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Beyond the BIM utopia: Approaches to the development and implementation of building information modeling

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ABSTRACT

Building information modeling (BIM) refers to a combination or a set of technologies and organizational solutions that are expected to increase interorganizational and disciplinary collaboration in the construction industry and to improve the productivity and quality of the design, construction, and maintenance of buildings. In this paper we analyze first the rhetorical–promotional dimension of the BIM implementation sometimes characterized as a "BIM utopia." Second, we analyze the views of the enhancement of BIM implementation. Although BIM visions and promises are needed for BIM implementation, they need to be complemented with a more realistic view of conditions of the implementation. For this we outline an activity–theoretical and evolutionary view by drawing conceptual tools from science and technology studies and other relevant social scientific literature. According to this view, in addition to standards and guidelines underlined by normative approaches, local experimentation and continuous learning play a central role in the implementation of BIM.

1. Introduction

There is no single satisfactory definition of what building information modeling (BIM) is. Rather, it needs to be analyzed as a multidimensional, historically evolving, complex phenomenon. BIM can first be defined as a digital representation of a building, an object-oriented three-dimensional model, or a repository of project information to facilitate interoperability and exchange of information with related software applications. BIM tools support parametric modeling and allow new levels of spatial visualization, simulation of the behavior of the building, as well as more efficient project management. BIM is also emphatically a tool of collaboration. When BIM is extended from design to construction, and facility management and maintenance of the building, new levels of interoperability and collaboration can be achieved. The collaborative use of BIM reduces design mistakes and increases the productivity of the construction industry. BIM therefore, provides an emerging new paradigm for construction management or "an emerging technological and procedural shift in the Architecture, Engineering and Construction industry" (Succar [1], p. 357).

The high expectations of the increased productivity and a new level of collaboration express the rhetorical dimension of BIM development and implementation. As a matter of fact the term BIM, introduced in 2002 by Jerry Laiserin, may be regarded as a new promotional umbrella concept [2]. Historically, the need and possibility for developing more integrated or interoperable software was recognized already in the 1970s by researchers of construction projects developing "integrated design databases" [3] or "integrated design systems" [4] (see also Björk [5], p. 12). BIM can be seen as an evolution of CAD systems but providing more "intelligence" and interoperable information. These systems were named with terms like Virtual Building, Project Modeling, Virtual Design and Construction, and nD Modeling (see Aranda-Mena et al. [6], p. 420-1, Succar [1], p. 359). One central background for BIM was product data models concerning the information of buildings [5].

The literature is growing on how technological visions and promises are used for finding support and funding for the development of new technologies [7–10]. The promises are an essential part of legitimating the development of technology and getting the funders and future users convinced of the importance of investing in its development (Brown et al. [11], p. 881): "Initial promises are set high in order to attract attention from (financial) sponsors, to stimulate agenda setting (both technical and political) and to build 'protected spaces'." In its analysis of the European innovation policy, an expert group of the European Commission on science policy (Felt & Wynne [9], p. 24) found what is called a "regime of technoscientific promise." According to the group (Felt & Wynne [9], p. 25), the first principle or rhetorical move operative in this regime is: "the creation of a fiction in order to

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attract resources (…) that the emerging technology (biotechnology in the 1980s, nanotechnology now) will solve human problems (health, sustainability, etc.) through a wide range of applications."

These technical visions have been characterized in terms of "generalized technological promise" [8] "or a guiding vision" [12] or a "promotional metaphor" [13] by the science and technology studies. New technologies are naturally future-oriented and try to change reality, improve technology-mediated practices, and create new opportunities. These visions are generative and guide activities. The BIM can also be characterized as a *transdiscursive term* [14] that develops and operates simultaneously in research, policy making, and industry. Such a term must be loose and abstract enough in order to function as an interdisciplinary organizer enabling different groups to articulate a roughly shared direction of interests and moral commitments and still maintain their own identity and goals [15]. Because of its fuzziness organizing visions can constantly be complemented with new promises that reflect the development of the technology itself and react to the problems and challenges that emerge in the construction industry. This paper will focus on the rhetorical–promotional viewpoint of the BIM development and on the views of the enhancement of BIM implementation.

