From Finnish AEC Knowledge Ecosystem to Business Ecosystem: Lessons Learned from National Deployment of BIM

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Government actors, public agencies, industry and academics have struggled to change the rules of the existing business ecosystem to support the networked practices that were envisioned back in the 1980s with the introduction of Building Information Modelling (BIM). Despite the industry's far-reaching technological capabilities, BIM has primarily assumed productivity improvement by individual firms, which has not lead to a systemic change in the Finnish architecture, engineering and construction (AEC) business ecosystem.

A field study of the Finnish AEC industry has resulted in a critical understanding of why successful and intensive R&D at a national level and wide adoption of BIM technology in Finland has not led to the expected systemic evolution of its AEC business ecosystem. Additionally, a methodology based on inductive grounded theory and historical analysis has been used to capture and identify the evolving and dynamic relationships between various events and actors between 1965 and 2015, which, in turn, has aided in the identification and characterisation of the knowledge and innovation ecosystems. The research findings provide insights for BIM researchers and governments in terms of establishing new policies that will better align BIM adoption with the systemic evolution of business practices in the AEC business ecosystem.

Keywords: Business Ecosystem; Building Information Modelling; BIM Adoption, Policy Development, AEC industry, grounded theory

Introduction

Finland is known as one of the leaders in the implementation of Building Information Modelling (BIM) on a national scale (Takim *et al.*, 2013, Ciribini *et al.*, 2015). Its long history of trust and open standards, and its small and agile construction industry are viewed as the perfect environment for BIM implementation (Taylor and Levitt, 2007). Indeed, Tekes, the National Technology Agency of Finland, led one of the most advanced and longest research and technology programmes in history of BIM, a programme that has been recognised as an international success story (Froese, 2002). Despite the globally recognized success, Finland's AEC industry has struggled to establish a new business ecosystem to support networked practices with BIM. Despite the industry's far-reaching technological capabilities, BIM has primarily assumed productivity improvement to deliver high quality projects, but that has led neither to a systemic change nor to a business transformation within the sector.

Despite lessons learned - that technological solutions could not solve the systemic problems of an industry – there is a disproportionately high level of concentration, both in the academy and in terms of policy implementations, on the technological merits of BIM which is still and largely viewed as central to industry transformation. Various governments are currently developing strategies and mandates in an attempt to integrate their industry with the use of BIM (Dainty *et al.*, 2017). The UK government views BIM as an enabler of the industry transformation agenda, as indicated in its industrial strategy (HM Government, 2013): "*... only through the implementation of BIM will we be able to deliver more sustainable buildings, more quickly and more efficiently*". Dainty *et al.* (2017) point to a potential danger that "performance improvement" could easily be elevated beyond a mandated technological improvement and seen as the only possible mechanism for realizing "radical, transformational change", as is the case with the positioning of BIM in the UK government's industrial strategy. The same report (HM Government, 2013) further emphasizes the emerging need for a more critical perspective to address the diverse implications of the BIM policy approach. Some of these critical perspectives have already been examined by a number of researchers who have focused on the role that industry plays in the adoption and use of Information and Communication Technologies (ICT), including the socio-cognitive, socio-organizational, business and other contextual dimensions of the architecture, engineering and construction (AEC) industry in relation to (ICT) (Jacobsson and Linderoth, 2010, Mosey *et al.*, 2016, Jacobsson *et al.*, 2017, Vass and

Gustavsson, 2017). These perspectives provide valuable insights concerning possible ramifications when the main drivers for ICT use are inconsistent with the central characteristics of the industry in question.

The process of aligning the drivers of ICT use (e.g. BIM implementation) and the industry dynamics will not always lead to the desired progress if the conditions created to aid ICT adoption are incompatible with those required to transform the industry in terms of the preferred direction, as was the case in Finland. Thus, our central aim is to establish a critical understanding of why a successful and intensive BIM R&D at the national level has not led to a systemic change in business practices and has not contributed to the emergence of a new business ecosystem in the AEC context.

The business ecosystem concept was first introduced by Moore (1993), as an approach to viewing firms, not as a part of an industry, but as an ecosystem where interdependent complementary actors cooperate, compete, and co-evolve capabilities around a new innovation in the global market, all in order to achieve a global competitive advantage (Moore, 1993, Iansiti and Levien, 2004, Clarysse *et al.*, 2014, Adner, 2017).

Pulkka *et al.* (2016) have suggested that the ecosystem concept would be beneficial for the construction industry in order to connect innovation with new value creation. An ecosystem approach was adopted in our research as a useful framework for the identification and analysis of the emergent value networks in the Finnish construction industry since the inception of the national technology programmes in 1983.

The contribution of the research to existing knowledge is twofold. Firstly, a cross-disciplinary ecosystem concept has been adapted to analyse the evolution of the AEC industry in the context of national ICT development in Finland. Secondly, it provides an understanding of several types of ecosystems' co-evolving interactions in terms of policy making. The research lies at the intersection of the intellectual domains of strategic management, social science and organization science.

The paper is structured as follows. Firstly, we introduce the ecosystem concept, its merits for the purpose of our research and characteristics of various ecosystems which forms our unit of analysis and explains the rationale behind our data collection and analysis framework. We then present the historical analysis of the developmental change between 1965-2015, providing insights into how new cooperative, competitive and regulatory relationships have emerged to support the development and implementation of ICT innovations, resulting in the evolution of knowledge and innovation ecosystems. The historical analysis provides useful empirical data that assists in understanding the complex relationships between different entities in the ecosystems while describing the conditions under which the technological change occurred. We then present the interview analysis which helped us to identify a range of contradictory relationships between the actors within and across knowledge and innovation ecosystems that inhibited the development of a business ecosystem within the AEC industry but supported wide BIM adoption.

The Ecosystem Concept

Over the past 20 years, the term "ecosystem" has become a focus of great interest in strategic management literature. It is characterised by an interdependence of cooperating and competing (but complementary) network of partners, a structured community, and it plays a critical role in determining value co-creation and co-capture (Moore, 1993). In addition, Teece (2007, p.1325) recognises an ecosystem as the environmental context not of an industry but of a business community of organisations, institutions and individuals who determine the institutional logic and formation of collective value creation. The network logic of the ecosystem is usually aligned with a keystone and is characterised by a large number of loosely connected actors (niches) that depend on each other for their mutual benefit and, through interdependence, can co-create value that no single actor can. Keystones play a key role in sustaining health of their ecosystem with the productivity, robustness, diversity and niche creation capabilities (Iansiti and Levien, 2004).

Pulkka *et al.* (2016, p.130) have suggested that the ecosystem concept can be used to bridge "t*he gap between general and construction industry-specific organizational and innovation literature*". Therefore, we adopted an ecosystem concept to understand the interrelationship (co-evolution) between various actors in the ecosystem by shifting the focus away from individual innovators (firms) to an analysis of the emergence of technological innovations within interfirm networks and communities.

Following Moore's (1993) business ecosystem concept, some authors have proposed different *types* of ecosystems such as *knowledge, innovation, industrial, economy, digital business*, and *social* ecosystems (Peltoniemi and Vuori, 2004). There are several examples of such ecosystems (business, knowledge, innovation etc.) that usually co-exist, co-evolve and mutually enable and contradict each other. For example, a *knowledge ecosystem* creates strategies for knowledge generation around knowledge hubs within a certain geographic proximity; Silicon Valley, Boston, and San Diego are good examples of a knowledge ecosystem (Clarysse et al. 2014). An *innovation ecosystem* is an integrating mechanism that fosters the exploration and exploitation of new knowledge hubs by involving policymakers and intermediary actors to generate value co-creation (Adner and Kapoor, 2010), while *a business ecosystem* is a network of competing and cooperating organisations that collectively provide new value to customers. Business ecosystems bring together competing and collaborating actors of different types that can co-create and co-capture business value, thereby introducing innovation to the market that cannot be created by a single organisation or any traditional business model (Moore, 1993).

The underlying logic of the ecosystem types is explained in Table 1.

Table 1. Characteristics of knowledge, innovation, and business ecosystems.

