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"A Knot" – breaking the inertia in construction?

Abstract

The aim of this paper is to contribute to new collaborative processes in construction practice, which are challenged by a traditional understanding of teams in construction project management. A dynamic innovative and open-ended expansive process is requested and badly needed. The development and implementation of new technology require a parallel process of developing the use of technology and the social processes of its use. Knotworking represents a distributed collaborative expertise in pursuit of a task that is organised among designers from different design disciplines and other players in a construction process. In Finland and Denmark experiments with Knotworking is being developed and tested: Experiments with Knots, how can it change or create new objects and solutions in construction?

The method of the study is action research and applied ethnography that is a practice-oriented approach to contribute to change processes. The degree of authors' participation varied from being a facilitator, consultant or observer in the Danish case and from being a facilitator and observant in the Finnish case. The data collection was a participant observation in a Finish and Danish case. The participants of the experiments were architects, contractors, energy specialists, HVAC design engineers, structural engineers, a cost calculator, representatives of property owners and researchers. The data was saved in digital format using several video cameras. We also gathered BIM documents, process charts, advisors' reports and photographs.

Experiments with Knots have the potential to break inertia in construction, multiple solutions will persist and it implies learning by experimenting with the new practice. The Knots are organised to solve specific problems or tasks requiring multidisciplinary expertise. Working with Knots as a successful process requires intensive collaboration across organizational boundaries and hierarchies through object-oriented actions, i.e. objects of activities that include both material and cognitive constructions which lead to entail directionality, purpose, and meaning to collective activities.

Keywords: construction project, Knotworking, BIM, activity theory, collaboration,

1. Experiments with Knotworking

This research paper defines and investigates "A Knot" as a construct and concept for change in Construction. From our research, we present two experiments with Knotworking from a Finish and Danish context. Our aim is to provide critical reflections on the current situation of facilitating construction projects with new technology – BIM – and a new way of collaboration – Knotworking. Our normative proclamation is that Knots can be drivers for implementing the potentials of BIM, and as an opportunity to break with the inertia in construction, which leads us to the research question: *Experiments with Knots, how can it change or create new objects and solutions in construction?* As practise-based researchers, we have created experiments with Knotworking in our eager to understand and find solutions the construction industry and the build environment.

There has been an expectation about that BIM as a tool can be a central vehicle to increase productivity and efficiency in the building industry. This assumption covers elimination of design errors and quality of design, management of processes in construction, collaboration and communication between partners in the construction process and new forms of collaboration with clients. Miettinen and Paavola (2014), describe the inertia of construction with an activity-theoretical approach and socio-technical perspectives on BIM implementation. Starting with a critique of the traditional rational (normative) approaches continuing to technology implementation, the definition of BIM, and future vision, from the BIM Handbook (Eastman, Teicholz, Sacks and Linston, 2011); including the "new-won" understanding of collaborative cooperation - Integrated Project Delivery (IPD). IPD is an American framework for construction processes, it requires a high degree of cooperation, coordination and knowledge sharing among participants, with the purpose of generating a common understanding of the project and using the available knowledge. IPD is the supported by BIM tools for building modelling together with calculation and simulation tools (AIA National, 2007). Lahdenperä (2012) describe with reference to Cohen (2010). IPD as a project delivery method and which is a contractual agreement between a minimum of the owner, design professional and the builder, where risk and reward are shared and stakeholder success is dependent on project success (Cohen, 2010). By the use of BIM, the AEC facility management industry learns how to use the technology to support integrated teams (Eastman, Teicholz, Sacks and Linston, 2011).

Miettinen and Paavola describe four key elements (promises within the BIM rhetoric): "These four elements are 1) all relevant data needed in the design and construction of a building will be included in a single BIM model or is easily available with BIM tools, through common repositories or distributed database systems. 2) In allowing interoperability between data (shared with open standards like IFC) from several native design models, BIM becomes a tool of collaboration allowing new integrated ways of working. 3) BIM will be maintained and used throughout the lifecycle of the building. 4) BIM is expected to increase considerably the efficiency and productivity of the building industry" (Miettinen and Paavola, 2014, p.85.).