This paper is a position paper. We analyze how the development and future of BIM has been represented in BIM literature. We complement the existing literature by introducing theoretical concepts of technology development and implementation which are not yet widely used. They originate from cultural historical activity theory, science and technology studies, as well as from information systems and innovation studies. This allows us to construct two alternative frameworks of understanding and analyzing the BIM implementation, which we respectively call the *normative* and the *activity–theoretical/evolutionary* frameworks. These are theoretical constructs that help to make sense of the ways in which BIM implementation can be understood and how the implementation can be enhanced. We are not arguing that either of these frameworks is true, but rather that they emerge from different theoretical traditions, complement each other and suggest different ideas and means for the enhancement of the BIM implementation. Since the latter framework is less known in BIM research, it may serve to enrich the discussion and to provide new ideas and means for BIM implementation.

We proceed in the paper as follows. First, we characterize four key promises of the BIM rhetoric that can, in a full-blown form, be called a "BIM Utopia." These promises are integral means of promoting awareness of the usefulness of BIM, and can be found in many of the BIM definitions. On the other hand, these promises have also been criticized and questioned in BIM literature. Second, we analyze the ways in which BIM development and implementation have been discussed in BIM literature and their connection to guidelines and capability maturity models developed in information systems theory. Thirdly, we briefly characterize how technology implementation has been discussed in activity theory, science and technology studies as well as information science and innovation studies during the last decades. The theories that will be reviewed find the mediating tools, local learning and collaboration with users essential for the implementation of new technologies. We present three constitutive features of an activity theoretical and evolutionary view. Finally, we compare it with the normative framework and discuss the recommendations for enhancing the BIM implementation they suggest.

We analyze promises of BIM and how the problem of implementation has been dealt with in the BIM literature resorting to systematic reviews of the field (e.g. [1,16,17]), the recognized handbook of the field [18], as well as a set of papers which deals with the development and implementation of BIM (see the list of references). We have selected concepts from science and technology-, information system and innovation studies that deal with the problem of implementing new technologies and specifically information systems. Although the paper is mainly theoretical, we also refer to our own empirical studies on uses of BIM in Finland which provide a local perspective on the BIM implementation. Our research group [19,20] has followed consecutive life-cycle projects of four public schools in Eastern Finland. In addition, we have followed several projects in different phases of the construction process as well as the uses of information technology in facility management and maintenance [21].

2. Four elements of the BIM utopia

All new technologies include potential to improve productive activities. These potentials are expressed in future-oriented visions of the advantages that will be achieved when the new technology is fully implemented. Such visions have also been called BIM "utopias" [22] or "idealistic goals" of BIM (Howard & Björk [23], p. 277). A central concern in the building industry is to increase productivity and efficiency of the business, and BIM is seen as a central vehicle here. BIM promises take many other forms: to eliminate design errors and quality of design, to help management of processes in construction, to deepen collaboration and communication between partners in the construction process, and to provide new forms of collaboration with clients. The influential *BIM Handbook* [18] lists several benefits of BIM in relation to preconstruction, design, construction and fabrication, and post construction phases (Eastman et al. [18], p. 19–25). The handbook also points out that BIM is a buzzword used by the software vendors: "The term BIM is a popular buzzword used by software developers to describe the capabilities that their products offer" (ibid. 19). That is why the definitions of BIM are "subject to variation and confusion."

Borup et al. [12] point out that the technological visions are future-oriented abstractions. They tend to transform the technological potentiality into a picture of future reality simultaneously disregarding many of the conditions and constrains that in reality will complicate and retard the realization of the vision. The technological visions particularly tend not to take fully into account the social and human conditions of the implementation of a technology.

In the following we discern four key elements of the BIM rhetoric or promises often included in the BIM definitions and accounts of the BIM implementation. They are characterizations that concurrently are included in the visions of BIM. 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. As the following examples show, many definitions in the literature reproduce and combine these elements:

> "Building information modeling (BIM) is an IR-based approach that involves applying and maintaining an integral digital representation of all building information for different phases of the project lifecycle in the form of a data repository." (Gu & London [24], p. 988)

> "BIM refers to a set of interacting policies, processes and technologies that generate a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle." (Succar et al. [25], p. 120)

Shen et al. ([26], p. 197) characterize FIATECH's roadmap for systems integration:

> "Information is available on demand, wherever and whenever it is needed to all interested stakeholders. (…) Interconnected automated systems, processes and equipment will drastically reduce the time and cost of planning, design and construction. (…) With a common data model, it is possible for building information to be created once, re-used and enriched in the rest building lifecycle."