The ecosystems share similarities and differences in terms of the structures and values they create and the competition they generate. For example, the success factors for the knowledge and business ecosystems look similar – diversity of organizations and keystone players – but, according to Clarysse *et al.* (2014), there are differences in relation to their system dynamics, how value is created and captured, and the actors involved. Key players in knowledge ecosystems are typically public research organizations. In business ecosystems, "*the keystones are large, established companies that provide* *key resources and commercial infrastructures to the different ecosystem niches*" (Clarysse *et al.*, 2014, p. 1174). In turn, while knowledge ecosystems are based on value chains in which value creation flows from upstream to downstream players, business ecosystems are characterized by a non-linear value creation process where groups of firms deliver integrated solutions to clients and/or end users. Both ecosystems, according to Clarysse *et al.*, (2014), have different policy implications implying that strategies to support each type of ecosystem must be carefully tailored by policy makers.

As for the implementation of these concepts in this research, namely the in-depth analysis of the Finnish BIM innovation journey, the following section will provide an overview of the research framework and discusses how the ecosystem concept has been adopted.

Research Methods and Design

The interviews

The data collection started with an assumption that Finland, as an exemplar of BIM adoption on a global scale, could provide useful guidelines for other countries that are yet to experience an industry-wide BIM implementation. However, in the analysis of the interviews it became clear that the successful adoption of BIM technologies had not led to the expected business transformation within the industry. This finding changed also the focus of the research in progress to identify the reasons for this shortcoming.

The first phase of the research started with the review and analysis of literature (published in and outside Finland, 1965-2015) on the adoption and implementation of Information and Communication Technologies (ICT) in construction. A historical data analysis covered the periods from 1965, when active ICT development by the industry champions started, to 2015, when the interviews were conducted. The collected material helped prepare for a long interview process which aimed at uncovering the following: (1) the history of ICT use in the construction industry and the emergence of BIM (historical perspective); (2) the barriers, benefits and challenges of BIM as experienced by the interviewees at the project and industry levels; (3) interviewees' own ideas regarding the mechanisms to accelerate the implementation of BIM in the industry; (4) categorisation of the Finnish BIM development process into distinct phases.

Twenty interviews (31 hours of interviews) were conducted in 2015 with representatives spreading across five key stakeholders and end-user groups, namely: i) the government funding agency that sponsors technological development in Finland (Tekes); ii) academia; iii) management and business; iv) BIM users; and v) public building and infrastructure clients. In 2017, an additional four interviews have been collected with new representatives from three levels: CEOs, managers and operations to validate the analysis of the interviews collected in 2015. A total of 24 interviews have been collected. Twelve interviewees were actively participating in in the national BIM development and other 14 were not involved in the national BIM development. The juxtaposition of different viewpoints on technological development brings into focus contrasting views of socio-technical change and development that possibly led practices to today's situation with BIM adoption. Such integration provides contrasting pictures of the same processes without nullifying each other (Van de Ven and Poole, 1995). Table 2 presents information on the sectors and occupation of the interviewees.

Table 2 Selection of interviewees at five levels Analytical Framework

The Analytical Framework

Finnish AEC industry is a qualitative case study aimed at contributing to both the theory and practice of developmental change towards ICT-driven practices from an ecosystem perspective (Yin, 1994). An inductive grounded theory (Glaser and Strauss, 1967) approach was adopted for the continuous comparative analyses of the data obtained through literature and interviews, in order to generate a descriptive and explanatory view of the phenomenon under study. Grounded theory is an exploratory empirical research - as the researchers, we developed theories to explain our own observations, which were grounded in the data collected (Glaser and Strauss, 1967). The approach diverges from the traditional grounded theory approach as it is underpinned by a relativist position whereby researchers construct theory as an outcome of the interpretation of participants' stories. A particular emphasis, as acknowledged by Corbin and Strauss (1990) is devoted to integrating a multiplicity of perspectives and "truths," thereby extending the range of theoretically sensitizing concepts that are crucial in the analysis of human action/interaction (Macdonald, 2001. Multiplicity of perspectives enables simultaneous analysis of data and theory construction that is truly reflective of the participants' (namely the interviewees') context. Grounded theory has proved to be a particularly useful approach to understand the observed phenomenon, not through established "frames of reference", but in reference to its processual and contextual characteristics.

Through the sifting of various theories in relation to technological change, industry platforms and business models, the ecosystem concept has proved to be a useful framework that explains the struggle to translate the knowledge developed in national programmes into new businesses which would necessitate taking into consideration firms" attitudes, industry dynamics and their interaction with external actors. Our analysis did not reveal the presence of a new "business" ecosystem, rather, it underlined the existence of other types of ecosystems (knowledge and innovation) which have come to dominate and characterize the industry dynamics in Finland during the national programmes. Research in strategic management studies has recently recognised the need to look at the co-evolution of several ecosystems (Clarysse *et al.*, 2014, Valkokari, 2015), as is the case in the Finnish AEC sector. Therefore, we continued our analysis to identify the co-evolving proponents of those ecosystems that supported and potentially constrained the emergence of a new business ecosystem in Finland. Valkokari (2015), Clarysse *et al.* (2014) and Peltoniemi and Vuori (2004) outline the characteristics of various ecosystem types that helped to identify and explain the co-evolving ecosystems and absence of a new business ecosystem.

The Research Method

In order to build a grounded theory, the relevant literature was included as a secondary data source, such as quoted materials, as well as descriptive materials concerning events, actions, settings and actor perspectives. The interviews complemented the literature/document analysis by providing a qualitative understanding of the problems experienced by those in the industry, thereby revealing hidden actors and their motivations.

The triangulation and cross-verification of data from multiple sources has been beneficial in theory generation, yielding stronger substantiation of emerging concepts (Glaser and Strauss, 1967). To increase theoretical sensitivity (Corbin and Strauss, 1990), we referred to the literature that provided examples of similar phenomena as well as generating information about the contexts in which the interviewees were located. Triangulation of data and theory stimulated our thinking about new dimensions that we could use to examine the data collected through the interviews. In turn, this contributed to an analysis of additional data concerned with uncovering the conditions that might have influenced the interviewees' responses. Triangulation has involved the use of multiple methods to examine the same dimensions of the research problem. Multiple methods are a use of the ecosystem concept, grounded theory and historical approach to study the process of innovation development over time (Van de Ven and Poole, 1990).

An emphasis was placed on historical data collection encompassing the period 1965-2015. Capturing and analysing the historical data via document and interview analysis proved to be critical in tracing the complex relationships between various ecosystems. An advantage of this historical approach is its focus on capturing the developmental sequence of events as well as the tangible and intangible outcomes that they produce through different activities in space and time (Van de Ven *et al.*, 2008). A historical approach was taken for a number of reasons. Firstly, and as stated by the founders of grounded theory, "*historical moments are to be into account in the creation, judgement, revision and reformulation of theories*" (Strauss and Corbin, 1994, p. 280). Secondly, *"failure to analyse historical change in a general equilibrium context tends to result in a unidimensional perspective on the relationships bearing on technical and institutional change" (*Ruttan and Hayami, 1984, p. 2016). A historical data collection covers a period of approximately 50 years. A historical timeline (see Figure 2) has been developed, not only to document the analysis results, but also to aid the process of capturing new interrelationships across various actors and events. Therefore, the historical timeline has served both as an analytical and a representational tool to help us trace paths of connectivity between various actors, conditions and events, thereby aiding our data re-construction in such a way that its broader context – namely the knowledge ecosystem – became apparent.

Data analysis

The detailed process of data analysis is comprised of 14 steps as depicted in Figure 1.

Figure 1. Iterative analysis framework based on grounded theory

Based on the collected and coded data about the events (steps 1-2, Figure 1), a preliminary visual historical timeline was created (step 3, Figure 1) (see **Error! Reference source not found.**). The preliminary timeline was used effectively during the interviews as an external stimulus to trigger memories about past events (step 4, Figure 1). Specific periods of BIM development in Finland were identified since they were referred to regularly by the interviewees and later generalised through analysis (steps 5-6, Figure 2).