The disappointing news is even though potentials for implementing BIM seem obvious, these promises seems to be a utopian vision, which means it is impossible to achieve or at least fulfill

only to some degree. BIM enables sharing of information and communication across 'silos' even now to some extent, new forms of collaborating, are emerging. The development and implementation of BIM is studied as a long-term historical process, and the various conditions must be investigated. Miettinen and Paavola claim that there is a need to study the specific uses of BIM in different phases of the construction process and the different actors in the construction process (stakeholders) that can gain value by using BIM. They also suggest a way out of the locked situation, based on their activity theoretical background, three principles on BIM development and implementation are proposed: 1) BIM development and implementation is an open-ended expansive process; 2) Multiple solutions will persist: the development is a differentiation-integration process; 3) Implementation of BIM implies learning by experimenting and invention of novel uses in which process the practitioners and users play a key role (Miettinen and Paavola, 2014).

We are following these principles in our research. The purpose of our research is to study the development of new collaborative practices in BIM-based building projects. We use the theory of expansive learning to enable a creative process that entails experimentation of new kind of collaboration such as Knotworking. The creation of new practices inevitably involves working with processes that persist the new. However, experimentation makes it possible to explicate and reflect the prevailing processes and to develop new ways of working (Engeström, 2008).

Our paper starts with the introduction of the theory of expansive learning and the main concepts of Knotworking based on cultural-historical activity theory; followed by a historical projection from teams to Knots in the construction projects and industry. This theoretical and historical explanation is followed by methodological reflections about doing experiments with Knotworking. Two experiments from Finland and Denmark open new perspectives and alternative frameworks on collaborative process of cooperation. Both cases have a focus on common understanding and BIM development and its implementation, solving tasks through IT model-based and simulations tools as well as local experiments and solutions. However, the cases complete each other in terms of the research context (development program/client-driven building project), client and end-user participation and instrument development. The concluding section is reflecting upon whether Knots can break with inertia in construction.

2. The theory of expansive learning and activity-theoretical concepts of Knotworking

The theory of expansive learning and activity-theoretical concepts of Knotworking Engeström (2015/1987) introduced the theory of expansive learning as a form of learning that can support change processes in human activity. The theory of expansive learning is often visualized as a cyclic process that starts in the emergence of needs for changing collective activity (figure 1). Actors experience the need to change the activity as tensions and contradictions such as errors, disturbances, and incongruences in current activity. In successful processes, reflection and analysis of the tensions and contradictions lead to envisioning a new model of an activity. The new model contains a working hypothesis of new instruments, rules, and division of responsibilities. The working hypothesis is experimented (i.e., examined and tested) in practice.

During experimentation the new model is improved and for instance instruments are adjusted and enriched in the activity. The phase of experimentation may require several cases until the model has reached the maturity level required for implementation. After the implementation the entire process of expansive learning is reflected before it is consolidated. In figure 1, the ideal model of expansive learning is depicted as learning action through which the process of expansive learning takes place. In real life, all phases of the process are completed or reported in one study (see for instance Engeström & Sannino, 2010). In this study, we examine only the experimentation phase of expansive learning in both cases.

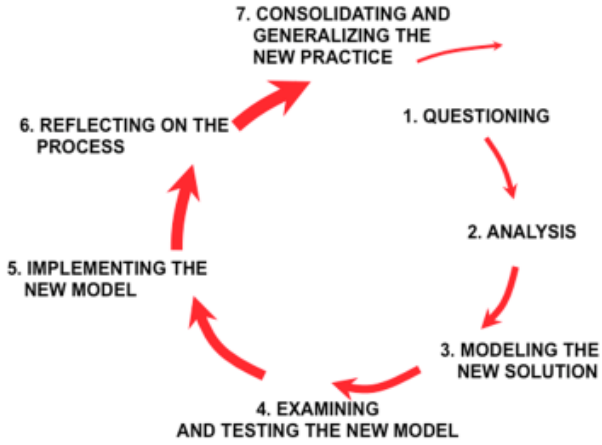

Figure 1. The model of expansive learning actions (adopted from Engeström & Sannino 2010, 8)

Expansive learning based on the cultural-historical activity theory (CHAT) originating from the work of cultural psychology in 1920s (Vygotsky, 1978; Leont'ev, 1978). The object-orientation of a human activity is the *first* characteristic of Knotworking. Objects of activity are both material and cognitive constructions that entail directionality, purpose, and meaning to collective activity (Engeström 2008, 204). Human activity is often depicted as an activity system that entails the relations between subjects, objects and instruments involved in production as well as the social aspects of an activity such as rules, division of labor and community (figure 2).