The US National Institute for Building Sciences has given a following vision and a definition for BIM (Eastman et al. [18], p. 15–16)

> "An improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about the facility in a format usable by all throughout its lifecycle."

The elements of the BIM utopia have also been questioned. Empirical studies have found a tension between the promises and the reality. They have referred to fragmentation of the field, adversial relationships between partners, discontinuities of projects, and organizational conditions that prevent and retard BIM implementation. We think a richer picture of nature and means of BIM implementation is needed in order to evaluate the elements of the BIM utopia. In the following, we review some of this discussion which shows that there are several ways of seeing BIM.

2.1. A single BIM data or a variety of BIM models used together with other software and tools

The technological promise of BIM has its basis on the idea of interoperability and integrated wholly sharable information allowed by ICT and standards. Many papers [27,28,17] see interoperability and systems' integration as continuous big challenges for BIM. Different technical solutions have been suggested to data sharing and exchange of information [29,30]. Howard and Björk have, however, suggested ([23], p. 273) that the comprehensive single BIM "has been the holy grail but it is doubtful whether there is the will to achieve it." An alternative way of defining BIM is to see it as a multifunctional set of instrumentalities for specific purposes that will increasingly be integrated, but to what extent is an open question. Howell and Batcheler ([22], p. 6–8) maintain that BIM is only one of the many purpose-built models, e.g. software constructed to be used in the specific task of functions such as architect design, modeling of lightning, or fire simulation. They concluded (Howell & Batcheler [22], p. 9) that BIM is likely to be developed through the production and implementation of models for special purposes. In addition, BIM is implemented as a part of "hybrid practices": BIM tools are used in parallel with other digital tools and also with many nondigital tools [31,32].

This idea of multifunctionality and heterogeneity of information technologies has been widely discussed in the study of implementation of enterprise information systems. They have been characterized as *architectural* [33] or *configurational technologies* [34]. Typically parts and modules developed by several vendors are combined and adjusted to meet the local needs of the user [35,36]. This is also what we found when we studied the information tools of the Center for Properties and Facilities of the Helsinki University. It had five different software systems (a space management system, a maintenance manual, a cleaning measurement and management system, a room reservation system, and an outdoor maintenance management system) from five different developers. The Center has been active in developing and tailoring these tools for their own purposes and in assuring their compatibility. A link from the space system to both the maintenance manual and the cleaning system was constructed so that the space information in all three systems is similar. The property manager characterizes their strategy in the development of the systems as "modular". By keeping multiple systems, it is easier to change one system to a more suitable one if needed and in this way one maintains the flexibility and control of the system [21]. It is an open question whether and in which ways these systems can be integrated to BIM.

2.2. BIM and transformation of collaboration

A part of the BIM rhetoric is that the deployment of integrated technology allows and requires an integrated way of collaboration. Various versions for such collaborative arrangement have been developed as project partnering, project alliancing and Integrated Project Delivery [16]. Some observers, however, conclude that increased use of BIM has not caused a qualitative change to the basic ways of working in disciplinary "silos" in the construction projects. Neff and her colleagues ([37], p. 2–3), for example, conclude in their paper on observation of BIM use that "even though BIM usage has doubled since 2007, work practices that support increased collaboration and knowledge sharing across organizational and disciplinary boundaries have been slow to emerge." Several studies suggest that the fragmented and dispersed structure of building industry feeds adversarial attitudes that do not favor trust-based forms of collaboration [38]. Organizational and legal issues seem to be central barriers for extended collaboration [39,17]. Forgues and Koskela ([40], p. 378) report how this fragmentation frustrated the establishment of an integrated team in a Canadian project. An attempt to solve this problem is the development of multi-party relational contracts based on sharing of the risk and reward [16].

An alternative to an ideal organizational integration would be a stepwise or a gradual transformation of existing organizational and collaboration practices. This requires understanding of real-live problems of BIM implementation [41]. In a Finnish project we studied, the participant organizations were convinced that IPD, or a Big room, even if they are good as ideal targets for developing more integrated collaboration, were not realistically to be implemented in the near future in their projects. Instead, they started to look for alternative ways of deepening collaboration with BIM. One solution developed and experimented was an intensive and carefully organized two day collaboration (characterized as a "knot") to produce the design alternatives for the customer [42].