Figure 2. A historical timeline developed as an analytical and representational tool to capture and record historical sequence of key events/actors of the BIM "Finnish Innovation Journey"

Coding of the secondary and primary data was undertaken using Nvivo 11 software. The interview coding was conducted parallel to the construction of the historical map (step 3, Figure 1). The historical map was divided into distinct "*periods*" defined by key events and actors (step 5, Figure 1). For example, all quotes relating to the time of the "*Vera Technology Programme*" were linked to the period of "*Technology Development*" whereby the "*PROIT project*", although part of the "*Vera Programme*", marked the start of the "*Practical Implementation*" period. This helped refine the timeline by removing irrelevant events and retaining only the key events and actors. The historical map helped to construct a timeline with a qualitative description of each period identified in Table 3. Theoretical findings of the historical development of the Finnish innovation journey. The emerging concepts from the interview analysis describing periods were grouped under "*the name of programmes*", "*focus of programmes*", "*phases of development*", "*drivers*", "*organisational change process*", "*standards*", "*technological change process*", and "*examples of Finnish software*" (step 7, Figure 1). The historical analysis provided useful empirical data for understanding the complex relationships between different entities in the ecosystems and described the conditions under which the technological change occurred. The results are presented in Table 3.

Table 3. Theoretical findings of the historical development of the Finnish innovation journey

The results of the historical analysis were further refined by extracting concepts to identify the keystones which gave important clues regarding the nature of the ecosystem each period was defined by. For example, during the interviews, Tekes was often referred to as an actor that played a key role in BIM development at the national level. The role that Tekes played had been identified as a characteristic of "keystone" in the knowledge ecosystem, whereby the value it created was "knowledge of ICT development" in the national programmes.

Through the coding process of the interviews, 24 diverse categories emerged in relation to, respectively, Finnish and work culture, context, change management, drivers, industry, regulation, role of government, markets, academia, collaboration, contracts, lack of benefits evidence, socio-cognitive factor, business development, marketing, education, old business models, values, information, projects, standards, software market, and technologies (step 6, Figure 1). The concepts that emerged through interview coding were further analysed iteratively by extracting the opposing concepts and merging them into new groups (step 9, Figure 1), for example, "collaboration vs. competition", "technology push vs. market pull", "sub-optimising small tasks vs. seeing the whole picture", "international vs. national efforts" etc. The opposing concepts were cross-referenced with existing theories and observed patterns of the "innovation journey" presented in Van de Ven *et al.* (2008) (step 10, Figure 1). Additional four interviews collected in 2017 have contributed to the validation process of the findings (step 11, Figure 1). This was further juxtaposed to the characteristics of the ecosystem analogies (Table 1) explaining the dynamics of the knowledge and innovation ecosystems and the contradictory relations between the various actors that validated the lack of a business ecosystem in Table 4 presented in the discussion section (step 12, Figure 1).

Data Analysis Results and Findings

Historical Analysis

The mapping of the historical process of developmental change shows how new cooperative, competitive and regulatory relationships have emerged to support the development and implementation of ICT innovations, resulting in the creation of knowledge and innovation ecosystems.

The main findings of the historical analysis were the identification of four distinct phases (between 1965-2015) and seven key periods (Table 3), each corresponding to distinct actors and events associated with the co-evolution of a dominant knowledge and supporting innovation ecosystems, and, most recently, given the emergence of the digital business ecosystem:

- **Phase 1. The Emergence of the Knowledge Unit, 1965-1983:**
    - **Period 1**. The emergence of a knowledge hub is exemplified by the establishment of Tekla "*to challenge the industry with new technological solutions*" (Quote_Fin17).
- **Phase 2. (Developmental phase). Formation of the Knowledge Ecosystem and the Emergence of the Innovation Ecosystem, 1983-2002:**
    - **Period 2, 1983-1990. Abstract Development**. Formation of a knowledge ecosystem courtesy of the establishment of Tekes and the first national programme, RATAS, in order to develop theoretical knowledge using emerging concepts based on Building Product Modelling (renamed to BIM by Autodesk in 2002).
    - **Period 3, 1991-1995. Depression: Knowledge Loss & Gain.** The emergence of the Innovation Ecosystem across international boundaries due to the establishment of the

International Alliance for Interoperability (renamed buildingSMART in 2008) between 12 international companies in 1994. Depression time has significantly impacted the Finnish AEC industry’s business environment and Tekes increased the public funding provided to the AEC sector alongside the development of IFC (Howard and Björk, 2008).

  - **Period 4, 1995-2002. Intensive Development of Industry Specific Technologies** in second national Vera programme with a vision “*Management of information through the entire life cycle of the built environment*” (Kiviniemi, 2002). The RATAS programme’s theoretical concepts (which led to the evolution of BIM), were developed into real technological solutions that were tested in pilot projects. For example, HUT-600 is the world’s first pilot project where “*international research partnership extensively applied to the product modelling approach, tested the Industry Foundation Classes (IFC) interoperability standards, and employed an array of design, visualization, simulation, and analysis tools*” (Fisher and Calvin, 2002, p.5) (such as first tests of Solibri, the clash detection software), which was led by the largest Finnish public client, Senate Properties, in 2001-2002.

- **Phase 3. Mature building phase, 2002-2015:**
  - **Period 5, 2002-2007. Practical Implementation**. Establishment of the Sara programme (2003-2007) to create new business models supporting new technological solutions resulted in ineffective efforts. The pilot project, Aurora 1 (a continuation of HUT-600), became standard practice for BIM champions. The ProIT project first developed theoretical Product Modelling standards at the industry level; since 2003, Finnish champions shared knowledge to help create the first BIM requirements for GSA in 2007 (General Services Administration) in the USA that in 2008 resulted in an international Statement of Intention to Support BIM with Open Standards (Winstead *et al.*, 2008); in 2007, the first BIM guidelines were created for Senate

Properties and in 2007 BIM use became mandatory in all Senate Properties projects above €1million.

- **Period 6, 2007-2015. Building Maturity**. Stagnation. Incremental small improvements in the productivity of various processes in the AEC sector. COBIM 2012 and National Common BIM requirements were developed for industry-wide use. Large organisations adapted COBIM 2012 to address the specific use of ICT inside individual organisations.

- **Phase 4. A new wave of exploration, 2015-present:**
    - **Period 7, The emergence of Open Digital Business Ecosystem.** The Kira-Digi programme in 2016 brought about a new experimental platform that nourishes the creation of new digital businesses in the Built Environment sector through enabling various industries' cross-border mobility.

In Phase 1, Finnish entrepreneurs and champions were driven by technological potential in 1966, when Tekla was established as a consortium of several large architecture and engineering companies to challenge the AEC industry using technological solutions. Standardisation and efficiency were at the core of the technological development. There were no tools on the market that could fulfil entrepreneurs' ambitions; therefore, the tools had to be developed.

In Phase 2, the knowledge hub was expanded under the official programmes sponsored by Tekes, the Finnish Funding Agency for Innovation, with the intention to resolve the problems of technological integration, thereby eliminating information incoherencies between various industry specialists. Tekes has played a major role as a keystone, incentivising knowledge generation for technological development between the industry and VTT (Technical Research Centre of Finland) in the RATAS, Vera, SARA, and RYM Pre programmes (Kiviniemi, 2006).

This knowledge generation in the programmes followed a logic from Abstract Development (theory development in RATAS programme in Periods 1-3), to Concrete Development (Vera programme for technological development in Period 4), Practical Implementation (in the Sara and RYM pre-programmes, Periods 5-6), and more recently leading to the expansion of digital services in a platform-based economy in the Kira-Digi programme (Period 7).

