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Published in:
Construction Management and Economics

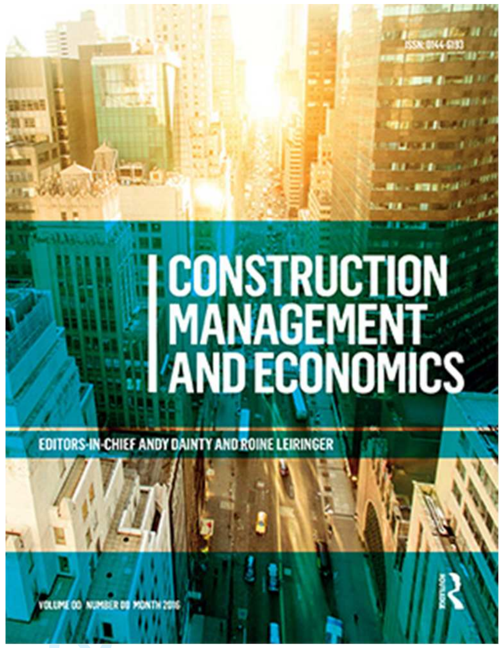
DOI:
10.1080/01446193.2018.1476729

Published: 13/11/2018

Document Version
Peer reviewed version

Please cite the original version:
Lavikka, R., Kallio, J., Casey, T., & Airaksinen, M. (2018). Digital Disruption of the AEC Industry: Technology-Oriented Scenarios for Possible Future Development Paths. *Construction Management and Economics*, *36*(11), 635-650. https://doi.org/10.1080/01446193.2018.1476729

Lavikka, R., Kallio, J., Casey, T. & Airaksinen, M. (2018) Digital Disruption of the AEC Industry: Technology-oriented Scenarios for Possible Future Development Paths, Construction Management and Economics (accepted for publication on 8th of May, 2018).



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Journal:	*Construction Management and Economics*
Manuscript ID	RCME-MS-17-2898.R3
Manuscript Type:	Research Paper
Keywords:	Boundary objects, Construction industry
Keywords (user-entered):	Scenarios, Digital, Boundary spanning

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Abstract

Decision-makers in the architecture, engineering, and construction (AEC) industry lack knowledge about the implementation of digitalisation to generate value. We applied a scenario planning method developed by Schoemaker and Mavaddat to provide decision-makers with information for using digital data and technolo-gies to create value for customers. We aim to theoretically understand how the scenario planning process helps AEC decision-makers to make sense of the fu-ture. Our findings show that boundary spanners are needed for steering the dis-cussions among industry actors toward shared knowledge about the technologi-cal, social, economic and political changes needed at the industry level to opti-mise the benefits of digitalisation. Our findings also show that boundary spanners apply scenario figures as boundary objects to cross knowledge boundaries. Based on our findings, we theoretically conceptualise scenario planning as a boundary-spanning activity that enables AEC decision-makers from different fields to share tacit knowledge and to cross knowledge boundaries. The practical implication is that scenario planning provides a method for AEC decision-makers to make sense of the changes needed to realise the preferred future for the industry.

Keywords: Digital; scenarios; boundary objects; boundary spanning; construc-tion industry

Introduction

The architecture, engineering and construction (AEC) industry is the largest industrial sector in the world; thus, it has been addressing many global challenges. For example, a recent report by Gerbert et al. (2016) stated that 30% of global greenhouse gas emis-sions are attributed to buildings. Every day, 200,000 people move to urban areas, and they need healthy and affordable housing (Gerbert et al., 2016). Thus, the industry's impact on global warming and people's living conditions is remarkable. Unfortunately, the industry has not been innovative enough during the last couple of decades, and this is verified by its flat productivity curve. The industry is required to make enormous improvements to efficiently and effectively meet the growing expectations resulting from urbanisation (Winch, 2003).

Digitalization presents great opportunities for the development of the AEC industry. For instance, digital solutions support data-driven decision-making based on visualisations and simulations (Gerbert et al., 2016). Digitalization also provides a basis for collaborative value creation through new forms of interaction, improved information sharing and transparency among stakeholders (Schober and Hoff, 2015). According to Bock (2015), construction automation technology, such as robots, is slowly becoming an inherent element of buildings and building components.

Digitalisation poses threats to the future of the AEC industry, however. Start-ups with digital innovations may disrupt the traditional AEC businesses such that the current players will earn less revenue (Christensen, 1997). In Finland, more than 80 start-ups that base their businesses on digital technologies have emerged and have started to operate in the AEC industry during the past five years (Lehtinen et al., 2017). Technological innovations such as social media, cloud computing, sensors, big data and wireless networks are no longer buzzwords. They have the power to transform traditional businesses (Porter and Heppelmann, 2014). The incumbents of the media, commerce, and music industries have experienced the enormous forces of new business models based on digital technologies and data. Uber, Airbnb and the App Store are examples of digital services run on platform-based business models. (Gawer, 2014; Van Alstyne et al., 2016)

Digitalisation has started to affect the conservative AEC industry. Building information modelling (BIM), wireless sensing, and data analytics have the potential to transform infrastructure construction and maintenance (Gerbert et al., 2016). Because of the possible disruption to the industry, AEC decision-makers have raised questions about which digital technologies, key trends and uncertainties will affect the industry (Linderoth, 2016; Jacobsson et al., 2017). A recent study conducted by Schober and Hoff (2015) found that AEC decision-makers are uncertain about realising the benefits of digitalisation. In other words, company decision-makers are struggling to understand how to manage the change from current construction practices to digitalised construction supply chains. Studies have shown that the lack of knowledge on how to change practices is one reason that digital tools such as BIM have not been used to stimulate change throughout the AEC industry (Fox and Hietanen, 2007; Schober and Hoff, 2015; Vass and Gustavsson, 2017).