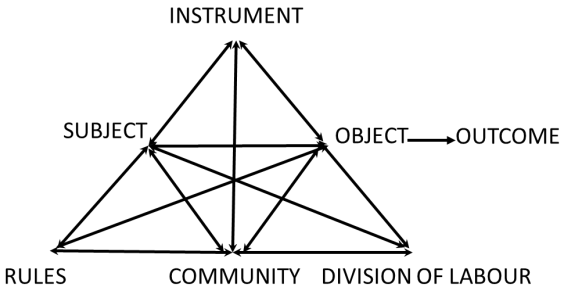

Figure 2. The model of an activity system (adopted from Engeström 2015/1987)

A material object of collective activity entails the basic motive and sense of the activity (Leont'ev 1978, 52). From the activity-theoretical perspective, to have groups of people or professional groups working on a shared object is important in the creation of novelty and innovation (Miettinen, 2006). Different experts constitute the overall object of activity through inter-connected tasks in building projects. Poor integration of tasks may prevent the effective performance of the activity in project teams. At the same time, different actors may not know how their contribution is connected to the overall object of a building project.

The mediated nature of human activity is the *second* characteristic of Knotworking. According to CHAT, the elements of an activity system mediate human activity. For instance, various instruments such as manual and software tools, building plans, building schedules, and meeting procedures, mediate a building project.

The *third* characteristic of Knotworking concerns the concept of activity. An activity is realized by human goal-oriented actions and their components 'automated operations' (Leont'ev, 1978). The levels of activity and actions/operations are often examined as separated in previous studies (see for instance Bakker, 2010). However, the activity and its realization in actions and operations cannot be distinct from each other but need to be analysed in dynamic relations (Engeström, 2001). The analytical distinction between levels of activity, actions and operations is important in order to examine the embeddedness of actions (or operations) in an activity. For instance, actions related to previous activity may prevent the creation of new actions and operations during the change of activity (Engeström, 2008). For instance, actions related to the use of CAD may cause problems in the use of BIM if not made explicit during the change process.

Examining contradictions as sources of change is the *fourth* characteristic of Knotworking. Contradictions are historically accumulated tensions between and within different activities that manifest in disturbances, gaps as well as innovative solutions (Engeström, 2008, 205). For instance, a contradiction may emerge between the adoptions of new digital technologies such as BIM and organizational structures developed during a prior technological paradigm (Kerosuo et al., 2015).

The historicity of human activity is the *fifth* characteristic of Knotworking. Engeström connects Knotworking to the emerging historical type of work called co-configuration. Building on activity-theoretical research tradition Knotworking is connected to an emerging historical type of work called co-configuration. The features of co-configuration involve:

- 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
- Multiple collaborative producers operating in networks within and between organizations (Engeström, 2008 p. 195-196).

Engeström (2008) describes Knots as an elusive and improvised phenomenon in the context of distributed expertise. A movement of tying, untying, and retying together characterizes seemingly separate threads of Knotworking. The tying of a Knot is not reducible to any specific individual or fixed organizational entity as the center of control.

3. From temporary teams to Knots in construction projects

In general, the construction industry differs from many other industries by being project-oriented as temporary teams with a significant share of unique production, an organizational form which who implies, that clients, advisers, the production team, and suppliers are composed anew for each project. Thus the cooperation process in the construction industry is challenged by a vast number of different stakeholders and professions (Winch, 2010), which must cooperate with each other on project-based contracts during the individual project lifecycle. The process being made more complex by projects which are uncertain endeavors. Projects do not consist of a decision at a single point in time; rather they are, in many ways, an ever deepening and broadening sequence of decisions through time (Winch, 2010/2015).

Karrbom Gustavsson and Gohary (2012) describe (with reference to Chan et al, 2003; Dainty et al, 2006; and Winch, 2010) the traditional building practices as being based on rigid and impenetrable border between the different phases of the process, e.g. design and production and professions such as architects, engineers and the contractors, making the processes of communication, cooperation and integration of projects in practice difficult. The process of cooperation becomes difficult when the advisers, users, and client, and later contractors, are located at different locations, have different working methods, technologies, tools, structures, and cultures. Knowledge sharing becomes inefficient and is often more disclaimer and personal positioning than true sharing of expertise.