The knowledge ecosystem established by Tekes in Period 2 was linked to the activities and actors associated with an innovation ecosystem facilitated by the International Alliance of Interoperability (IAI) in Period 3. The IAI's core function was to support open standards and interoperability at the international level. Our analysis also revealed that efforts put into the creation of knowledge and innovation ecosystems during Periods 2-4 did not lead to an emergence of a new business ecosystem during the Sara programme in Periods 5-6. Although the Vera programme generated recommendations for the Sara programme to focus on the change of business models and contractual relationships to support the adoption of BIM (Penttilä, 2005), the business models and contractual relationships did not reach the desired level to support collaborative practices with BIM. In fact, the Finnish AEC industry stopped evolving during the Sara programme and increasing stagnation was visible from 2002 until 2015. Although the Finnish AEC industry had made technological changes within individual large companies, thereby improving productivity, the vision for the management of information through the entire lifecycle of a building (proposed by the visionaries during Periods 2-4) had only been partially realised, while the conception of ICT's potential business value for clients remained unclear. There is an emerging recognition by the Finnish AEC industry of the need for alliance contract model and Public-Private Partnership (PPP) type projects to support qualitative changes in BIM practice. Nowadays, the AEC industry (Quote_Fin_01, 02, 07, 08, 16) perceives that there are no technical challenges with BIM as they have overcome these in the past and the move towards BIM is accelerating given the increasing maturity of BIM tools.

Period 7 has seen the establishment of a new Kira-Digi programme in 2016. It is currently led by the Ministry of Finance, which has employed new mediators to coordinate discussions between itself, the Ministry of the Environment, cities, and various industries, while "*The €16M programme's vision is to develop an open, interoperable information management ecosystem for the built environment*" (Törrönen, 2017). In 2018, Tekes and FinPro joined, forming a new organisation called Business Finland (Soini, 2018). Period 7 is not analysed because the possible outcomes can only be speculated on. However, at the moment, it seems that it might succeed in changing the business ecosystem for the Finnish AEC industry because of a very different approach compared to the previous efforts.

Interview analysis

The interview analysis helped us to identify a range of contradictory actions within and across knowledge and innovation ecosystems that inhibited the development of a business ecosystem for the Finnish AEC industry as presented below:

Technology push rather than market pull

Finnish BIM development was based on a technology push rather than a market pull, as was mentioned repeatedly by the interviewees. Three distinct reasons have been identified as the main cause of this: (1) public funding incentivised organisations to rely on the public sector to focus on technological development; (2) the software market did not offer either industry-specific tools or interoperability solutions to support new visions when the national development started in 1982; and (3) the cultural enthusiasm for technological development and "*large number of champions for a small country*" (Quote_Fin17) were fixated on technological solutions for productivity improvements, as captured in the following quotes:

> I guess the driver in the early days was that we must improve the productivity of the industry. […] but the culture and the business processes have not been developed. (Quote_Fin04).

> It is about productivity and efficiency. And, it gets adopted where it needs productivity and efficiency to get benefits […] The tools exactly benefit the actors to be more efficient […] and are more for individual actors […] It is more like a productivity tool for individual actors rather than a real product model or building information model. If we look at that part of the process, you get productivity improvements, so you can do the design work more efficient [sic] and with better quality (Quote_Fin19).

> It was a focus on technology. Business have not been a driver. Now we have to look at the business model and a change of business thinking. […] We have been the thought

> leaders in Finland, but it has been very private, and company driven. It is not anymore about technology, it is the question of innovation. (Quote_Fin14)

> I see too little organized innovation taking place within the industry. Tools and information management have evolved profoundly over the last 10 to 15 years, but business processes have remained the same. That leaves doors wide open for outsiders to radically change the business. (Metsi, 2018)

A review of Finland's R&D BIM portfolio has revealed that most of the nation's R&D expenditure went on technological developments or developments around technological implementation, stressing radical innovation (Hannus, 2006). By 2007, Tekes alone had funded over 150 technology programmes (Korhonen, 2008), however it later realised that the funding had not brought about the desired results:

> Tekes has been quite critical towards Built Environment in Finland. They gave a lot of resources for these different BIM-based projects and, at some point, they felt that there are not enough results from the given resources (Quote_Fin21).

This over-incentivisation of publicly-funded technological development created a local and inward competition between companies and too much reliance on these funds for business development. Consequently, companies limited their capacity to compete in the global market, while the AEC culture's "local thinking" (Quote_Fin12) further intensified during Phase 2.

Diminishing market diversity through the mechanism of public funding

The Finnish champions and participating organisations developed strong digital capabilities, knowledge, interdependencies and technological visions by exploring the technological possibilities of BIM. In turn, these conditions created a successful environment for BIM development while also making it equally difficult for small organizations to compete with this accelerated pace. Consequently, the Finnish construction market changed significantly, where diversity diminished due to smaller companies losing their competitive capacity and the market currently being dominated by large companies, as described by the interviewees:

> Market has changed a lot in last five years [sic]. Ramboll and Sweco are biggest and there are some other Finnish companies that have been merged together. Small companies have almost disappeared from the market. They do not even have a possibility to enter the market because they cannot fulfil client demands. (Quote_Fin23)

> I think that all companies which are bigger, more than €50 million, can make big projects. They must be able to use BIM if they really want to be [in] the market nowadays. (Quote_Fin11)

> BIM is not being adopted because of its promises, but because it's necessary to do so to stay in business. (Quote_Fin15)

Diminishing market diversity has been facilitated mainly by publicly-funded support mechanisms introduced by Tekes, which meant that only large companies could afford the necessary matching funding. Large organisations would get funding and employ small companies to do R&D for them. Later these small companies were joined or acquired by big companies.

High levels of idea diffusion versus established competencies

The excessive dominance of a certain group of champions, described in the previous section, created a small circle of decision-makers, which led to a silo. This has increased the gap between BIM champions and traditional practitioners. However, the pre-existing relations between firms and social networks helped the champions to build trust with organisations in an attempt to reconstruct the industry. This created a situation, as characterised by (Linderoth, 2017), whereby choices that significant actor groups make are grounded in what was perceived (by them only) as benefits or advantages derived from technological innovation. On the other hand, the established talents and competencies of those who hold power, constrained as they are by working almost exclusively in an industry context, seems likely to have inhibited the development of the industry's collective intelligence. The following quotes illustrate the situation:

> We are a small country and I think Finland has a very critical size, […] In Finland, we always gather around, like five people around the table, and those five people would

> decide what is going to happen in the next 10 years. […] This group can decide and influence others. […] So, once you get to know the whole team, they may move to other jobs. But you still keep meeting them in different jobs for a very long time. (Quote_Fin18)

On the other hand, there were companies willing to adopt BIM, while it was mostly middle managers who resisted changing their traditional work culture and used BIM within the context of traditional working practices:

> Everybody wanted to use BIM, but they wanted to use it exactly the way they had always worked. (Quote_Fin07)

The above-mentioned challenges are related to variations in BIM competences and skills, while Mäki and Kerosuo (2015) have examined how these have affected different roles, responsibilities and decision-making powers. The established talents and competencies of the network of champions and those that hold power, somewhat constrained by their comparatively limited milieu, was limited to a vision to transform the industry with technological implementation.

Leading such a transformation would require a diligent commitment to change management and the establishment of a business ecosystem strategy that would necessitate a keystone. Consequently, at the beginning of Phase 3, there was no motivation to change the existing business models or to adopt new industry contractual and procurement frameworks. This lack of motivation was also attributed to the realisation that the initial expectations set by Tekes were too high for the AEC industry's project-based nature and its capacity to accommodate the growth envisaged during the RYM Pre-programme.

Lack of government-driven mandates encouraging industry for systemic changes

The industry interviewees acknowledged the lack of government support during Phases 1-3 alongside the necessity of receiving a government mandate as a national building and infrastructure sector strategy. Although Tekes is a governmental body, its function was limited to providing public funding for technological development:

> In Finland, the field is ready, because we started earlier […] We cannot go further if the government does not help us. We are now at a level that we cannot evolve anymore. […] If it is mandated, then everybody does it (Quote_Fin11).