The implementation of digital technologies and solutions is an important topic for industry practitioners and construction management scholars (Bröchner, 1990; Fox and Hietanen, 2007; Jacobsson et al., 2017). Industry practitioners are unsure about what should be implemented because the future is very uncertain. One way to help AEC decision-makers to overcome these challenges is to apply methods targeted at predicting the future. Scenario planning offers an effective method for anticipating and dealing with uncertainty systematically and holistically (Schoemaker and Mavaddat, 2000). Environmental uncertainty, the assumption that the future will not be constant, has been recognised as supporting the need for scenario planning, which facilitates strategic adaptation by challenging decision-makers' preconceptions (Schoemaker, 1995). However, as several researchers, such as De Smedt et al. (2013) and Chermack (2004) have noted, no studies have examined the role of scenario planning in managing uncertainty.

We set out to empirically explore how scenario planning helps AEC decision-makers to understand the changes needed to optimise the benefits of digitalisation. Our goal is to conceptualise scenario planning theoretically based on our empirical findings.

We have structured our argumentation in the paper as follows. First, we discuss the literature on scenario planning. This sets the stage for applying scenario planning in the empirical context of anticipating the future of digitalisation in the AEC industry, especially in Finland, our domestic market. We then explore the literature on boundary objects and spanners, which are essential components of the boundary-spanning activity in which various knowledge boundaries between organisations are crossed to enable knowledge co-creation. We consider the boundary-spanning activity crucial for making sense of the digital future at the AEC industry level. After the theoretical discussion, we present our empirical research method.

In the empirical section of our study, we applied a scenario planning method developed by Schoemaker and Mavaddat (2000). We identified the key forces and create four technology-oriented scenarios that we applied in three expert workshops to validate the scenarios and to facilitate the AEC decision-makers' understanding of the technological, social, economic and political changes required for the industry to optimise the benefits of digitalisation. We analysed the empirical data using the theoretical concepts of boundary objects and spanners (Star and Griesemer, 1989). Based on our findings, we conceptualise scenario planning as a boundary-spanning activity in which experts from different fields engage in knowledge-sharing that is often tacit and embedded in practices. Finally, we discuss the limitations of our study, provide theoretical and practical implications, and suggest further avenues for studying scenario planning at the inter-organisational level of the AEC industry.

Scenario Planning for Supporting Decision-Making under Uncertainty

If the current AEC organisations could foresee the future, they could plan and respond to future demands by taking corrective action to achieve the desired outcomes of digitalisation. Anticipating the future is challenging; however, it is useful for aligning, directing and renewing current organisational strategies in the AEC industry (Harty et al., 2007; Harty and Leiringer, 2017). Scenario planning is a commonly used approach in many industries to facilitate long-range planning and decision-making during uncertainty. This approach can be used to embrace uncertainty, complexity, change, and the possible consequences of decisions. At best, the approach provides strategic decision-makers advice on moving from the current situation to probable futures (Harty et al., 2007).

We characterise scenario planning as social processes that involve humans embedded in an organisational context. A review of scenario planning conducted by Balarezo and Nielsen (2017) shows that scenario planning has been used mainly to improve strategic adaptation and renewal in the intra-organisational context. We aim to apply scenario planning in an inter-organisational setting. In this way, we aim to help AEC decision-makers to understand the changes needed for the industry to better realise the benefits of digitalisation. In a review of AEC industry studies, Jacobsson et al. (2017) found that aspects of the industry, such as the market structures and governance systems, have a reciprocal relationship and influence the implementation of digital technologies.

Chermack (2004) showed that scenario planning can help decision-makers to limit the impact of four types of errors that cause decision failures in organisations. The first error is bounded rationality, which is caused by the limited mental abilities of decision-makers. March and Simon (1958) noted in their famous book on organisation theory that humans cannot effectively process all the available information and alternatives. The second error is the consideration of exogenous and endogenous variables. Exogenous variables are external to the process under consideration, whereas endogenous variables are internal. Exogenous variables are more easily observable as they are not coupled to the system; thus, they are included in the decision-making process. (Chermack, 2004)

The third error originates from information stickiness and knowledge friction. Stickiness refers to the difficulty of acquiring, transferring and applying information. Information stickiness increases the cost of information transfer, as Von Hippel (1994) has shown. Friction has been defined by Weick and Roberts (1993) as the nuances that are a part of social interactions in work processes. Friction allows individuals to have experiences that help them to identify errors early. Scenario planning reduces information stickiness and increases friction among decision-makers.

The fourth error originates from decision premises and mental models. Decision premises are guiding norms – best practices that help individuals to make decisions under uncertainty. Senge (1990) explained that individuals use mental models to draw assumptions about alternatives, and mental models steer them to frame their experiences in the world. The goal of scenario planning is to alter the mental models of decision-makers and to provide the capacity for individuals in organisations to make sense of their environment.

Scenario planning belongs to the field of future studies, which includes a variety of methods, such as the Delphi method and the growth-share matrix, to anticipate the future (Ringland, 1998). Varum and Melo (2010) grouped the literature on scenario planning under three topics: 1) definition of scenario planning and its advantages, 2) scenario planning methods and 3) revealing knowledge for managers. Ringland (1998) indicated that scenarios are often constructed as stories to describe different and equally plausible futures. Scenario construction involves the use of systematic methods to aggregate trends, certainties, and uncertainties in the environment. The scenarios are usually either exploratory or normative. Exploratory scenarios are plausible future worlds that emerge through credible cause-and-effect developments, whereas normative scenarios represent desirable worlds (Ringland, 1998). According to Chermack (2004), one of the main benefits of constructing explorative scenarios is that policymakers and managers are forced to consider how they could act under different alternative paths to the future.