Fragmentation of the construction industry links to project organizing in temporary teams with a significant share of unique production, different working methods, technologies, tools, structures and cultures between the participants, and a process of continuous sequences of decisions, etc. Fragmentation in the construction process and the resulting adversarial relationships between involved participants have been an ongoing topic of critical writing (Lahdenperä, 2011). In parallel, there is a vision of integrated trust based practices also developing. Collaborative approaches are one way of dealing with the fragmentation and the lack of integration that has complicated previous attempts to improve project performance in construction projects (Bresnen and Marshall, 2000).

In the previous literature, the challenges of temporary organization and temporary teams were concerned with the effects of the limited time of their existence, the team processes, and the nature of their tasks and the characteristics of contexts under which they are operating (Bakker, 2010). Temporary teams are oriented to the demands of a situation and they do not anticipate future interaction with each other beyond the imminent deadline (Saunder and Ahuda, 2006). Construction projects are typically composed of temporary teams from several companies for one particular purpose. In general, such a working process entails negotiation among trades, different

ownership interests and architectural and engineering design. This implies that the participants of the construction industry are influenced by an internal conflict of interest between the project and the company. For instance, subcontractor companies' obligations to the company goals influence the decisions about the marketplace allocation of personal and time across different projects. The company prioritizes the values of optimizing profits with respect to time across multiple projects (Dossick and Neff, 2012).

Temporary teams function under constraints of high uncertainty and interdependence during a limited time, if the functionality is dependent on their members´ sets of diverse skills and knowledge (Kerosuo, 2015). This creates very often communication challenges, which reinforced the obligations to individual scope, at the expense of commitment to the building project. The various participants are following their scripted roles, each concentrating on the successful performance of the assigned actions or "presentation of the self" (Engeström, 2008).

Knotworking, in co-located "Knots", is organised on a temporary basis to solve a specific task, a problem or an open question requiring multi-disciplinary expertise in a building project, and last typical one or two days. Several Knots can be organized during the project (Kerosuo, 2015). Through workshops, opportunities for participants to work concentrated on practical solutions of specific themes are established. These themes are pre-defined, for instance demands /wishes to design, construction, cost, construction time, environmental impact and energy consumption, etc. In practice, these thematizations develop as a Knot(s) in combinations of plenary discussions, frequencies where the individual subject specialists are working separately on the problem in each Knot, for then subsequently in plenum being presented as different scenarios solutions. In order to identify the most advantageous choice in the process, various disciplines through modelling and simulation tools are participating. The process provides a visible picture of the consequences of the different scenarios, which are discussed and gives the participants opportunity to take joint qualified decisions, including visibility of some new Knots/challenges. Plenary discussions and scenarios create a merge of process and technology where participants can continuously make informed choices and thus is a common create a practiced understanding, grounded in perspectives of different occupational groups. Next sections give Knotworking examples from Finland and Denmark.

4. Methods and data of the study

The method of the study is applied ethnography that is a practice-oriented approach to contribute to change processes (Chambers, 2000). Applied ethnography is often applied in action research projects that serve public good and/or decision-making. It emphasizes collaboration with the participants of the change projects and those involved as subjects in fieldwork. Applied ethnography resembles developmental approaches drawing from the methodology of expansive learning with regard to its orientation to practice and participation in change processes. The focus of developmental approaches on tensions and disturbances is also similar to applied ethnography. The idea of both these methods is that researchers make the tensions and disturbances of the work practice visible (Kerosuo, 2006).

The method of the data collection was participant observation in both studies (Hammersley & Atkinson, 1983). The first and the second author of this paper did the fieldwork in the Danish study and the third author conducted it in the Finnish study. The degree of authors' participation varied from being a facilitator, consultant or observer in the Danish case and from being a facilitator and observant in the Finnish case. Besides the authors here students were observing and making field notes in the workshops of the Danish case. The data was saved in digital format using several video cameras. We also gathered BIM documents, process charts (Finnish case), advisors' reports (Danish case) and photographs. For the analysis, we have selected only those parts of the data in which object of activity, mediating instruments and the tensions, as well as contradictions are dealt with in the data.

5. Finish Knotworking experiment: Initiating and experimenting in a research and development program

The idea of Knotworking emerged during an intensive seminar organized in a Finnish research and development program during 2012-2014. Members of the steering group in Model Nova work package participated the seminar. The program in question was called Built Environment Process Re-engineering Programme (http://rym.fi/program/pre/). In the seminar, the purpose was to create a new method of collaboration based on sharing ideas and fluent communication between different players in a building process. The participants the seminar represented various expertise and specialized knowledge such as contracting, facility management, project and knowledge consultancy, architecture, structural and HVAC-E design, contracting and academic research from the technological university and social sciences.