> We are making the strategy for the country level [sic]; still I think, we are lacking the support from our government. But bit by bit this is changing. […] If you want to get everybody involved, the entire private infra(structure) [sic] industry and the government, then I think there must be some kind of push effect from the government side. It is all about people, not the money. (Quote_Infra Industry)

> Governments are not very agile, they can be bureaucratic, and to change the process takes a lot of time. So, they're not able to be in the forefront. (Quote_Fin04)

However, the "mandate" is viewed as a negative connotation by some actors because the "*realisation of the benefits*" (Quote_Fin21) should be the main driver of change:

> We want to have more carrots than sticks. […] I do not know if BIM mandate will make any better [sic]?! (Quote_Fin21).

The only mandate that was implemented by Senate Properties (the largest public client in Finland) was in 2007 for public projects above 1 million euro. As a result, Senate Properties implements around 50 BIM projects per year. The number is constrained by the nature of the properties owned; 83% of all projects are refurbishments of existing buildings and often very small. The organisation reported in the interview that they do not have direct evidence whether "*the projects implementing BIM are successful because of BIM or not*" (Quote_Fin07,11,20) and whether this justifies a need for a diligent change management for BIM-based business models. This has also been emphasised by Vass and Gustavsson (2017). For example, Senate Properties questions if they will be able to use the same model in ten years' time:

> We have 500 buildings that are bigger than 500m². Currently, the most optimistic estimation is that around 50 buildings could be modelled per year during actual projects. That would still mean a 10-year transition period to BIM-based FM […] The models

> need to be kept current over that interval. Otherwise, they are not very useful as initial information for the next renovation. […] We would like to keep the models up to date. But it is a hard sell. If there is no use for the model and I cannot say if 75% of the data will be useful in 10 years. […] What if it will not work in 10 years with all the effort we were trying to do now? (Quote_Senate Properties)

Moreover, Senate Properties had a well-established system in place based on 2D electronic documents and it would require a systemic change to move the data to a BIM-based system. The following interview quotations illustrate this more clearly:

> The key players in Finland are cities, and owners have not been very active. […] Senate Properties has been active, but when I analyse them, it is not real. […] BIM people were in the office doing development in their own silo. (Quote_Fin12)

> So, Senate properties have not really invested enough into the personnel, implementing things in a proper way. One of the examples of that is that they are still not using BIM in their facility management. Senate Properties use BIM only to manage [the] design and production of construction projects but, after that, nothing. (Quote_Fin20)

An indirect consequence of having no government mandate was the industry's difficulty in terms of demanding its employees use BIM technologies:

> The challenges are people again. Some are very conformable with the new technologies and some are not. […] It is hard to get the team so that everybody is at the same level because people are at different levels at this moment [sic]. We do not want to make [sic] any punishment if you are not a BIM expert. (Quote_Fin09)

Contradicting the above quote, despite Senate Properties' mandate there is a mismatch between the implementation and the reality:

> We do not have our own designers, contractors, we hire them. And we cannot say to them what kind of technologies they should be using […] basically, we tell them what we want, so, we kind of hope that they will be using BIM. But we cannot make them… (Quote_Senate Properties)

The tension between the industry's desire for the government to mandate BIM and the mismatch between Senate Properties' BIM mandate and its actual implementation, raises the question whether a government mandate would have been more effective.

Supportive culture and "*relations based on pre-existing relations*" allow "*deviation*" (Quote_Fin07) in BIM practices. This is possibly one of the reasons why the Finnish AEC industry still hopes that the government will become more active and support the Finnish champions through an improved strategy targeting technological innovations at the national level courtesy of the new KIRA-Digi programme. However, governmental support also includes risks regarding preventing further development, such that managers can change a given firm's organisation much more easily and quickly than governments can change their institutional structures or requirements.

Mismatch between business model of software market versus BIM-driven innovation model

Research on the role that software vendors potentially exert on BIM-adoption is limited. There is an opportunity for vendors to support the growth of inter-organisational practices through coordination of strategic decisions between companies. The first attempt to implement this was initiated by Finland in 1996 through the International Alliance for Interoperability, which aimed at setting international standards via Industry Foundation Classes (IFC) (Howard and Björk, 2008). This meant that stakeholders could set the necessary international mechanisms to coordinate technical standards in IFC, enabling effective processes and the reduction of uncertainties (Laakso and Kiviniemi, 2012). In 2015, the buyers of BIM platforms still had comparatively low trust in interoperability across the BIM platforms:

> So, if I compare BIM to 2007, I'm actually quite disappointed, [...] I realised that having two separate systems talking to each other – it's not that impossible, it's 2015 and we went to the moon in the 60's [...] So, how come we can't get some sort of attribute from one system to another in 2015? [...] but the main problem […] is the collaboration between the IT systems of the suppliers. (Quote_Fin08).

> Another problem is interoperability […] There are some drivers against it, market-leading information technologies companies do not want their customers to change a system, because all of it for this work is locked into a specific system […] they stop the progress. It makes perfect business sense. You never see a market leader support the standard in the industry sector. […] We also have to understand business drivers for global IT companies (Quote_Fin18).

Howard and Björk (2008) have also argued that software vendors are a key element in BIM and that they should state their real commitment to IFC implementation. For example, by denying their liability concerning the data's technical quality, thereby increasing the risks that clients take, the software providers act as inhibitors and thus dilute the benefits of BIM adoption as also described by Mosey *et al.,* (2016).

Another inhibiting factor can be attributed to the oligopolistic nature of the software market, which is dominated by a small number of vendors. Because of the resulting monopolisation, consumers are usually reluctant to try and use software that is incompatible with mainstream products, even if they offer competitive prices and quality. Large software companies have "*a disproportionate control over the terms of market competition, by not only setting prices but manipulating product quality in ways that are privately profitable but not socially efficient*" (David and Greenstein, 1990, p. 21). This type of behaviour directly affects the users of BIM technologies, who are offered limited choices that inhibit innovation, thus creating an industry and public client perception that BIM does not offer enough value to make it worthwhile to invest in, although its benefits are evident (Miettinen and Paavola, 2014).

Consequently, a contradiction becomes apparent between the need for clients to support the transition to BIM-based practices and the business models of the fast-changing technological environment on a global scale.

Traditional division of labour versus the need for new contractual models

Quotes from the interviews clearly show that many stakeholders do not favour changes in contractual relations. This is partly due to the culture of the AEC industry in general; although industry stakeholders in Finland are keen to "*cooperate and reach a consensus*", they can also "*hide behind the contracts*" (Quote_Fin15). The following quotes illustrate this situation:

> The current contracts do not really emphasize collaboration, so everything is fine as long as the project is going well. But, if there are any problems that people should do extra work [sic], and if not, they can hide behind their contracts. (Quote_Fin15);
>
> Making people talk [to] and understand each other seems impossible! (Quote_Fin12);

The contractual changes that BIM requires entail both restructuring power relations and the reorganisation of roles in the AEC industry. This would also mean additional managerial responsibility that managers might be unwilling to undertake due to the inter-organisational politics involved.

Lack of business development and leadership competencies in education and practice

A number of researchers across the world have called for a move away from traditional architectural and engineering education to BIM-based instruction to address the digital/cultural change (MacDonald and Mills, 2011, Kocaturk and Kiviniemi, 2013). The interview analysis indicates that Finnish AEC education focuses primarily on traditional technical skills while there is a need to acquire competencies for leadership and business development:

> The education of architects and building engineers focuses very strongly on the traditionally important technical and design competences. There is practically no teaching of business or management skills. For architects, 'business' is almost a curse word. (Quote_Fin20)
>
> The problem in companies now is to organize its management and leadership. We have the background, software, technology but we didn't have those business managers who really create new ways of organizing businesses. The challenge was that we never got this support from top management in business. […] If you look at the construction business, top management has the same education. They all have [a] master's degree in construction, but they don't have, for example, an MBA or social sciences background.