Several reports on the future of construction have applied methods for anticipating the future of the AEC industry. Erdogan et al. (2009) provided a comprehensive review of previous future scenario studies regarding the construction industry and construction information technology in the United Kingdom, the United States and France. Based on this review, the authors envision how work practices, collaboration, communication and construction activities could take place in 2030. Their vision included ideas about Lego-style design and construction, smart buildings and off-site construction. These ideas are based on collaborative practices and integrated and adaptable information technologies. The future construction study conducted by Goodier et al. (2008) discussed the importance of collaboration in the fragmented construction supply chains. The authors added that energy scarcity and the 'inspirement' of young people to the field of engineering and technology are important topics to be considered. They provided five key characteristics of a preferred future. The first characteristic is collaboration among all stakeholders in the construction supply chain. The second is innovation through coordinated and collaborative investment in research and development. The third characteristic is a better understanding of customer needs and the ways to meet those needs. The fourth characteristic attracts people by creating a better image and training, and the fifth is better use of natural resources by reducing waste and energy consumption. (Goodier et al., 2008)

There are some methodological issues to consider when applying scenario planning. The information collected from the informants is not neutral. It is subjective; thus, the scenarios represent partial and specific perspectives (Balarezo and Nielsen, 2017). This means that the stakeholders can interpret the scenarios quite differently. For instance, a positive scenario for one stakeholder might appear as a negative scenario for another. Harty et al. (2007) raised two other important methodological points for consideration when providing advice based on future scenarios in the AEC industry. For one thing, the relationships between external and internal drivers should be acknowledged. For example, the relationship between changing demographics, such as an ageing population, which is external to the AEC industry, and developments in BIM-based design and offsite construction technologies, which originate within the industry, is not straightforward. It is assumed that an ageing population will somehow affect the AEC industry, but it might also be that the ageing population intersects with the internal dynamics, such as the organisation of the industry. When providing advice based on scenarios, it must be noted that internal and external drivers can be considered as either effects or causes of change, depending on the scenario.

Boundary Objects and Spanners for Crossing Knowledge Boundaries

Winch (2003) characterises the AEC industry as a complex system that manufactures complex product systems. Production in such an industry is project-based, combined with the temporary organisation and uniqueness of the product. As a result, the AEC industry is fragmented. Design and construction processes are highly separated. The actors come from different disciplines; thus, they have their own professional and educational backgrounds and working methods (Winch, 2003). This fragmentation creates knowledge boundaries that challenge communication and coordination among the actors (Brown and Duguid, 2001; Lavikka et al., 2015).

Carlile (2002, 2004) described three types of knowledge boundaries. The lack of a common syntax or language creates the first knowledge boundary – a syntactic boundary. The second boundary is semantic, which manifests in different interpretations of knowledge even though a common syntax would exist. The third is pragmatic when the interests of the different actors are in conflict. Boundary spanning is the act of reaching across these knowledge boundaries to create shared knowledge among the actors. Carlile defines shared knowledge as knowledge that the actors can share and use to assess one another's domain-specific knowledge (Carlile, 2004).

Boundary spanning often involves the use of boundary objects, which are artefacts that can be used to transfer knowledge across boundaries. The boundary object serves as an interface between different social worlds. (Star and Griesemer 1989) For example, design drawings and prototypes represent boundary objects for product and service development. According to Star and Griesemer (1989), boundary objects can be concrete artefacts, but they can also be abstract mental constructs. All artefacts are not boundary objects, but an artefact needs to be meaningful to the actors. In addition, it must be incorporated into the practices of the different actors to create a common identity for collaboration (Levina and Vaast, 2005). In the construction industry, for instance, BIM has been found to represent a boundary object that improves collaboration and creates shared knowledge among actors (Di Marco et al., 2012). Boundary objects also create accountability and control across knowledge boundaries, as Whyte and Lobo (2010) found in their study of digital boundary objects. In the current study, we analysed the scenario figures – the results of scenario planning – as boundary objects that can be used to cross the knowledge boundaries between the actors representing different disciplines of the AEC industry.

Boundary spanners are individuals who have been delegated to handle the challenges of managing knowledge across boundaries (Levina and Vaast, 2005). The boundary spanners steer the discussions among the actors from different organisations toward shared knowledge and help the actors to find common goals. Boundary spanners apply boundary objects as interfaces between the actors when steering the collaborative discussion. The concept of boundary spanning thus includes boundary spanners, who apply boundary objects to help the actors to cross knowledge boundaries. As previous research has shown (Weick and Quinn, 1999), when the actors have crossed their knowledge boundaries, collaborative work and required organisational changes become easier to implement.

Research Method

We engaged in scenario planning to study how it helps the AEC decision-makers to understand the changes needed to realise the benefits of digitalisation. Our empirical research followed the academically rigorous process of a scenario planning method developed by Schoemaker and Mavaddat (2000). We chose this method because it is widely accepted, and it has been used successfully for anticipating the future (Schoemaker and Mavaddat, 2000; Balarezo and Nielsen, 2017). In addition, it is well documented. The method consists of ten steps for building scenarios. Table 1 lists the steps.

*** INSERT TABLE 1 HERE ***

Table 1 caption: Ten steps of the scenario planning method (adapted from Schoemaker and Mavaddat, 2000).