Some members of the steering group had visited Big Rooms in San Francisco area hospital projects and had in mind to have something similar in Finland. However, the problem of Big Room was that designers and other experts are usually hired to various projects at the same time (as in many Nordic countries). The group adopted the idea of Knotworking from the activity-theoretical research group at the University of Helsinki. The concept of Knotworking had been created in the development of health care organizations and adopted in many other activities (Kerosuo, Mäki and Korpela, 2015).

The adoption of the idea of Knotworking was an open-ended expansive process in the seminar. The process of development Knotworking involved many of the ideal typical epistemic learning actions described by Engeström (2008) such as questioning and criticizing of prevailing design-meeting practices. The participants had used a considerable amount of time in the development of collaboration in BIM-based building process but no good solutions had been created. The idea of Knots raised enthusiasm and the group decided to test the idea in a concrete building project.

The idea of a Knot was to invite all relevant parties and experts to work one to two days in early design issues of a building project. The concrete case was a school and daycare building that also hosted evening and weekend activity. The aim was to provide alternative designs solutions to the client and end-users. The object of activity was to model several architectural scenarios and to calculate energy solutions and their costs in the project. BIM would be used in such a way that

the results would immediately be available after each design phase “that you don’t need to go to your own office to count and some results come out after a week or two.”

The group engaged the authorities responsible for the school premises and the teachers as well as the community members. The goals and procedures of the Knotworking workshop were set in three planning meetings during spring 2012. The contents and the acquisition of the initial information were planned, the division of labour between the designers and specialists was decided, and the means of client and user involvement negotiated in the meetings. The members of the group used considerable time for the creation of key performance indicators (KPI) and their measuring units to be used in the comparison of energy solutions. They also ensured the integrated use of the several software used by the architect and design experts in the workshop and created tools for the presentation of the alternatives to the client and end-users of the building.

The two-day Knotworking workshop was organized on May 21 and 22, 2012. The Knotworking consisted of two types of sessions. First, there were shared sessions with the representatives of the client and community participating that took place at the beginning and the end of the Knotworking workshop. Second, there were working sessions in which the designers and specialists were engaged on their assignment of creating and analyzing the alternative design solutions. The groups were allocated one afternoon and one morning to engage in the actual Knotworking. The final result of the Knotworking workshop was five architectural scenarios and 15…20 energy analyses and cost calculations created in eight hours by Knotworking, using BIM and efficient energy-simulation tools.

Learning by experimenting played an important role in the development of Knotworking. There were no explicit tensions expressed between players and experts in the Knotworking experiment. The information needed from other experts was available quickly. It was possible to solve design problems when they emerged with those experts needed in solving them. However, it is important to notice that the experimentation of Knotworking was carried out in a development program funded by TEKES (Finnish Technology Foundation Innovation) and participating companies. The group members were able to have a shared object of development and they were not contracted to provide an ordinary building project. The participation of the client and the end-users was limited to the beginning and the end of the workshop. It would have been profitable if the client could have been present during the working sessions. Working with the teachers and community members would also require more time.

The idea and the results of the Knotworking experiment were presented to the members of the industry in two seminars. Two other experiments were also organized. After the development program, the participants started to develop their own versions of Knotworking as part of their services. The perspective to organising new kind of Knots is open as new ideas Knotworking are emerging and change the industry.

6. Danish Knotworking experiment: Client driven development project

The idea of a Knotworking project in Denmark emerged in autumn 2013 during a number of meetings between Danish Defense Building Department (DDBD) and researchers from Aalborg University, Technical University of Demark and University College of Northern Denmark. Inspired by colleagues from Finland, DDBD chose in co-operating with the researchers to test Knotworking in the early design phases of the construction project, Rescue Station Skagen, at Skagen harbor. The project was a small building project to 13.5 mio. DKK. Besides the client (DDBD) and the researchers, participated rescuers (users of the building), architect and design engineering consultants, including specialists in sustainability, economy, and scheduling. Students who assisted with different digital/IT software as "design modelers". The purpose of the Knotworking project was to survey experiences from Finland and optimizes the design phases through collaborative innovation and decisions processes. More specific, the task was to design the building from brief to approval by the authorities using IT model-based tools and simulations. The process of Knotworking took place in spring 2014, starting with planning meetings covering several issues: expectations, working methods, necessary facilities, IT-equipment, software programs, data requirements, etc.