> We really need this kind of diversity in top management to understand business opportunities. (Quote_Fin14)

> I do believe, especially after all those years, that education is key. You need to train a new generation with a new way of thinking. (Quote_Fin18)

An understanding of business strategies seems to be a key to recognising new opportunities in emerging technologies. Similarly, marketing is also seen as a missing skill that could have improved the national initiatives, including initiatives in terms of internationalization and inter-organisational practices:

> I think we didn’t make much noise out of it [sic], sort of internationally. It was more like, ‘Okay, let’s just do that’. But, I think that might be a Finnish way of doing things. Which is kind of good when you are developing, but if you want to have commercial success, then Finnish way [sic] is not the best. Typically, many Finnish inventions have been commercialized by others. (Quote_Fin17)

There is limited or no engagement between specialist courses in universities which, in the long run, could overcome the cultural barriers created by an “us and them” distinction, e.g. “*engineers and architects are not friends*” (Quote_Fin11).

> On the long term, I think that we should change education of the construction industries. How architects, engineers, project surveyors, site managers should be educated that already during the education phase they have to collaborate and start to understand what the others are doing. Now we are educating people in the silos. (Quote_Fin20)

The Finnish knowledge ecosystem lacked educational training programmes and accredited degrees. According to the interviewees, such programmes are still not at the desired level. There is an evident lack of experts in BIM coordination and BIM management. In the last two decades, the number of students entering the Finnish construction market has decreased because other technological areas provide them with better opportunities. Even if the students are technically capable, there is an apparent lack of holistic understanding of BIM practices; the interviews revealed that some middle managers did not allow novices to use BIM technologies because they were afraid of losing control of the production chain. Meanwhile, BIM implementation is largely dependent on those project managers who are early adopters as indicated by Mäki and Kerosuo (2015). The boundaries of the industry's established communities were quite strict, which limited diversity in terms of practice, as explained below:

> Built Environment sector in Finland has been a quite closed community […] Established companies keep boundaries strict and they traditionally been hiring [sic] only people from certain degrees and universities and not people from outside areas. It has been a closed community and I have heard that from others too. But now things are changing. (Quote_Fin21)

Discussion

The Finnish national efforts and institutional arrangements around technological developments led to the creation of successful knowledge and innovation ecosystems expecting the technological knowledge to eventually translate into business ecosystems providing global competitive edge to the participating companies. This pattern of outcomes can be attributed to the fundamental differences in the value creation strategies adopted by different ecosystems. The knowledge, innovation and challenges related to the re-establishment of a new business ecosystem are illustrated in Table 4.

Table 4 Characteristics of knowledge, innovation and business ecosystems in relation to BIM development and implementation in Finland (1982-2015).

Several reasons have been identified to explain the reasons that impeded the emergence of a new business ecosystem:

(1) Tekes, with a technology vision, has incentivised the industry actors to rely on public funding for business development instead of seeking other strategies;

(2) Business ecosystem strategy requires a keystone that can drive or enable an industry transformation, propagating a new type of behaviour across the network of actors, and

promoting the health of the niche by increasing its collective productivity, robustness and diversity;

(3) There was a lack of participation of the necessary actors, such as owners, local governments, academia, software vendors and complementary industries. There was limited inter-dependency or co-evolution across participating actors beyond the life-time of the projects;

(4) There was limited understanding of the business value BIM-adoption could offer to clients and to end-users, until recently;

(5) Despite a wide adoption of BIM in Finland, the AEC firms only recently started to recognise the need for new contractual, procurement and business models.

Despite the above-mentioned challenges, the national development of BIM in Finland has been internationally well recognised and has provided Finnish companies and research institutes with global visibility. As a result, Finland has achieved a global position as one of the leading countries in BIM development and adoption. Additionally, technological development has led to success stories: 1) Some Finnish software developers, e.g. Tekla, Progman and Solibri, created successful businesses in the software market; (2) Leading companies in the AEC industry successfully adopted values in the knowledge ecosystem and improved intra-organisational practices using BIM. As a result, BIM has been developed and implemented successfully for improved productivity by the leading organisations. However, the focus on productivity improvement has not led to a business development as suggested by Fin04, 05, 08, 14 and 19. The research by Pekuri *et al.* (2013) have also showed that the managers in the construction industry do neither understand the concept of business models properly nor exploit any similar value creation analysis in their business; (3) The long-established incumbent, the leading building services company Granlund, and the challenger, general contractor Fira, have both become successful examples of Finnish companies developing service-dominant logic and client-centric business models based on BIM, even though the external environment did not support such developments. Although some of the interviewees indicated that a governmental mandate was a crucial element to improve the industry, policies are known to have limited influence on what will be implemented in the real world (Spencer *et al.*, 2005). The success of Granlund and Fira have also become notable examples to show that top management can indeed change the private organisations much more easily and quickly compared to government mandates.

Our research findings strengthen the findings of Pulkka *et al.*, (2016) by providing empirical evidence that the ecosystem concept does indeed offer a useful framework to understand emerging value networks in the AEC industry. The underlying strategic logic adopted in knowledge and innovation ecosystems with technological visions created in the national ICT development in Finland did not lead to the emergence of a business ecosystem in the AEC context at least during the period of 1965-2015. However, the disconnect between the knowledge and business ecosystems was emphasised earlier by strategic management researchers (Clarysse *et al.*, 2014) and a need to look at nourishing mechanisms for business ecosystems from a policy makers perspective (Rinkinen and Harmaakorpi, 2017); our research grounds and verifies these findings within the Finnish AEC industry context.

Conclusion

The main aim of the research was to establish why successful and intensive R&D and wide adoption of BIM technology in Finland has not led to the expected systemic evolution of a business ecosystem. The ecosystem concept has been adopted as a unit of analysis to capture the structural and functional interrelationships between various actors. Government actors, public agencies, industry and the academy have all struggled to change the rules of the existing business ecosystem in order to support the “networked practices” that were envisioned back in the 1980s with the first introduction of BIM. With far-reaching technological industry capabilities, the Finnish AEC industry has been able to establish successful knowledge and innovation ecosystems to support BIM’s early adoption. However, BIM has been adopted primarily for productivity improvement by individual firms, which has not lead to systemic change in the Finnish AEC business environment.

Finnish champions have offered crucial lessons based on the national development of BIM, particularly for countries that are either going to or consider adopting BIM. Although some of the findings are context-specific, the majority of our findings can be generalised and adapted to other (country) contexts and with critical policy implications.

Limitation of the analysis is focus on the Finnish national development of BIM as it does not explore the developments made by the international software market. The application of a limited number of theories in conjunction with the business ecosystem concept could also potentially be a limitation of our study. Broader theoretical underpinnings and system dynamics approach would enable a deeper understanding of the industry's dynamics and its actors.

Future research could explore: i) a viable keystone in an AEC business ecosystem; ii) the specific features of a future BIM-platform where various business ecosystem actors can co-create new value that no single actors can; and iii) the mechanisms that can nourish and facilitate self-sustaining behaviours in a business ecosystem.

Acknowledgement

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Figure 1. Iterative analysis framework based on grounded theory