In step 1, we focused on defining the issues related to time frame and scope. We decided to focus on a time frame of 2020 to 2030 to provide information for long-term strategic planning, which is often hindered by the prevailing socio-economic-technological environment. Regarding scope, we focused on the probable effects of digitalisation on the Finnish AEC industry. This covered topics such as stakeholder structure, data flows and end-user participation because these topics are of great interest when implementing digital technologies (Bröchner, 1990; Shirazi et al., 1996).

In step 2, we identified the major stakeholders who might be affected by digitalisation in the AEC industry, their current roles, interests and power. Appendix 1 depicts the major stakeholders involved in the various phases of a construction project.

In steps 3 to 5, we identified the main forces shaping the future in the social, technological, economic, environmental and political domains. We analysed these forces in terms of their importance, predictability of their outcome and their interrelationships. To gain a broad perspective on the forces, we conducted four in-depth thematic interviews in the autumn of 2016. Six interviewees were carefully selected based on their expertise and their knowledge of the practices and processes of the AEC industry. We also organised two AEC expert panellist workshops with a total of 28 participants. All interviewees and expert panellists were Finnish citizens.

The interviews and expert panellist workshops were organised in the same manner. First, the participants were introduced to the scenario planning method, key stakeholders and examples of social and environmental, economic, technological, and political and regulatory forces. Second, we solicited their professional opinions about the main forces related to the social, technological, economic, environmental and political domains. We then asked them to place the forces along two axes: importance and uncertainty. Each interview and workshop lasted about two hours, and we took detailed notes, which provided a deep understanding of the forces shaping digitalisation globally and the AEC industry specifically.

In steps 6, 7 and 8, we constructed four future scenarios based on the two most important uncertainties, described the stakeholder behaviour in each scenario and validated the scenarios. In a review of the scenario planning literature, Amer et al. (2013) discussed the validation of scenarios. In general, scenarios need to be plausible, internally consistent and relevant to the client's concern. They must also produce original perspectives. Schoemaker and Mavaddat (2000) added that the consistency of each scenario should be checked in relation to the key trends. We followed this advice and checked the internal consistency of each scenario in relation to the trends and the other scenarios. We also ensured that each scenario would be plausible in the given time frame (2020–2030). We organised three workshops with a total of 66 participants to validate the scenarios and to understand whether the scenarios could help the participants to understand how to shape the current AEC activities in response to future situations. As Harty et al. (2007) asserted, the final scenarios are not effective unless they connect current AEC activities to potential future possibilities. The workshop participants represented both academic researchers working in digitalisation and AEC company representatives.

Steps 9 and 10 provide opportunities to elaborate the results quantitatively. However, in this study, we did not get to the quantitative stage of this scenario planning method because it was not necessary for answering our research question. Table 2 presents a summary of our data.

*** INSERT TABLE 2 HERE ***

Table 2 caption: Data collection.

Findings

Here we discuss the identified key forces, the four scenarios that we constructed and the validation of the scenarios.

Key Forces Shaping the Future

Next, we will describe the forces that were identified and clustered based on the four interviews and two workshops. The clustered forces were documented on a four-quadrant matrix (Appendix 2). Based on the matrix, we identified seven key trends (T) and uncertainties (U) that are presented in Table 3. Key trends are defined as forces deemed important and are already taking place, whereas key uncertainties are defined as forces deemed important but for which the outcome is not very predictable.

*** INSERT TABLE 3 HERE ***
** Table 3 caption: Key trends and uncertainties. **

In the following sub-paragraphs, we describe the seven key trends (T) and uncertainties (U). Appendix 3 presents the remainder of the forces.

Social and Environmental Forces

A key uncertainty is the potential collaborative participation of end-users and communities in activities related to the design, construction and maintenance of a built environment (U2). Increasingly, city planning and design are becoming distributed. Participative decision-making is becoming more common, and co-creation and crowdsourcing frameworks are emerging.

A key trend is the new needs of millennials, who are driving new and more mobile ways of working (T5). Their needs are expected to be diverse, and their consumer habits can stimulate the creation of more tailored services (T1). Millennials are expected to be increasingly mobile. They do not have strong geographical roots, and they are willing to relocate. This trend can support the formation and growth of internationally competitive hubs or mega-cities with centralised talent and resources that attract millennials. At the same time, populations, especially in many developed countries, are ageing at an accelerating rate (T7). According to U.S. News & World Report, 22 % of the American workforce in 2015 was more than 55 years old, and this percentage was increasing rapidly (Soergel, 2015). Older demographics have more conservative attitudes and behaviours regarding new digital services.

Technological Forces

A key issue is the openness of information and communication technology (ICT) solutions in the AEC industry. We define an open solution as being free from external control, interference or regulation. A cloud platform is a solution that rents storage space and computing power for delivering services. The openness of cloud platforms (U1) is highly uncertain because of security and critical business operations, but more scalable and interoperable solutions are gaining ground. Mineraud et al. (2016) have predicted that open cloud platforms will be able to respond to the needs of business applications that apply various predictive and prescriptive models and digital data. The needs originate from increasing data volumes and technical complexity. The openness of ICT solutions is linked to the diffusion of open information standards and application programming interfaces (APIs), which allow better interoperability among actors.

The increasing role of wireless connectivity (T3) is the most likely technological change. Wireless connectivity enables users and devices to maintain an Internet connection while moving freely within a network area. However, security, network interconnections and power consumption are hindering the adoption of wireless technologies (Miorandi et al., 2012).

