The discussion was mainly future-oriented and directed by the search for new solutions in both phases. The generic model of an ideal BIM-based building process created in the Model Nova group's previous work was taped on the wall to direct the work of the sub-group. The ideal process was visualized in a flowchart, and it acted as an instrument of linear visibilization in the work of the sub-group (Engeström, 1999, p. 64). During the first phase of visualization, some errors, problems and ideas were identified and written on post-it notes or a flipchart, but they were not analyzed in depth. For instance, clients' needs, the juxtaposition of needs and costs and the usefulness of modeling for the clients were discussed.

The HVAC designer compared the ideal collaboration process to a Big Room and suggested a Finnish application of the Big Room concept. A Big Room is a current method of organizing collaboration among designers. In a Big Room, the client, architects and designers work side-by-side in the same place during the entire building project (Kanzode and Reed, 2008). The proximity of the workspace brings many advantages, such as the ability to share information instantly with the project partners.

The group members started to ask questions and share ideas about the HVAC engineer's suggestion. The process seemed to move suddenly to the level of developmental visibilization. The organization, participants and costs of the process were discussed. Group members asked which BIM models, what kind of other instruments and what kind of information would be needed in the process. The production of information would require some of the design disciplines to make changes, such as in the timing of their work procedures. Yet still some doubted whether a Finnish-style Big Room could develop into an applicable solution.

The contradictions of the collaborative activity were not explicitly analyzed in the developmental process. Instead, the idea of a Finnish version of the Big Room connected the diverse ideas of the participants into an idea of knotworking. The idea was pushed forward by an initiative made by the observing participant researcher. This initiative is considered here to be a landmark of the second phase of visibilization because the

discussion on the initiative connected the various purposes, goals and ideas into a coherent idea that could be explicated in a concrete way.

The idea of knotworking became an object and motive of the developmental process. The group members used the model of an activity system to create a knot to use for generating alternative design solutions. They called the outcome of the model, the "alternative knot" or "requirement knot". This knot was a new idea in the design and construction process compared to the prevailing design practices in that the architect and design engineers would work intensively together for a short period in the same space and then return to their own company. Working in the same space would enable the effective sharing of information, ideas and technical details during the knotworking session.

The group presented the idea of knotworking to other groups in the final session of the seminar. Some participants were critical, but others were in favor of the idea and started to co-design the model of knotworking. One design engineer proposed an experiment of knotworking in a school project. The designer organized a meeting with the city authorities in which the experiment was negotiated. The representatives of the city accepted the proposal, and the city architect provided the requirement report of the school as well as the information on two alternative building sites reserved for the school project.

The planning of the knotworking experiment and the explicating of the associated design instruments

The third visibilization step took place in four planning meetings in which the specific actions of the "alternative knot" were realized. The participants of the experiment were architects, contractors, energy specialists, HVAC design engineers, structural engineers, a cost calculator, representatives of property owners and researchers from two research institutes. Many of the participants had already participated in the Model Nova seminar and were familiar with the idea of knotworking. The number of participants varied between 17 and 21 in the three meetings. In one meeting, seven members of the planning group were assigned to design and specify the technical tools to be used in the experiment.

The purpose of the knotworking experiment was to provide information for the client's decision-making through the analysis of requirement of two alternative lots reserved for a school building. An old, historical building that could be renovated for school and community use was located on one of the lots. The other lot did not have any buildings. The aim of the experiment was also to consider the needs and ideas of the community. The lack of discussion of the client's and end-users' demands and needs often became a problem that hindered the proceeding of the building process. Discussing these issues were considered to be a "Pandora's box", the opening of which would be a huge challenge. In the planning group, some participants considered, however, that juxtaposing the needs and available financial resources with the building regulations and requirements would ease and speed up the entire building process.

The researchers interviewed the six voluntary representatives of the client and community to include the client's and end-users' perspectives in the design process. The findings of the interviews presented *the community-centered perspective* emphasizing the need to have a school building that could be used as a center of community activities (e.g. sports, theater performances, meetings). *The client view* included the ideas of the

city school system that stressed the purpose of building a daycare center, a preschool and a school. However, the building could also be used after school hours for community purposes.