During the workshops, the client, user and advisers sat around a table and participated various thematic discussions that they each contributed with their professionalism and expertise. Ideas and suggestions were discussed and argued in plenary sessions; Knots emerged in a learning process, where common sensemaking occurred.

One of the characteristics in Knotworking is the mediated nature of human activity, for instance, various instruments such as software tools. To "support" the process of new model of activities, the "modelers" fabricated different design solutions from ideas and suggestions from consultants, client, and users. This allowed the participants to constantly relate to the creation (or integration) of various design solutions and discuss the consequences of different choices. They worked with different requirements (ideas, problems, themes), where the leading design and simulations were modelled in several versions by the modelers (students). During the process, the models were expanded to include estimation and planning tools and 4d and 5d environments emerged with cost estimates and schedules. The different scenarios were discussed in collaborative work sessions (in plenary) - and independent work sessions.

There were Knots about the pier building, design and construction choices and climate challenges including water rising subjected to analysis in design and function, sustainable and energy technical solutions as well as cost and time. The facilitator ensured that all participants were consulted and asked for positions on all issues. An example of the process was that the design models were regularly visualized and thus the impact of different aesthetic and geometric choices was made visible compared to existing conditions at the site. By extension, new problems/challenges appeared as the user explained that they in recent years had seen a rise in water levels in the harbor and consequently had more frequent flooding inside the existing

building. That stimulated discussion of several different scenarios regarding the rescue station in Skagen:

- The structural engineer was aware of the possible pressure on the entrance to the boat hall by rising water.
- The HVAC engineer and the architect made analyses of a heat loss because users indicated that the entrance to the boat hall was open during rescue operations.
- The client and the architect looked into the surrounding harbor coatings by possibly rising water which would affect the surrounding harbor terrain.
- The Quantity Surveyor continuously calculated the various scenarios by comparing different solutions and conditions of which both the time and financial consequences were discussed.

The example shows that sharing knowledge causes the initiative to change from moment to moment within a Knotworking workshop. The center does not hold. The Knotworking represent a new collaborative cooperation that provides opportunities to develop and facilitate value-adding relationships and integrates different disciplines in a process supported by digital tools. Exploitation of digital technology such as information exchange between disciplines/domains and the underlying data models and interfaces, in some cases, challenged the provision of data. It meant a relapse into known methods instead of supporting new ways of collaboration, but the process showed, opposite to traditional working processes with clear defined roles and tasks, that the participants interacted on re-conceptualizing organisation and the content emerged through common knowledge and created new objects and solutions in the process.

7. Concluding reflections - breaking inertia?

Knots connect groups of people, tasks and tools across organizational boundaries to work intensively to get a problem or task performed in building design. The Finnish and Danish projects worked with BIM-based collaboration, experimenting with new 3D and simulations tools to provide alternative plans for a client's decision-making. Expansive transitions in new collaboration emerge when the participants solve their problems, tensions, and contradictions in their activity (Engeström, 2001).

Through scenarios, the contradictions, which are historically accumulated tensions between and within different activities and that manifest in disturbances, gaps as well as innovative solutions, emerge new organizational structures and activities. Working with Knots through object-oriented actions, i.e. objects of activity that include both material and cognitive constructions, entail directionality, purpose and meaning to collective activity. It implies that participants through their contribution are connected to the overall object of a building project. Another benefit is the problem in the "traditional process" with the poor integration of the different participants' contributions and tasks, which may prevent the effective performance of the activity in project teams may be solved.

Beyond that, the processes led to a specific knowledge to further use in the project design. New "meta – knowledge layer" also developed during the processes for instance in the future operation of the building and future construction projects.

Under the processes, the participants took part in the different Knots, where all contributed with their professional skills and expertise. The experiments with Knots created new objects of activity, enriching the interacting.

It is not possible to find a technology driven solution to the inertia in construction, it is unrealistic to assume that BIM/VDC or any technology can produce the needed change, but we can start by experimenting with open-ended expansive process in which multiple solutions will persist (the development is a differentiation-integration process). Working with Knots demands open-ended expansive processes and requires intensive collaboration across organizational boundaries and hierarchies.

Experiments with Knots have the potential to break in inertia in construction, we doubt that the Knotworking projects have realized the full potential - a paradigm shift in construction? Further research is needed about new ways of collaboration, new roles, contracting, use of technologies, producing – a new configuration of construction processes.

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