Another technological change that could emerge from digital real-time modelling is related to the continually updated and increasingly interactive digital environment (T4). For instance, 3D city models could be created in real time to benefit urban construction and city management. CityGML is currently the most promising exchange format for sharing information about a city to make analysis and simulation possible. In general, the evolution towards large-scale information models across different sectors is occurring. Government institutions and AEC stakeholders need cross-sectoral (e.g. water, energy, transport) and integrated urban solutions to achieve social and economic development and improved energy efficiency in cities.

Open collaboration and widespread real-time modelling technologies promote the use of decentralised technologies. Blockchain (U5) is a decentralised database that allows for the chronological recording and secure storage of transaction data. In construction management, blockchain could be used for improving the reliability of construction logbooks to prevent legal action (Turk and Klinc, 2017).

Artificial intelligence (T6) is increasingly used to enhance the optimisation of building operations. Predictive systems use statistics, data mining and machine learning techniques to predict the likelihood of future outcomes based on historical data. Self-learning systems employ optimisation techniques that are based on large data sets, business rules and complex mathematical models. Self-learning algorithms, which can include new streaming data, are continually improving the accuracy of decision optimisation. (Russell and Norvig, 2009)

Economic Forces

A key force could be the rise of the platform economy (U3) in a built environment (Pulkka et al., 2016). The Internet platform giants, such as Google, Facebook and Amazon, have already disrupted many industries, including media and commerce (Gawer, 2014; Van Alstyne et al., 2016). The role of the multi-national corporations that control these digital platforms can be significant.

The platform economy can also pave the way for many new business models and disruptive entrants in the built environment (U7). When new digital services and business models are introduced, key questions will be the ownership of the customer interface and the new actors' degree of vertical integration. Furthermore, work is becoming more fragmented (T2). In the future, individuals can have several roles during their working life – from freelancer to micro business manager. Individuals can provide their services on a global platform, and this in turn can lead to the emergence of new kinds of co-working spaces. This phenomenon can be referred to as the 'uberisation' of work.

Political and Regulatory Forces

A key uncertainty is the openness of digital databases and information systems (U4)**.** In many areas, a municipal- and governmental-level regulatory push for open standards and data is taking place. This could pave the way for interoperable information systems across regions and cities, thus enabling a wide range of scalable new services. Another notable force is the move toward deregulation (U6). Impediments related to city planning and building permits are being removed, and new lighter legal frameworks are enabling the testing of new kinds of services.

Technology-Oriented Scenarios for Future Development Paths

In the sixth step of the scenario planning method, the two most important key uncertainties were selected, and their outcomes were arrayed on a matrix. Figure 1 presents an interrelationship matrix of the key uncertainty forces. A '+' symbol indicates an estimated correlation between the uncertainties, with '+' being the smallest and '+++' the largest. An empty field indicates no estimated correlation. We presented our analysis of the correlation properties in June 2016 to several academics to get feedback for the analysis.

*** INSERT FIGURE 1 HERE ***

** Figure 1 caption: An interrelationship matrix of the main uncertainty forces. **

Based on the relative importance of the uncertainties and the correlation properties (the two uncertainties should be as uncorrelated as possible), we selected U1 (Openness of cloud platforms in the built environment) and U2 (Distributed and participative decision-making) as the main uncertainty forces and used them as the *x*- and *y*-axes in a 2x2 matrix. We then set other uncertainty forces to represent either the *x*- or *y*-axis depending on their correlation with U1 and U2. For example, Figure 1 shows that U1 somewhat correlated with U4 (Municipal regulatory push towards open standards and data). Thus, U1 and U4 represent the *y*-axis, whereas U2 correlates with U3, U5, U6 and U7, thus representing the *x*-axis.

After constructing the *x*- and *y*-axes, we defined one scenario for each of the cells in the 2x2 matrix. We also added outcomes from the other key uncertainties and trends to the scenarios. For instance, the Internet of Buildings scenario resembles the Internet of things technologies, which, in general, are thought to benefit from open cloud platforms, open blockchains, deregulation and distributed decision-making (Miorandi et al., 2012; Crosby et al., 2016). Figure 2 provides a simple illustration of the scenarios as figures, showing mainly the relationships among the major stakeholders of a construction project. In the following sub-paragraphs, we describe the four different scenarios as short stories.

*** INSERT FIGURE 2 HERE ***

** Figure 2 caption: Four technology-oriented scenarios for development paths in the AEC industry.**

Scenario A: Closed Municipality-Driven Buildings

Scenario A embraces a 'closed' data sharing paradigm. Municipalities and the government play a key role in regulating all construction phases. For instance, they engage in city planning and issue building permits. The municipal regulators apply closed technologies, which prevent the flow of data among databases and construction phases. This scenario resembles the current state of data sharing in the Finnish AEC industry.

Because the data do not flow, end-users, owners and other construction stakeholders do not have enough data to make sophisticated decisions about the design and construction of buildings. In some cases, clients opt for specific design solutions without understanding the consequences of these decisions on constructability and construction costs. If enough design and construction data would be available, simulations concerning the balance between design solutions and constructability could be run, and the clients could make decisions based on real data.

The lack of digital data and transparency also leads to the minimal participation of the clients. Most likely, no co-creation or participative decision-making occurs, and this can lead to a situation where no end-user innovation happens. Nevertheless, innovations may occur at the project level. This is the usual case in the AEC industry where project work necessitates the creation of new solutions to new designs.

Scenario B: Collaborating National Conglomerates

In scenario B, construction companies control the information related to buildings and the customer interface. Municipalities and the government regulate the companies by setting service and quality requirements and by mandating the use of standards. The construction companies are responsible for all phases of a construction project.