The planning group worked on the list of basic information needed in the knotworking session during the first and the second meetings. The contents of the list included the information created by the city planning department, the examination of the soil, the parking and traffic conditions in the community and the available heating and plumbing solutions. The initial architectural models, energy simulation models and key figures for evaluating alternative design solutions were not yet available and had to be acquired and prepared for the experiment. In the first meeting, the parties with the responsibility of equipping the experiment with tools were decided, and they completed their work by the fourth planning meeting. In the fourth meeting, one of the design engineers, an energy specialist, explained how the energy calculations would be tested and what instruments would be used in the knotworking experiment. Another design engineer defined the instruments and the methods of cost calculation. Two building information-modeling experts presented an instrument in which the key figures of different alternative design solutions were integrated for the client's decision-making.

The idea of knotworking was re-examined and specified as the experiment proceeded. Quite soon it became clear that knotworking would not be limited to one period of working intensively in one space but was a process that involved the preparation and re-tooling of sessions, working between the sessions and reassembling for a session when needed. It was important to have clear goals for each session that were known to all participants of the knot.

Planning the schedule and working process also made the idea of knotworking visible. The "draft" of a schedule included a joint session with the client and end-user representatives and the participants of the knot in which the aims, instruments and expected outcomes were presented. After that, two design groups would be working in two different spaces. Several design solutions would be created over two days. These solutions would be presented to the client and the end-users at the end of the second day for discussion.

The contents, procedure and results of the knotworking experiment

The two-day knotworking experiment represents the fourth step of visibilization described by Engeström. The experiment started with a shared session in which the aims, contents and working method of the experiment were explained to two representatives of the client (i.e. city authorities), one representative of the school and two community members. Sixteen members of the two design groups that would work in the requirement knots and eight researchers from the two research institutes were present. The different parties explicated their general starting points in the experiment. One of the researchers presented the document files provided to the design groups to make sure that all relevant information was available. She also showed photographs of the two building sites and of the old building on one of the sites. The city planner summarized the present status of the plans for the school in the decision-making process of the city council and administration. The architect and the energy specialist presented the methods and instruments that would be used in the experiment. The first architectural designs for the two alternative lots were presented as well as one optional energy solution for the architectural designs. The idea was to provide many alternative

solutions for each architectural design. The key indicators of the different architectural designs, the energy solutions and their estimated costs would be presented to the representatives of the client, the school and the community on the following day.

The architectural designs and energy solutions raised a lively discussion among the participants. The community members actively commented on the plans for the space. For instance, the school gymnasium was too small for some of the ball games practiced in the hall. They had also some views on the use of the space of the old building and information on local energy solutions. The representatives of the city authorities emphasized the purpose of the shared use of school premises in surrounding communities. Although the functions of and regulations for education directed the planning of the schools, some purposes of community use were also able to be considered. For instance, the gymnasium could be bigger than usual in schools of that size.

The two design groups started to work on their assignments in different locations. The groups consisted of architects, energy specialists, HVAC-design engineers, cost analysts, BIM experts, structural engineers and contractors' representatives. One of the group members acted as a discussion leader, facilitator and timekeeper in both groups. Both groups had similar expertise, but the members of "Group New" had been actively involved in the planning of the experiment. The members of "Group Old" did not know each other well and were less involved in the planning. Both groups had access to the architectural models, the client's demands and the end-users' wishes for the school building.

The assignment of the knots was to produce design solutions that would correspond to the client's requirements and the wishes of the end-users. The assignment of "Group New" was to create design solutions for a school building in the empty lot, whereas "Group Old" would work on design solutions on the lot with the old building. Furthermore, the new industry-wide regulations considering solutions from the point of view of costs, indoor temperature and energy consumption needed to be considered.

First, the group members specified their goals, working methods, tasks and schedules. After that, the members of both groups engaged in independent work. Once the work had reached a certain point, the group members gathered together to comment on each other's models, calculations of costs and energy analyses. In these meetings, they projected the models and calculations for everyone to see and join in the discussion. Similarly to a traditional design process, the design work proceeded with the architect completing the architectural plan and providing it to the structural and HVAC designers, energy specialists and cost-calculating specialist, who then proceeded with their tasks, while the architect started to work with the second architectural plan. Half of the time was spent engaged in independent work and half engaged in the collaborative evaluation and the creation of the key performance indicators to be presented to the client and end-users. The division between the independent and collaborative work of "Group New" is depicted during the knotworking sessions in Table I. In Table II, the division between the independent and collaborative work of "Group Old" is depicted.