2.3. Use of BIM during the lifecycle

The promise of BIM use during the whole lifecycle of the building is a dream far from being realized. One of the central challenges in BIM development seems to be that BIM use and updating ends (at least mostly) during the construction phase. A recent review concludes (Volk et al. [17], p. 122) that owners, facility managers, deconstructors and related consultants are yet hardly involved in the BIM functionality development. Even if there is a growing interest in BIM use in facility management (FM), it is still not clear how BIM could be realistically used in FM, and there is little empirical data on the topic [43]. The facility managers use various information systems in their work. For instance in the Helsinki University the facility managers use five information systems and the maintenance personnel use four different systems. They have tailored the systems for their own needs and were hesitant about additional value of the BIM modeling tools [21]. In our interviews a property manager in charge of the maintenance of life-cycle project finds that the RYHTI maintenance manual software largely used in Finland in the 1990s is an excellent information tool both for the property owner and for the maintenance company [21]:

> It is an unbeatable tool for a property owner today… It's an absolute precondition for being able to do my job properly… The maintenance manual is a tool for a maintenance company. It's a tool for the management of a maintenance company. It's a tool for a property manager. It's a supervisory tool for a property owner. He will be able to see what's going on all the time. For the users, in this regard it is a tool, because all service requests are made using it.

He did not have trust in BIM models, because he regarded that the subcontractors are likely to deviate from the design models, and these changes are not brought to the models: "If such things are done and they are not brought to the model, the model loses its foundations." He doubted whether the players during a project have sufficient capabilities, time, or motives to update the model into an as-built model.

These observations may clarify why property owners and maintenance personnel have not been eager to invest in the implementation of BIM [43,44,17]. The key challenge seems to be whether they can draw parts of the information from the BIM tools and models. However, part of the information needed in maintenance – such as information of the technical equipment – will likely not be included in design and as built models. This information must be included in the maintenance systems in a separate way. This refers to the possibility of a partial integration of the systems.

BIM has without doubt potential to be used throughout the lifecycle of the building. There is, however, little knowledge about uses with authorities, or collaborative uses by designers and users in early phases of building design. The latter is an important challenge, if client and user involvement is to be increased in construction industry following the example of many other industries [45].

2.4. BIM and the increase of productivity

There is very little empirical, research-based evidence on the increased productivity of the implementation of BIM [46]. As Becerik-Gerber and Rice [47] point out, this kind of evaluation is complicated and the evidence presented on the efficiency of BIM is often anecdotal based on case descriptions. Both researchers and project participants have reported on successful cases of BIM use with figures concerning savings of time and reports of an improved quality. The BIM guidelines and textbooks employ the measurement of the advantages of BIM use as a means of promoting the implementation of BIM. There are, however, considerable difficulties in developing credible metrics, because the impact of BIM is difficult to isolate from the other factors that contribute to the success of a project and it is difficult to organize comparative research designs. On the basis of a survey, Becerik-Gerber and Rice ([47], p. 199) concluded that many respondents noted that it is "too early to determine the value of BIM, as the industry is still at its early stages of BIM adoption".

The discussion of the four elements of BIM utopia can *summarized* as follows: the potentials of implementing BIM technologies are evident. The development and implementation of BIM is, however, a long-term, historical process; the various conditions of which need to be studied. Side by side with the vision of an integrated trust-based team practice the BIM literature sees BIM as a set of software tools that are used simultaneously with non-BIM tools (e.g., [18]). Such view underlines the need of studying in detail the development of specific uses of BIM in different phases of the construction process by different disciplines and a group of practitioners as well as ways of organizing the new uses of BIM.

3. Normative approach to stages and means of BIM implementation

Most of the literature in the implementation of BIM sees the process as a socio-technical process. The adoption of the technology also requires changes in the forms of collaboration and contracts regulating the interaction between the stakeholders. These expectations are materialized in the idea of Integrated Product Development (IPD), Big room, project partnering and project alliancing [16]. The BIM handbook suggests (p. 357) that "[t]he benefits of integrated practice receiving wide review and extensive experience using IDP on specific projects has been accumulated. Leading AEC firms increasingly recognize that future building process will require integrated practice of whole construction team and will be facilitated by BIM."