The scenario is built on a few open and interconnected cloud platforms, and the data then flow among the buildings controlled by specific companies. However, openness does not pertain to decision-making at the construction project level as decisions are made within disciplines, and the end-users are not involved. For this reason, end-user innovations are limited. End-users can change service providers. This resembles the mobile operator model in the telecom industry where mobile operators are mandated by national regulators to use standard interfaces and to let end-users use the same handsets on all networks. This scenario could be considered the 'mobile operator' model of the AEC industry.

Scenario C: Internet of Buildings

In scenario C, data flow freely across buildings, construction phases and databases. End-users and owners control the building information, and they are free to choose from many services. End-user-driven innovation is highly plausible because distributed and participative decision-making flourishes. This scenario resembles the 'construction industry in 2030' scenario developed by Erdogan et al. (2009). The authors painted a picture of the construction industry where business processes are integrated and aligned with the goals of people, technology and place.

In this scenario, all buildings are interconnected with de facto open standards. Open blockchains are used for sharing data. However, in an open environment, sensitive and valuable data are at risk. Information security and privacy procedures regarding data integrity, access control, and system availability need to be in place. This scenario raises questions about who owns the created data, on which terms it can be shared and what kind of legislation should be enacted to prevent the sharing of sensitive data.

Open data sharing allows easy entry for start-ups that base their business models on available data. Thus, this scenario opens avenues for creating new digital services for the operation and maintenance of buildings. For example, older individuals could be provided activity trackers that enable them to live longer in their own homes. Thus, residency could also eventually become service-based instead of premises-based.

Scenario D: Platform Giants Rule

In Scenario D, platform giants such as Microsoft, Amazon or Google control the information related to buildings, and the customers can choose services from actors within an ecosystem. Each platform is protected by private blockchains; thus, data are locked in private platforms that become closed de facto standards.

At the beginning of this scenario, the platform giants compete fiercely to lock customers in. Eventually, customers become locked in to a single platform that can provide all their services. End-user innovation takes place within the closed platforms and their ecosystems. This scenario resembles the 'winner-take-all' model where platform giants collect most of the revenue at the expense of the other stakeholders. This scenario is possible as the giants control and own all the data and lock the customers in to their respective platforms.

Validation of the Scenarios

This same process was used for the three validation workshops. We first presented our scenario construction process, the key forces and the scenarios to the participants. We then let the participants discuss each scenario in groups to understand whether they considered the scenarios plausible and original. We also asked the participants to consider how the AEC industry would need to change its current practices to conform to their preferred future. We emphasised that our goal was not to prioritise one scenario over another but to provide input for the decision-making processes of the AEC strategic policy makers.

Scenarios C (Internet of Buildings) and D (Platform Giants Rule) provoked a lively debate around digitalisation. For example, in relation to scenario C, the workshop participants discussed whether service providers should use already existing digital data about the built environment to create services related to daily living. The participants agreed that a platform-based ecosystem could be one solution for creating these services. However, the participants disagreed with Scenario D, which stated that there would be only big platform players offering digital services. The participants seemed to be sure that there would be many relatively small AEC-related platforms owned by 'small' players instead of technology giants. According to some participants, the creation of services related to daily living could lead to the further development of the concept 'living as a service'. If the trends on 'consumerism' and 'millennials as a family' continue, the concept of 'living as a service' would soon have potential customers. Scenario C also prompted a discussion on data storage and its utility in construction projects. The participants agreed that, in the future, construction project data would need to be stored in the cloud, from which it could then be easily retrieved.

As the participants did not start discussing the needed changes on their own, the researchers asked about the kinds of changes that would be needed to accomplish future undertakings. After some discussion, the participants agreed that educational institutions would need to educate more experts in user-centred interfaces. The participants also agreed that, in the future, a wireless network connection would be needed on every construction site to enable the storage of data in and its retrieval from the cloud. Finally, Scenarios C and D, which were built on open data environments, raised concerns about adequate information security and privacy procedures regarding data integrity, access control and system availability.

These new ideas generated by the workshop participants reassured us that our scenarios could produce new perspectives that create interest. To our surprise, Scenarios A and B did not arouse much interest among the workshop participants even though we had imagined that they would generate discussion about the dangers of accepting the status quo in the industry. When we asked about Scenarios A and B, the participants told us that those scenarios resembled the current AEC industry situation in Finland in which changes were being made through the digitalisation of construction supply chains. The participants agreed that the worst case would be that the current AEC players lose some business to technology-based start-ups if they continue to conduct business as usual. From those comments, we realised that the participants had envisioned our scenario figures as business models for AEC stakeholders. We were surprised by this finding because we had not designed the scenarios to be business models; rather, we expected to provide input for the AEC decision-makers' long-term strategic planning, especially concerning decisions about data openness, use of digital technologies, interoperability and technical standards.

Discussion

Our findings from the validation workshops showed that the scenarios helped the workshop participants from different organisations to discuss the future of the AEC industry, to create new service ideas and to decide on the changes needed to realise their desired future. The validation workshop participants considered the development of partnerships and an AEC ecosystem as ways to keep pace with the digital transformation in the industry. These findings suggest that the scenario figures worked as boundary objects that helped the participants to cross their knowledge boundaries, especially the semantic boundary where the participants experienced differing interpretations of knowledge. The findings also suggest that the boundary objects helped in crossing the pragmatic boundary where the interests of the different actors were in conflict (Carlile, 2004).