The results of the assignment were presented to the representatives of the client, the school and the community at the end of the experiment. A feedback session was also organized with the participants after the experiment. The participants thought that the experiment was successful and that the knotworking method improved the collaboration between the designers. However, further experimenting was required in

Time	Phase: "Group New"	
Day 1		
30 minutes	Set up, deciding how to continue	Collaborative work
1 hour 30 minutes	Modeling	Individual work
1 hour 40 minutes	Presenting 2nd architectural design	Collaborative work
2 hours 10 minutes	Modeling	Individual work
2 hours 30 minutes	Energy calculations of the 1st architectural design	Collaborative work
3 hours 50 minutes	Modeling	Individual work
4 hours 30 minutes	Combining results, making a decision about 3rd architectural design	Collaborative work
5 hours 30 minutes	Solving the problem of high temperatures	Collaborative work
5 hours 40 minutes	Presenting the results	Collaborative work
Day 2		
20 minutes	Set up, presenting 3rd architectural design	Collaborative work
1 hours 20 minutes	Modeling, combining results	Individual work
2 hours 20 minutes	Preparing presentations	Preparing presentations
2 hours 50 minutes	Checking results	Preparing presentations

Table I.
The division between the independent and collaborative work of "Group New" during the knotworking sessions

Time	Phase: "Group Old"	
Day 1		
30 minutes	Setting the target, delegating tasks	Collaborative work
1 hour 20 minutes	Defining the premises of design and choosing the alternatives	Collaborative work
2 hours	Modeling	Individual work
2 hours 25 minutes	Presenting 1st architectural design	Collaborative work
2 hours 35 minutes	Checking the costs	Collaborative work
3 hours 30 minutes	Modeling of the next version	Individual work
3 hours 45 minutes	Checking the energy calculations	Collaborative work
4 hours	Presenting 2nd architectural design	Collaborative work
4 hours 45 minutes	Modeling continues	Individual work
Day 2		
40 minutes	Set up, deciding how to continue	Collaborative work
1 hours 30 minutes	Working	Individual work
1 hours 50 minutes	Checking the costs	Collaborative work
2 hours 00 minutes	Preparing presentations	Preparing presentations
2 hours 10 minutes	Checking the costs	Collaborative work
2 hours 35 minutes	Preparing presentations	Preparing presentations

Table II.
The division between the independent and collaborative work of "Group Old" during the knotworking sessions

certain phases of the design process. The participants regarded the opportunity to learn from each other's work as an advantage of knotworking. The information between the designers flowed quickly, and each designer's competence fed into that of others.

Unexpected problems and errors arose in the knotworking experiment. Technical problems emerged in the transfer of data from the architectural model to the cost-calculation software and energy-analysis programs. The cost analyst and energy specialist had to enter the basic figures manually from a printed document into the

programs they used. The groups would have needed a Web-enabled data transfer method and a printer connected to the workstations. The schedule of the experiment was deemed too tight, but working together did speed up the pace of work. New questions emerged as the design work progressed, and it became necessary to discuss them with the client. Due to the client's busy schedule, the information was not received until it was too late.

The two groups worked for approximately 8 hours each. They produced six alternative architectural plans for the school and 15-20 energy solutions and cost calculations for each architectural plan. Thus, the method of knotworking proved to be effective, and despite its short duration, the quality of the design work was good. In the feedback session, the participants concluded that the designers could assemble for a knot from time-to-time, then dissolve and return to their own offices and reassemble again when needed. One participant regarded knotworking as useful but saw working intensively in a group as a challenge. However, the participants were satisfied with the result. Accomplishing the same results would have taken several days if the prevalent way of working was applied.

Discussion: knotworking and learning in the context of a development project

The development of knotworking has been analyzed as a process of learning in the development of collaboration between different designs disciplines in building design and construction. The learning process became visible when the members of the project group were developing and experimenting with the idea of knotworking as a new way of collaboration.