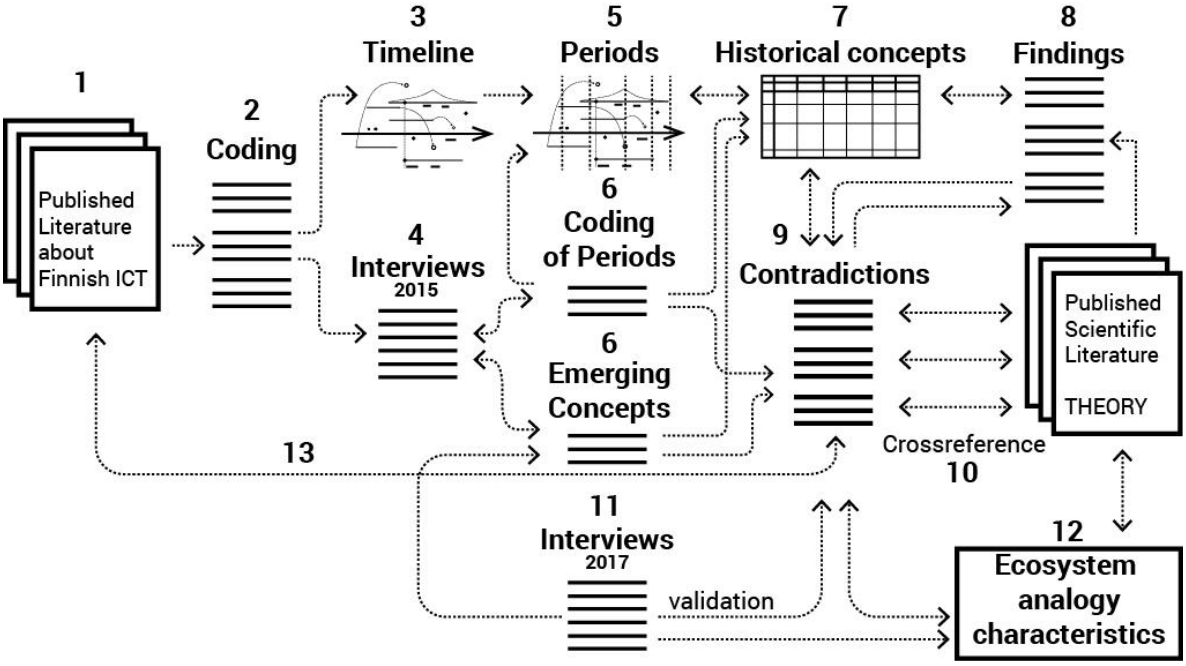

Figure 2. A historical timeline developed as an analytical and representational tool to capture and record historical sequence of key events/actors of the BIM "Finnish Innovation Journey"

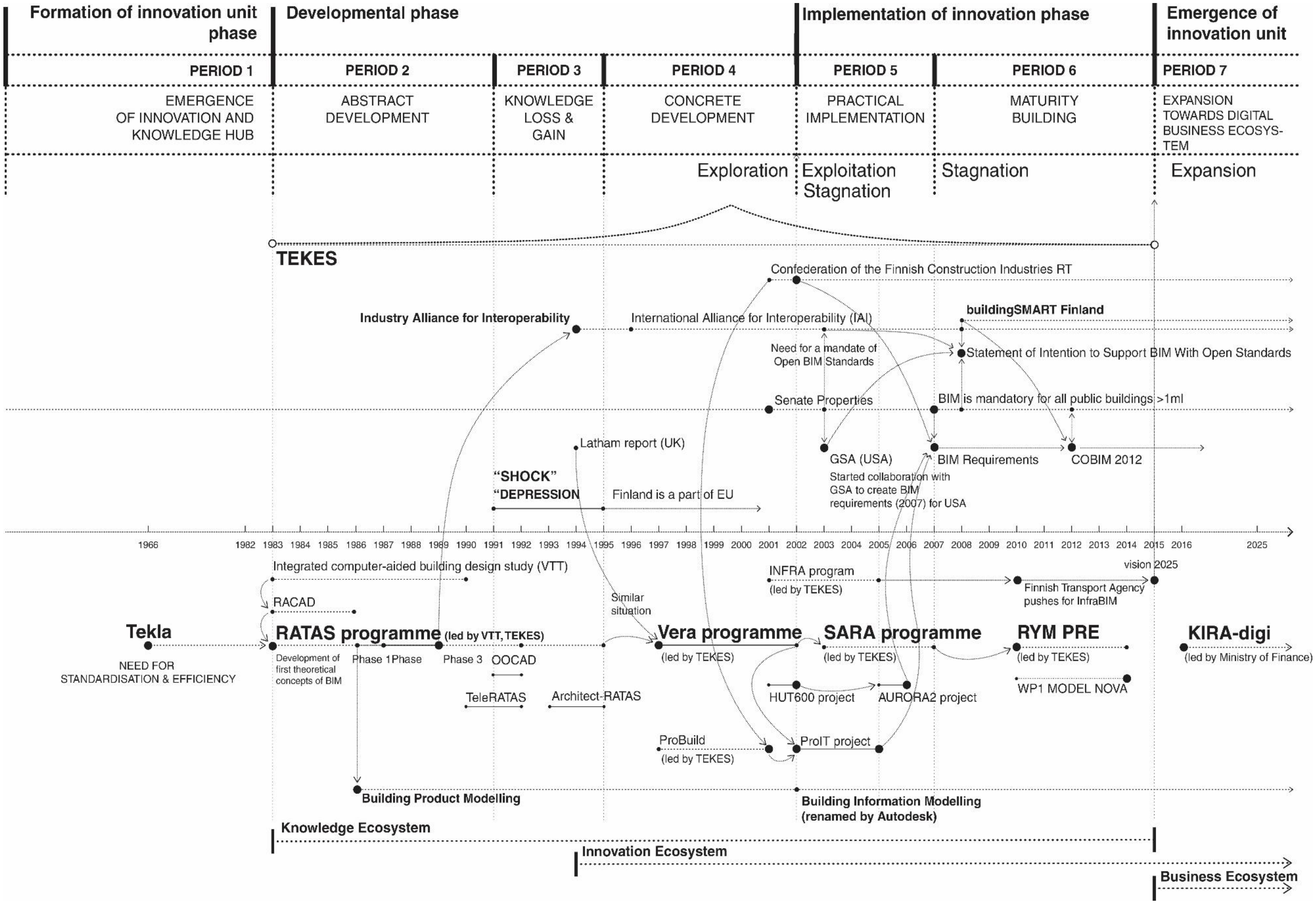

Table 1. Characteristics of the knowledge, innovation, and business ecosystems.

	Knowledge ecosystem (Clarysse et al., 2014)	**Innovation ecosystem (Adner & Kapoor, 2010)**	**Business ecosystem (Iansiti & Levien, 2004; Moore, 1993)**
Logic	Knowledge exploration, co-creation and sharing around knowledge hubs	Innovation co-creation, sharing and capturing throughout all actors fostering the creation of growth, interaction, and innovative start-ups around so-called knowledge hubs	Business value co-creation, sharing and capturing for customers amongst competing and cooperating actors with a complementary niche
Connectivity	Geographically clustered knowledge hubs to co-create and share knowledge between non-competing actors, closed and open, high density of actors	Geographically or internationally clustered actors that create an open network to diffuse innovation, closed and open, high speed innovation diffusion	Global value network, closed and open decentralised decision-making, loosely interconnected actors
Actors	Public and private research institutes, academia, technology entrepreneurs serve as knowledge nodes	Innovation policymakers, local intermediators, innovation brokers, international alliances, absence of customer actors	Suppliers, customers, and companies as a core, other actors more loosely involved as complementary actors
Keystone	University, PRO	Alliance or an intermediary organisation	Global large company or an alliance

Table 2 Selection of interviewees at five levels

Levels	Sector	Occupation	No of participants	Hours of interviews	No of interviews
Academia	Academia	Research Scientists	6	10	6
Public owned clients	Senate Properties (Building sectors)	BIM managers	3	2	2
	Finnish Transport agency (Infrastructure sectors)	BIM manager	1	2	
Public organisations	Governmental funding agency, Tekes	Manager	1	1	3
	Strategic Centre for Science, Technology, and Innovation of Built Environment in Finland	Manager	1	2	
	Intermediary interdisciplinary mediator	Manager	1	1.5	
Business & Management	Software developer	Manager	1	2	8
	General Contractor	Innovation & Business Managers	3	5	
	Architectural office	Managers	2	2	
	Private Organisation	Consultant	1	2	
	Engineering service provider	CEO, Manager	1	1.5	
	Engineering service provider	Senior Specialist Digital	1	1.5	
Users of BIM at the operational level	General Contractor	Site Manager	1	1	4
	Engineering service provider	HVAC Engineer	1	1	
	Architectural office	BIM technician	1	1	
	General Contractor	Production planning engineer	1	1.5	
		TOTAL	**26**	**33**	**24**

Table 3 Theoretical findings of the historical development of the Finnish Innovation Journey