The findings show that the researchers had an important role in asking relevant questions and ensuring that the participants also discussed the necessary changes to be made. It can be argued that without these small 'researcher interventions', the discussion would have focused on certain scenarios only, and the needed changes would not have been discussed. This finding implies that the researchers acted as boundary spanners who were needed to guide and to summarise the inter-organisational discussion toward a shared knowledge about the changes needed at the AEC industry level.

The findings demonstrate that the scenario planning approach helped the AEC decision-makers to make sense of the changes needed to digitalise the industry. The scenario planning method gave the researchers a tool for creating scenarios that enabled the AEC actors to make sense of an uncertain future and to decide on a few social, technological and economic changes that would need to be implemented to reap the benefits of digitalisation. The scenario planning workshops enabled inter-organisational sense-making, which can be the first step towards more collaborative relationships. This is considered an essential part of the digital AEC future, as indicated by previous scenario studies conducted by Goodier et al. (2008) and Erdogan et al. (2009). Usually, AEC decision-makers do not consider inter-organisational collaboration a necessity. This stems from the loosely coupled structure of the AEC industry, which encourages sub-optimisation and undermines inter-organisational collaborative development. The current relationships among the stakeholders tend to be short-term and market-based because of the lowest-price tender policy in the industry (Dubois and Gadde, 2002).

The literature on boundary spanning, especially the constructs boundary objects and boundary spanners, provides a useful lens for a theoretical understanding of the role of the scenario planning process in helping AEC decision-makers to make sense of the future. Based on our findings, we conceptualize scenario planning applied in the context of the AEC industry as a boundary-spanning activity that enables AEC experts from different fields to engage in sharing knowledge that is often tacit and embedded in practices. The essence of this boundary-spanning activity lies in the boundary objects, which were manifested as scenario figures in our research. These boundary objects were applied by the boundary spanners, who were the researchers in the current study.

Conclusions

Advanced digital technologies and tools have changed traditional businesses and opened avenues for new actors from other industries to enter the AEC industry. Decision-makers lack knowledge about how to implement digitalisation to create value for customers and to remain in business in the future. In addition to the application of new digital tools to improve data sharing and transparency, digitalization necessitates a change in the business ecosystem, as previous research has shown (Gawer, 2014; Porter and Heppelmann, 2014). To change the construction ecosystem, the socio-technical system, which includes institutional barriers, needs to be understood (Geels, 2004; Linderoth, 2016; Pulkka et al., 2016; Jacobsson et al., 2017). For instance, the current successful players in the AEC industry aim to protect their business models as these models have been successful in increasing the profitability of their companies. This protective behaviour undermines innovation and inter-organisational collaborative development.

We studied the role of scenario planning in helping AEC decision-makers to understanding the changes needed to optimise the benefits of digitalization. To empirically study the phenomenon, we followed the rigorous process of a scenario planning method developed by Schoemaker and Mavaddat (2000). We identified key forces and created four technology-oriented scenarios based on interviews and expert panel workshops that we depicted as figures (Figure 2). We applied these scenario figures in three validation workshops.

Based on the empirically grounded analysis of the use of a scenario planning method in anticipating the future of digitalisation in the AEC industry, the existing theories on scenario planning were extended in two ways. First, we showed that scenario planning provides a method to help AEC decision-makers to making sense of the changes needed to realise the preferred future for the industry. Second, we explained the role of the scenario planning process as a boundary-spanning activity that advanced the stakeholders' understanding of the benefits of inter-organisational partnering and an interoperable ecosystem based on digital data and technologies. To conclude, our research contributes to two topics in the scenario planning literature: revealing knowledge for the stakeholders and defining scenario planning and its advantages (Varum and Melo, 2010).

We studied scenario planning as a boundary-spanning activity in one context – the AEC industry. In our future research, we will continue to use the scenario figures, the boundary objects, in AEC development workshops to understand how practitioners apply scenarios in discussions related to the implementation of digital tools and technologies. This allows us to understand how boundary objects evolve into concrete infrastructures or disappear. The longitudinal study will also allow us to understand the practical outcomes of the boundary-spanning activity.

We also propose future work on scenario planning in the AEC industry without the researchers' acting as boundary spanners. This approach would allow us to better understand the role of boundary spanners in the scenario planning process, as our study showed that they play a key role. Future research should study whether the scenario planning process works as a boundary-spanning activity without the boundary spanners. The practical implication of our study lies in acknowledging the important role of the boundary spanners, represented by the researchers, who acted as a neutral party and facilitated the discussions with the organisational representatives.

This study has some important limitations. The identification of key forces provided input for the scenario planning process. Domain experts were interviewed in this environmental scanning phase for assistance in identifying the key forces. Balarezo and

Nielsen (2017) noted that individuals tend to focus on issues that they consider important from their preconceived image of reality. We constructed the scenarios based on the key forces identified by the experts. This means that our scenario planning was influenced by the biased nature of environmental scanning; thus, it included a subjective component.

Regarding the forces shaping the future, technological advances can cause rapid developments and sudden surprising changes to the existing business environment. For example, electric cars, solar roofs and power walls can potentially disrupt the business models for multiple related industries. Thus, it might be that the weighting of emerging technologies in the scenarios was too small. Nevertheless, our goal was not to provide ready-made future visions but to provide valuable information for AEC industry practitioners' decision-making processes. We encourage other scholars to consider including expert knowledge from other areas, such as health, social, energy and transportation, in the scenario planning process. This approach would broaden the discussion on significant changes and help decision-makers to develop broader mental models for interpreting the future of digitalisation in the AEC industry.

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*** INSERT APPENDIX 1 HERE ***

Appendix 1 caption: The major stakeholders involved in the various phases of a construction project.