Technological research aims at defining the efficient and economic functioning of a system or process. This optimal way is included in the guidelines and standards and is used both as a model for implementation and as the criteria for evaluation of the process. This *normative approach* seems to be characteristic also in the BIM literature. The means of enhancing implementation are national guidelines and presentations of the exemplary cases in which BIM has been implemented with significantly increased efficiency and economic benefits. This can be interpreted in terms of the classical theory of diffusion of innovations [48] and the theory of lead users in innovation [49]. The forerunners first adopt a new technology and the majority will follow their example. The normative approach has its roots in the history of technical sciences. It has traditionally strived to optimize the efficiency and economy of the technological systems. By experimenting the best parameters for driving a system can be found and included in a normative model or to an "evidence-based" best practice [50]. This might also be a foundation for an attempt to find or define one optimal normative model and clear guidelines for the BIM implementation.

A theoretical framework widely used to make sense of the organizational changes in construction industry is *lean production* focusing on the improvement of the process and flow of information, actions and materials. *Last planner* has been used as an instrument inspired by lean thinking to improve the coordination in construction projects (see [18,51]). Arayici et al. [52] have used lean-inspired action research interventions to enhance the adoption of BIM in an architectural company. The project developed detailed guidelines on an operational level to be used in implementation.

Another source for enhancing the implementation has been maturity models developed and largely and successfully used in the information systems research and development [53]. Attempts have been made to apply this procedure also to the construction industry [54]. In Bilal Succar's [1,25] model of BIM capability stages the maturity model is connected to the ideal of IPD: (…) "the major milestones that need to be reached by teams and organizations as they implement BIM technologies and concepts." The stages are used both to conceptualize the BIM development and to provide metrics for measuring BIM performance which would help BIM users to evaluate the level and maturity of their BIM use. The first version of the model (Succar [1], p. 363) defined five stages of the development: 1) Pre-BIM, 2) Object-based modeling, 3) Model-based collaboration, 4) Network-based integration, and 5) IPD as the long-term goal of BIM implementation. The final stage, IPD, is characterized as follows:

> "The integrated project delivery (IPD) is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize projects results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication and construction." (Succar [1], p. 365)

Succar refers to AIA (The American Institute of Architects) California Council's Guide for Integrated project delivery [55] as a presentation of IPD. It is a strongly rhetorical and wishful future-oriented paper that seduces readers to a new kind of collaboration. In the beginning, the guide asks the readers to envision a new world where among others:

> "… facilities managers, end users, contractors and suppliers are all involved at the start of the design process… all communication throughout the process is clear, concise, open, transparent, and trusting.… This is the world of Integrated project delivery," (IAI [55], p. 2)

This ideal world will be achieved through collaborative integrated project teams composed of the key project participants. These teams are guided by nine principles which include among others trust, transparency, effective collaboration, open information sharing, and shared risks and rewards. Relational contracts allow just distribution of the rewards among the partners of a project for the team members. They function as incentives to collaboration, efficiency, and innovations. The selection of core team members is important, and team-building methods such as personality assessment and communication training may be used.

In a later version of the model Succar and his colleagues (Succar et al. [25], p. 124) adopt the term Virtually Integrated Design, Construction and Operation (ViDCO) as "the ultimate goal of implementing BIM" (Succar et al. [25], p. 124). It is used instead of the IPD "to prevent any confusion with the term's evolving contractual connotation in the United States" (ibid.). The new version is used as a foundation for developing a performance assessment system and metrics to measure how the BIM is used in an interoperable way.

We are hesitant in which sense the IPD or the ViDCO really can be seen as the 'final end' of the BIM development and implementation.[2] In our understanding, they are far too general to depict the potential richness of the future BIM uses. Even if the relational contracting will be an important part of the future of BIM and the construction industry, IPD's conception of the nature, quality, and conditions of the division of labor and collaboration in the design and construction process is highly wishful. We find it likely that several workable ways of utilizing BIM will be developed to respond to the structure and specific circumstances of national, regional, and local construction businesses. For instance, instead of an integrated central team, efficient tools and collaborative ways of solving critical tasks in the design, construction, and FM process will be developed. 'A knot' for joined, effectively concerted production of design alternatives is an example [42]. Such a solution may be more usable for instance in situations where project teams cannot stay regularly together and are involved in several projects simultaneously.

4. Elements of an activity theoretical and evolutionary view of BIM implementation

An activity theoretical and evolutionary view of BIM development and implementation draws from theoretical traditions that have not yet been widely used in the BIM literature: cultural historical–activity theory, science, technology and organizational studies, and evolutionary economics of innovation (e.g. [56–58]). In spite of their differences these traditions share a number of ideas, among them: an unanticipated nature of technological and social development, a focus on tools and artifacts, the significance of continuous learning and the importance of studying user activities and local experiments in detail. In addition activity theory underlines the significance of *agency*, that is, motives and commitments of individuals and groups of people to transformative projects, interventions and experiments as means of studying and enhancing the development of human activities.