Concepts	**Period 1**	**Period 2**	**Period 3**	**Period 4**	**Period 5**	**Period 6**	**Period 7**
Time periods	**1960-1983**	**1983-1990**	**1991-1995**	**1997-2002**	**2003-2009**	**2010-2014**	**2015>**
		ICT development supported financially by TEKES (1983-2015)					
Programs		**RATAS**	**DEPRESSION**	**Vera**	**Sara**	**RYM PRE**	**KIRA-digi**
Focus	**Innovation**	**Theory**	**R&D**	**Tools & Process**	**Business**	**Process**	**Open Digital Business Ecosystem**
	Exploration				**Exploitation**	**Stagnation**	**Expansion**
Phases of development	**Formation of Innovation Unit phase**	**Developmental phase. Formation of Knowledge unit**			**Implementation of Innovation phase**		**Formation of Business Unit phase**
Names of periods	**Emergence of Knowledge Hub**	**Abstract Development**	**Knowledge Loss & Gain** **"SHOCK"**	**Concrete Development**	**Practical Implementation**	**Maturity Building**	**Emergence of an Interdisciplinary Mediator**
Drivers	Future champions develop first IT skills in universities, first access to computers, formation of first ideas for digitalisation of practices, technological enthusiasm	TEKES drives interest in champions to do R&D projects	Recession forces champions to invest in development of tech. skills and technologies because of heavy losses of experts and resources	Need to develop tools not available in the market to support new information management	**Positive trends:** Industry-wide implementation, small incremental improvements, maturity building, infrastructure sector starts BIM implementation, increasing focus on use of BIM in safety management, acceptance of a new way of working increases slowly, fast diffusion of BIM amongst architects, understanding of the need for improved collaboration and contract changes, new industry champions are emerging. **Negative trends:** interest in ICT slows down, champions retire, BIM is used mainly in large projects, "BIM is co-business". Lack of support from some top management to share information, manifested mistrust between contractors and architects/engineers that "hide behind contracts"; culture and contracts do not change and are based on 2D documents that do not support collaboration. Unclear what is needed, who should deliver it and when; unclear value of BIM for clients, difficulty in explaining BIM in a simple way to diffuse innovation amongst stakeholders, BIM is used widely as a standard practice only in the design phase		Ministry of Finance initiated and financing Kira-digi in partnership with Ministry of Environment, cities and private sector to start negotiation between focus on interdisciplinary cooperation and start-ups to generate new businesses based on platform economy and creation of interoperable information management ecosystem for the built environment. AEC industry acknowledged the nature of their practice as non-scalable, increasing. BIM is diffusing to construction sites
Key activities in Finland in relation to national development	Creation of fundamental principles and knowledge, use of computers for calculations and simulations, establishment of new universities, need for standardisation, emergence of small software companies, recognised problems of culture and organisation, use of computers in design requires expensive computer systems which most companies cannot afford	Lobbying for Tekes funding, spread of theoretical knowledge and ideas for ICT, establishment of vision, first theoretical research, increasing international collaboration, architects resist adopting new tools	Loss of knowledge, experts and young generation. downsizing of companies, increased need to be efficient. Champions develop in-depth expertise in ICT, Finland becomes high-tech society, increased adoption of computers and CAD, first Lean Construction group	Development of practical knowledge and technologies for integrated information management for the whole lifecycle, first piloting projects. Increased spread of knowledge at national level and heightened influence at international level, strong emphasis on tools development previously unavailable to support new ideas	Increasing number of pilot projects, wider adoption only after 2005, development of roadmaps for business, but "no significant results," increased R&D inside companies, top management level in most companies unready to share information	Spread of practical knowledge at industry level, internal adaptation, focus on inter-organisational collaboration, increased awareness of the need for new modes of collaboration, architectural models are becoming less precise than in 2005 because consultants hired by the client still base calculations on 2D documents. Lack of managers who can lead change, decreased need for the construction of new buildings in Finland	Emerging changes in inter-organisational collaboration supported by new contracts and business models, some use of new contractual models, e.g. IPD, Alliance and Knotworking. Focus on energy research. Less research on BIM. The latter is still used mainly in large scale buildings vs increasing gap with traditional industry. Champions like Fira reorganise their business models, moving to a client-centric logic while Granlund expands its services towards a digital business ecosystem. Diffusion of BIM to construction sites through mobile technologies.
Standardisation	Emergence of the need for standardisation to resolve integration issues	CAD standards are emerging	CAD standards are mature. First national attempts to develop BIM standards, e.g. OOCAD	Strong participation in the international development of the IFC standard begins	IFC implementation is not yet mature enough for practical use. Industry and Research Institutes (VTT) collaborate to develop first world BIM guidelines for architectural modelling for Senate Properties	Industry develops national BIM requirements (COBIM 2012) for all specialities at the national level	Expansion of standards to BIM dictionary in collaboration with Norway, development of unified standards that allow other industries to "plug in" to open city model based on automated machine-readable IFC
Technological change process	In-house development of new tools that were not available on the market, 3D visual marketing, provision of digital services to companies. Technologies support structural, mechanical and electrical design, first time international vendors enter Finnish market (1970s), CAD technologies are too expensive for most companies in the AECO industry	Development of research concepts, solid modelling becomes available for commercial use (1980s). Investment in immature technology	No usable building product model tools yet. Increased focus on technological development in a few organisations.	Development of technologies on a large scale, need for more reliable and extensible tools.	Software able to conduct complex design only became available after 2005	Market offers a range of tool sets to support new information management processes	Focus on mobile technologies, Internet of Things, energy simulation, space organisation and use for FM, networked platforms that link the public and private sector, mobile technologies
Examples of Finnish software	Tekla (1966), Vertex Systems (1977), Kymdata (1979), Progman (1983)			Solibri Model Checker, MagiCAD (by Progman), Tekla Structures	Constructor/ Vico software	Tekla BIMsight	SiteDrive (by Fira)

Table 4. Characteristics of knowledge, innovation and business ecosystems in relation to BIM development and implementation in Finland (1982-2015).

	Knowledge ecosystem until 2015	**Innovation ecosystem**	**Challenges associated with new business ecosystem emergence**
Logic	Knowledge exploration, co-creation and sharing around knowledge hubs for technology development e.g. IFC	Knowledge co-creation and diffusion by buildingSMART	Business transformation was not considered (technology push); Lack of scalability of existing business value and understanding of value for the clients and end-users until recently
Connec-tivity	Geographically-clustered knowledge hub of technology champions that co-created knowledge in national programmes' pilot projects; extensive international collaboration	Geographically and internationally clustered actors that create an open network to diffuse innovation; extensive international collaboration	Regional network of individually operating large organisations, most businesses are still organised in a traditional way; Senate Properties have not implemented diligent change management strategy for business model innovation based on BIM for FM or changed the procurement practices for AEC services
Actors	VTT, technology entrepreneurs (e.g. Tekla, Solibri, Progman), large leading contractors (e.g. NCC, Skanska, YIT), leading consultants (e.g. JKMM, Granlund, Gravicon) and public owner (Senate Properties)	Software Vendors, A/E Consultants, and Construction Companies, Senate Properties	End-users: no services; Owners: Senate Properties (business models have not changed, BIM is a "co-business"); Construction companies: e.g. NCC, YIT, Skanska; Software developers: e.g. Solibri, Tekla, Progman; Consulting Services, e.g. Granlund, JKMM, Gravicon; Most actors on supplier's side, cities (powerful drivers), clients, academia were absent including other complementary industries
Keystone	Tekes Finnish Funding Agency for Innovation	International Alliance for Interoperability that later became buildingSMART	Absence of a keystone that sustains the health of the ecosystems, its productivity, robustness, diversity and the niche creation capabilities
Platform	Public funding through national programmes	Collaboration forum funded partly through national programmes	Lack of understanding of what constitutes a platform on which various actors can co-create new value
Vision	Increased national competitiveness, export AEC/FM software and construction services (see cic.vtt.fi/vera)	Disseminate information on Open BIM and support its member companies in implementing BIM-based processes in order to promote dialogue between the software vendors and end users. To help the member companies to both recognize the benefits of BIM and to develop and implement BIM-based business.	Open Standards (e.g. IFC) as a solution to problems of software integration and exchange between various disciplines**,** technological vision that did not lead to a business development or transformation: national practices are not developed to the desired level