Can the process of developing knotworking be considered a process of expansive learning in this study? Expansive learning is realized through the collective solution of historically and societally based contradictions manifesting as disturbances, tensions and conflicts. However, it is also realized through innovative attempts to change the prevailing activity tied to the reconceptualization of the object and motive of activity (Engeström, 2001). The ambiguity embedded in expansive learning identified, for instance, in the special issue edited by Martin and Peim (2009) is obvious in the current study. The development of knotworking was not based on learning through analyzing the macro-level contradictions but through the visibilization of problems, disturbances and tensions on the level of practices. However, the connection of these problems, disturbances and tensions to macro-level contradictions was not analyzed. This was perhaps related to the analyzed development not being an intervention project. The analysis of contradictions is usually a phase in a developmental work project included in the assignments of the participants and the researchers, which was not the case in this study. However, the participants made solution-oriented attempts to change the current activity through the process of ideation and experimentation on a new way of working, and this process represented learning. The participants were searching for a concrete solution to the problems and challenges raised in the Model Nova group during the past year:

- designers working in isolation from each other;
- slowness in the exchange of information and decision-making;
- lack of expertise on the level of the overall project; and
- old-fashioned processes.

The object and motive became specified as purposeful action in the development of the "alternative knot", and it was finally anchored in the design of a school. Bishop *et al.* (2009, p. 245) emphasize that the object of activity is not easily shared in the construction industry because actors can have very different aims and commitments in terms of objects, which can inhibit the development of collaborative working. In our study, regardless of having different disciplinary-based aims, interests and orientations, the participants were able to work on a shared collective purpose of developing the "alternative knot". They were also able to develop and share the tools needed in the process. The developmental context freed the participants from the prevalent socio-economical context and power relations, which at least partly made the development of knotworking possible in the context of design and construction.

Concluding remarks and suggestions for further development and research

After the first experiment, knotworking has been adopted to two other commercial projects. The preliminary observations from these projects raise new questions related to the contradictory relations between the clients and designers, the design and use of the buildings and between the different design disciplines. Clients can require "real" alternative designs of buildings, not modifications of one design. Users of the buildings want to be heard in the processes of design. Presenting the needs of different users at the same time may turn the "Pandora's Box" into a useful resource for designers. When users hear the needs of other users, their requirements may become more realistic. Finally, knotworking does not necessarily improve the collaboration between different design disciplines. Some disciplines, for instance architects, may experience the change of their position in the professional hierarchy more as a threat than a possibility.

Knotworking has been presented on the program level as an innovative form of organizing inter-professional collaboration in the construction industry. Plans have been made to commercialize knotworking in building design, and new technical tools have already been developed for knotworking. For instance, practitioners have developed tools for energy calculations and key performance indicators for the evaluation of design outcomes. However, further development is needed, for instance in the development of cost calculation tools. Knotworking itself requires further development and experimentation in the other parts of the design and construction process. Questions still to be answered include discovering the critical phases of the design and construction process that require knotworking; the potential for knotworking to be institutionalized and the consequences of this in the network of design and construction companies; and the tools, instruments and social forms of collaboration needed in different knots.

Considering third-level activity theory, new conceptual formulations and methodologies are needed, as has been suggested by many practitioners and critics of activity theory (Martin and Peim, 2009 and other authors in the special issue; Bishop *et al.*, 2009; Engeström, 2008). The emergence of a purposeful and material object, the role of practitioners as active agents and the relation of macro-level discussions and project management to micro-level practices need further exploration and reconceptualization in the context of interdependent and complex activities such as building design and construction. The contradictions embedded in the current socio-economy of building projects were not diluted or eliminated as a result of the

developmental process in this study. Therefore, it is an interesting question in which forms contradictions emerge (or whether they remain invisible) after the initiation of knotworking within the construction industry. A careful analysis of the data from the knotworking experiments conducted thus far and further studies of the development of knotworking provide good opportunities to answer this question in the Finnish construction industry.

Notes

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2. The research was done in a research group led by Professor Reijo Miettinen at the Center of Research on Activity, Development and Learning (CRADLE). The members of the research group were Hannele Kerosuo, Jenni Korpela, Jiri Lallimo, Tarja Mäki and Sami Paavola.

References

Alvesson, M. (2009), "At-home ethnography: struggling with closeness and closure", in Ybema, S., Yanow, D., Wels, H. and Kamsteeg, F. (Eds), *Organizational Ethnography: Studying the Complexities of Everyday Life*, *Sage*, Los Angeles, London, New Delhi, Singapore and Washington, DC, pp. 156-174.