Cultural historical activity theory originally emerged from psychology from where it has been extended during the last decades to the fields of education, learning at work, development of information systems [59], in study of innovations [60] and recently also to the study of design collaboration [61]. It provides a structured model of human activity that allows an analysis of the development of an activity.[3] Activity is object-oriented (purposeful) activity mediated by tools and signs, a division of labor and rules [62–64]. Elements are interdependent and historically changing. When one of the elements changes (e.g. introduction of BIM as new means), it clashes with the elements (the division of labor, rules) established in the previous phase of the development. The solution to these structural contradictions involves learning in the form of *re-mediation*; that is, the adoption and development of new concepts, tools and organizational forms to meet these incompatibilities [20]. Such a learning process is typically expansive: complex objects call for extended collaboration and mobilization of different kinds of knowledge and expertise. Activity theory finds experimentation of new solutions with novel tools a central way of learning and developing new practices. In such a process the practitioners of an organization take the initiative to define the objects of improvements and become agents of development supported by the researchers.

Science and technology studies (STS) is a heterogeneous area of research that has developed such approaches as actor network theory [65,66], theory of infrastructures [67], or the idea of boundary object that allows "different groups work together without consensus" (Star [68], 602). These theories have been applied also in the studies of the construction projects [e.g. 31,32,69]. We want to take up such STS studies that have discussed implementation of technology and have been applied in organizational, design and information systems research [70]. Economic theory has long explained the gradual increase in productivity with *learning by doing* [71] and with *learning by using* [72]. In his seminal study on the adaption of computer-aided production management systems by a firm James Fleck [34] found that it took great effort, over substantial period of time to bring such complex company-wide information systems to the point where they can be used effectively. The implementation required substantial reworking of the systems to get them to meet the tradition, local circumstances and specific requirements of the firm. The learning is not the incremental learning by doing but rather *learning by trying* or "by struggling to get the overall system to work" (Fleck [34], p. 638). Fleck concluded that innovation continues during the implementation[4] and therefore could be called "*innofusion*".

Numerous studies on the implementation of automation systems [73] and business management systems [74,35] have shown that there are a lot of bugs, problems and failures in the beginning of adaptation that need be resolved by innovative solutions to get the system to work efficiently. In a review article on empirical studies on user involvement in the development of IT systems Kujala ([75], p. 11) found among others the following benefits of the involvement: more accurate user requirements, avoiding costly system features that that the user did not want or cannot use, improved levels of the acceptance of the systems and greater understanding of the system by users. It is also likely that users are able to require and develop uses for the technology that the designers have not anticipated. The adoption of a technology requires the learning and tuning of the technology to meet the local conditions, which often result in redesigning of the technology. The contribution of users is also the central theme in innovation studies [76–78].

Evolutionary economics of innovation is the predominant theoretical framework in innovation studies [57,79]. It uses the metaphor of biological evolution as a framework for analyzing technological change. Variation of technological solutions is the source of development, and a selection among these variants takes place by competition in the market, through standardization and regulation. However, in contrast to biological evolution, the technological development is not a contingent process of adaptation. It is driven by human agents who have their objects of activity and interests: the International Alliance for Interoperability creates standards, software firms do business by designing and selling BIM software, and developers want BIM software to be used to get better quality plans for construction etc.

Economics of innovation has also introduced the concept "techno-economic" paradigms (or long cycles of economic development) each of which is based on the development of new generic technology, the full deployment of which requires the creation of new forms of organization and institutions [80]. It, however, suggests that there is a time lag in this process. The new technology is first brought to

[2] ViDCO seems more open-ended than IPD being a "variable ending point" (Succar al. [25], p. 125) but is outlined only very briefly.

[3] "Activity theory focuses on activities instead of processes, and provides a much richer framework than traditional variance or process approaches used in social science to investigate complex phenomena (Nardi 1996)" (Forgues & Koskela [40], p. 374).

[4] "The term 'implementation' is particularly appropriate here… the verb 'to implement' means 'to complete, perform, fulfill.. to supplement'. As a noun 'implement' refers to 'things that serve as… instruments employed in any trade… There is also substantive use (…) meaning 'full performance'" (Fleck [34], 640).

organizational structures based on a previous paradigm, and it takes about two decades before the new social and institutional arrangements start molding. This view fits well to characterize the situation in the construction industry: the challenge is to reform the organizational, institutional, and contractual practices that allow the full deployment of BIM.

Drawing from these social scientific resources, we outline three principles of an activity theoretical evolutionary view of BIM development and implementation.

4.1. BIM development and implementation is an open-ended expansive process

To say that BIM implementation is an open-ended process is to say that it will not be a realization of any predefined final goal or state as suggested by the normative or "teleological" theory of the BIM development. Teleological is a view according to which final causes or ends exist in nature and are analogous to purposes found in human action. According to activity theory and other practice theories, although men set goals, transform institutions and make history, the development of society or technology does not have any preconceived purpose or end goal. Contingency is always involved: unanticipated and only partially understood developments and events that are independent of goals of an individual or an organization decisively influence the course of the development (e.g. [81]). As the history of technology has convincingly shown, attempts to foresee the future development of technology have repeatedly failed (e.g. [82]). Following the evolutionary conception, a variety of BIM software and other software tools will emerge also in the future which will be connected to each other in unexpected ways. Novel solutions open new possibilities and new constraints.

Instead of following maturity stages that could be defined reliably in advance, the process can be characterized by its nature to be expansive: according to this BIM will be used in a widening array of functions in design and building and it will be used by ever more wider networks of collaboration. Although the early developers of product models and BIM were inspired by the idea using the model during the whole lifecycle of building, BIM development has thus far primarily been applied to increase collaboration and sharing of information between the design disciplines.[5] It is now spreading to the construction, project management, analysis of building behavior, and to the fabrication of building elements. Eastman et al. ([18], p. 359) characterize this process of tool development as follows: "BIM vendors are increasingly expanding their scope and providing special tools to an expanding set of disciplines (…) adding discipline-specific interfaces, objects, design rules, and behaviors to the same base parametric modeling engine (….)." As a result of this, also new extended collaborative relationships will emerge.

The idea of functional and social expansion can be applied at a firm level. Firms have their own strategies and ideas of increasing the use of BIM. The Finnish firm Skanska, for example, established a BIM center of expertise in 2009. The Vice President of Research and Development of Skanska (Finland and Estonia) characterized the development of the center as expanding zones in which new uses and functions emerge at each level. The first zone includes clash detection and product site planning; the third zone included supply chain management, logistics and energy, and fire simulations.[6] Like in the implementation of enterprise information and production management systems, the process will likely be configurational and in many points unexpected. The prioritization of software tools and adopted functions reflect the history, culture and key challenges of a firm or a coalition of partners.

4.2. Multiple solutions will persist: the development is a differentiation–integration process

The nature of BIM development and implementation may be described by using the metaphor used to characterize the development of science: processes of integration and differentiation happen simultaneously. In spite of the promotional work and standardization efforts by national and international agencies, multiple solutions will continue to develop. In science and technology studies this phenomenon has been analyzed in terms of simultaneous development of standard procedures and tools and their constant reconfiguration locally [84]. Schmidt and Wagner [85] have analyzed it in architectural design and planning.

The software producers develop competing BIM-software platforms and environments. It is hard to predict if a branch manages to become a dominant solution regionally or globally. When the users adopt specific combinations of software and complementary tools they need to develop practices to get them to work in a proper way. When BIM is becoming a strategic asset in construction business, the strong players develop their own ways of managing BIM use to achieve a competitive edge. Constellations of regular partners may regionally develop joint solutions.

On the other hand, standardization takes steps forward, guidelines will be written, and governments and public authorities will increasingly require the implementation of BIM. The construction industry, software developers, and public sector initiatives have all influenced the development of the IFC standardization in unexpected ways (see [86]). For example, the decision in the United Kingdom that BIM will be mandatory in all public sector contracts from 2016 has had a huge impact on the interest in BIM in the UK. These measures together constitute a strong tendency toward the unification of practices. Evolutionary economics of innovation would characterize the process of implementation in terms of a balance between variation and selection [87]. On one hand, too much and strict standardization will inhibit innovations, whereas on the other hand too much variation will lead to a chaotic situation which curbs the development of technology.