Bishop, D., Felstead, A., Fuller, A., Jewson, N., Unwin, L. and Kakavelakis, K. (2009), "Constructing learning: adversarial and collaborative working in the British construction industry", *Journal of Education and Work*, Vol. 22 No. 4, pp. 243-260.

Blackler, F. and McDonald, S. (2000), "Power, mastery and organizational learning", *Journal of Management Studies*, Vol. 37 No. 6, pp. 833-851.

Dossick, C.S. and Neff, G. (2010), "Organizational divisions in BIM-enabled commercial construction", *Journal of Construction Engineering and Management*, Vol. 136 No. 4, pp. 459-467.

Edwards, A. and Kinti, I. (2010), "Working relationally at organizational boundaries – negotiating expertise and identity", in Daniels, H., Edwards, A., Engeström, Y., Gallagher, T. and Ludvigsen, S.R. (Eds), *Activity Theory in Practice – Promoting Learning Across Boundaries and Agencies*, Routledge, Taylor & Francis Group, London and New York, NY, pp. 126-139.

Engeström, Y. (1999), "Expansive visibilization of work: an activity-theoretical perspective", *Computer Supported Collaborative Work*, Vol. 8 No. 1, pp. 63-93.

Engeström, Y. (2001), "Expansive learning at work: toward an activity theoretical reconceptualization", *Journal of Education and Work*, Vol. 14 No. 1, pp. 133-156.

Engeström, Y. (2008), *From Teams to Knots – Activity-theoretical Studies of Collaboration and Learning at Work*, Cambridge University Press, Cambridge.

Engeström, Y., Engeström, R. and Kerosuo, H. (2003), "The Discursive construction of collaborative care", *Applied Linguistics*, Vol. 24 No. 3, pp. 286-315.

Engeström, Y., Engeström, R. and Vähäaho, T. (1999), "When the center does not hold: the importance of knotworking", in Chaiklin, S., Hedegaard, M. and Jensen, U.-J. (Eds), *Activity Theory and Social Practice: Cultural-historical Approaches*, Aarhus University Press, Aarhus, pp. 345-374.

Engeström, Y., Kaatrakoski, H., Kaiponen, P., Lahikainen, J., Laitinen, A., Myllys, H., Rantavuori, J. and Sinikara, K. (2012), "Knotworking in academic libraries: two case studies from the University of Helsinki", *Liber Quarterly*, Vol. 21 Nos 3/4, pp. 387-405.

Fenwick, T. (2006), "Organisational learning in the 'knots'. Discursive capacities emerging in school-university collaboration", *Journal of Educational Administration*, Vol. 45 No. 2, pp. 139-153.

Hardin, B. (2009), *BIM and Construction Management: Proven Tools, Methods and Workflows*, Wiley Publishing, Indiana.

Harty, C. and Whyte, J. (2010), "Emerging hybrid practices in construction design work: role of mixed media", *Journal of Construction Engineering and–Management*, Vol. 136 No. 4, pp. 468-476.

Kangasoja, J. (2002), "Complex design problems: an impetus for learning and knotworking", in Bell, P., Stevens, R. and Satwicz, T. (Eds), *Keeping Learning Complex: The Proceedings of the Fifth International Conference on Learning Societies*, *Erlbaum, Mahwah, NJ*, pp. 199-205.

Kanzode, A. and Reed, D. (2008), "A practitioner's guide to virtual design and construction (3D/4D) tools on commercial projects: case study of a large healthcare project", in Kymmel, W. (Ed.), *Building Information Modeling. Planning and Managing Construction Projects with 4D CAD and Simulations*, McGraw Hill, New York, NY, pp. 173-204.

Kerosuo, H. (2006), "Boundaries is action", *An Activity-theoretical Study of Development, Learning and Change in Health Care for Patients with Multiple and Chronic Illnesses*, Helsinki University Press, Helsinki.

Kymmell, W. (2008), *Building Information Modeling. Planning and Managing Construction Projects with 4D CAD and Simulations*, McGraw Hill, New York, NY.

Martin, D. and Peim, N. (Eds) (2009), "Critical perspectives on activity theory", *Educational Review*, Vol. 61 No. 2, pp. 131-138.

Succar, B. (2009), "Building information modeling framework: a research and delivery foundation for industry stakeholders", *Automation in Construction*, Vol. 18, pp. 357-375.

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