4.3. Implementation of BIM implies learning by experimenting and invention of novel uses in which process the practitioners and users play a key role

All research approaches mentioned above regard implementation of a technology as a creative process. The designers of technology define the specification for the product to meet the needs of the client or the user. The designers' idea of the function and use of technology has been called a 'script'. However, the implementation of technology by a user in a specific situation always includes interpretation and learning. In science and technology studies Madeleine Akrich [88] has described such a 'redefinition' of a script as *de-scription* of a technological object. The designers of a technology have a limited view of the user situations and particular conditions in which the technology will be used. In new situations users are likely to develop and invent new uses. BIM has thus far mainly been used by architects, engineers and contractors and they "still dominate the elaboration of BIM functionalities" (Volk et al. [17] 124). That is why it is no surprise that its uses during construction create new functionalities and extend the significance of BIM.

The adoption of the tool cannot be fully based on general guidelines and it is unrealistic to suppose that the first attempts produce excellent results. The guidelines must be interpreted to get them to meet the local circumstances. The development of workable solutions of BIM use requires experimenting, learning from the problems and ideas for improvement. They are becoming visible in the attempts to implement BIM (e.g. [89,90]). The development by experimenting (continuous learning and improvement) is needed from the beginnings of

[5] "BIM software was developed as a response from design professional who began to see the need to create a single source of information that can shared, added to, altered, and responsibility distributed among the design team" (Hardin [83], p. 35).

[6] A keynote lecture of Ilkka Romo (Skanska Finland and Estonia) "BIM Utilization in Skanska" in ECPPM 2012, Reykjavik July 27, 2012.

implementation and should not only be addressed to the highest level of maturity, as some maturity models suggest [25].

5. Conclusions

In this paper, BIM has been analyzed both as a technology and an emerging new collaborative practice which requires new contractual arrangements, as well as local experiments and solutions. It might be characterized using the term – introduced by evolutionary economics – as a new socio-economic paradigm. The idea of a shift from fragmented into an integrative way of construction is a generalized technological promise based on the potentiality of BIM technologies. This future-oriented promotional rhetoric is as such a natural part of the development of the BIM technology. However, this rhetoric does not provide a realistic conception of the complexity of the conditions of the implementation of the new technology.

We have suggested that a normative view needs to be complemented by an activity theoretical and evolutionary view that draws from cultural historical psychology and sociological and organizational studies of technology implementation. This view regards the BIM development and implementation as an open-ended process directed by ideals of integration with no well-defined final stage. It is an expansive process where the organizations and coalitions of partners learn to improve their activity, use BIM technologies with other tools and find ways of transcending the problems caused by the fragmentation of the field. This takes place through conscious experimentation and learning by the practitioners [91,92]. This view suggests that simultaneously with the integration by standardization and national guidelines, differentiation through the development of competing software platforms and local configurations of tools and practices the BIM use and development will continue. In addition to general guidelines, solutions that respond to the specific circumstances, the size of the project, composition of the partners, and the set of software tools used are needed.

The two approaches have different views of the means of enhancing the implementation of BIM and learning related to it. The normative framework relies on guidelines of different levels that define the best or mature state of technology development, training as well as descriptions of the cases of BIM use in which savings, efficiency and rewards have been achieved. These are used for providing exemplary cases of the advantages of the BIM use and constitute a positive model for the implementation. We however think that this framework needs to be complemented with more practically oriented approaches for effective organizational learning.

The activity theoretical approach suggests that accounts of experiments of BIM implementation in different organizations and contexts are needed. BIM implementation does not only provide solutions that can be adopted and further developed in other organizations and contexts sharing the similar challenges. It also provides knowledge about problems and bottlenecks of implementation which informs the further development of BIM models, complementary tools and organizational arrangements [93,94]. That is why well-documented accounts of experiments help to assess both achievements, problems and further challenges of developing the BIM use. They need to include detailed analyses of the forms of collaboration, ways of exchanging information, and of the uses of tools in order to allow learning across organizational boundaries. In addition, expansive learning in an organization or networks of stakeholders requires several successive cycles of experimentation through which new functionalities and uses are achieved. It is no surprise that the most developed production control systems in the industry include the 'standard part' in which the agreed and proven parameters and practices are preserved as standards and guidelines, *and* the 'problem part' in which problems of production and open questions are studied by trying and experimenting until the proven solutions has been achieved [95]. In the same way well-documented cases of the implementation can help keeping guidelines updated and inform the development of BIM-related tools and practices.

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