*** INSERT APPENDIX 2 HERE ***

Appendix 2 caption: A summary of identified key forces regarding importance and uncertainty.

*** INSERT APPENDIX 3 HERE ***

Appendix 3 caption: A description of forces.

Table 1: Ten steps of the scenario planning method (adapted from Schoemaker and Mavaddat, 2000).

#	**Step**
1	Define the issues related to time, scope, and decision variables.
2	Identify the major stakeholders or actors who could have an interest in these issues, and their current roles, interests, and power positions.
3	Identify and study the main forces that are shaping the future within the scope, covering the social, technological, economic, environmental, and political domains.
4	Identify trends or predetermined elements that will affect the issues of interest from the list of main forces.
5	Identify key uncertainties (forces deemed important whose outcomes are not very predictable) from the list of main forces. Examine how they interrelate.
6	Select the two most important key uncertainties, and cross their outcomes in a matrix. Add suitable outcomes from other key uncertainties, as well as trends and predetermined elements to all scenarios.
7	Assess the internal consistency and plausibility of the initial scenarios, and revise.
8	Assess how the key stakeholders might behave in the revised scenarios.
9	See if certain interactions can be formalised in a quantitative model.
10	Reassess the uncertainty ranges of the main variables of interest, and express more quantitatively how each variable looks under different scenarios.

Table 2: Data collection.

Type and dates	Scope and participants	Target
In-depth thematic interviews (15.11.2016 and 21.11.2016)	Four 2-hour interviews with altogether six interviewees that represented construction, built infrastructure and property management service companies, and city building supervision.	To gain a broad perspective on the social & environmental, economic, technological and political & regulatory forces and to identify the main forces shaping the AEC industry.
Expert panel workshop (7.11.2016)	2-hour academic workshop with nine experts in smart cities, interactive buildings, industrial value chains in construction, business renewal and innovations, and cyber-physical systems.	
Expert panel workshop (8.12.2016)	2-hour workshop with 19 participants from the AEC industry representing smart cities, construction management, housing business development, building control and financing, and facilities management.	
Workshop (5.6.2017)	1-hour workshop with 29 academic and industrial participants representing computer science, industrial engineering and management, service engineering, economics, social sciences, and law.	To validate the scenarios and to understand whether the scenarios could help the participants in understanding how to shape the current AEC activities in response to different future scenarios.
Workshop (30.8.2016)	2-hour workshop with 20 participants from the AEC industry.	
Workshop (20.9.2016)	3-hour workshop with 17 academic, industrial and public sector participants representing the AEC industry, industrial engineering, computer science, and Ministry of the Environment.	

Table 3: Key trends and uncertainties.

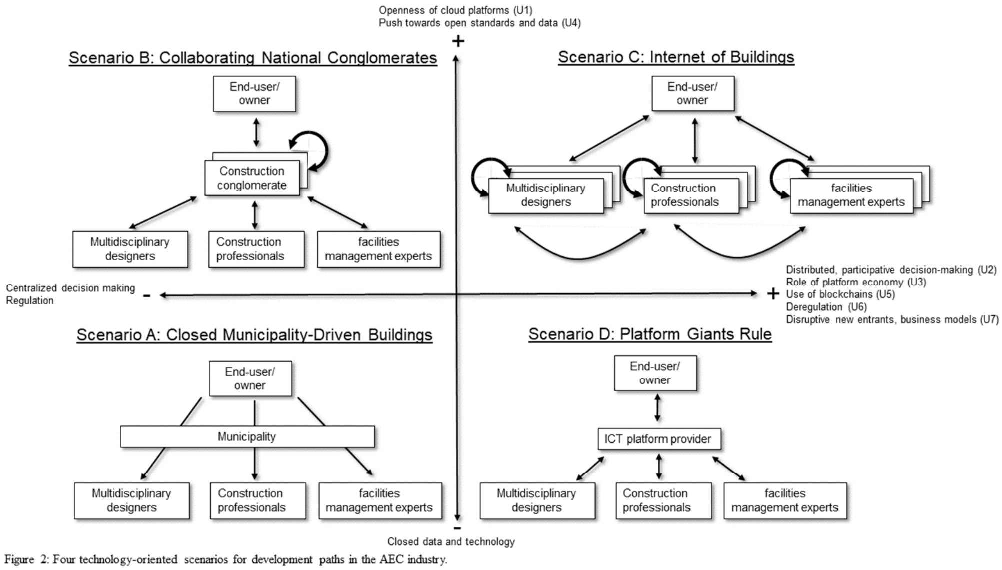
Trends (T)		Uncertainties (U)	
T1 (Social)	Fragmentation of user needs, consumerism	U1 (Technological/ Economic)	The openness of cloud platforms in the built environment
T2 (Economic/ Social)	Fragmentation of work, several employers (freelancer, uberization, micro-companies)	U2 (Social)	Distributed & participative decision making
T3 (Technological)	Role of wireless connectivity	U3 (Economic)	Role of platform economy increases
T4 (Technological)	Importance of digital real-time modelling	U4 (Political)	(Municipal regulatory) push towards open standards and data
T5 (Social/ Environmental)	The "millennials" at work and as a family	U5 (Technological)	Blockchain
T6 (Technological)	Artificial intelligence, Predictive and self-learning systems	U6 (Political)	De-regulation
T7 (Social)	Ageing population	U7 (Economic)	Disruptive new entrants, business models

	U1	U2	U3	U4	U5	U6	U7
U1				++			
U2			++		+++	++	++
U3					+	++	+
U4							
U5						+	++
U6							++
U7							

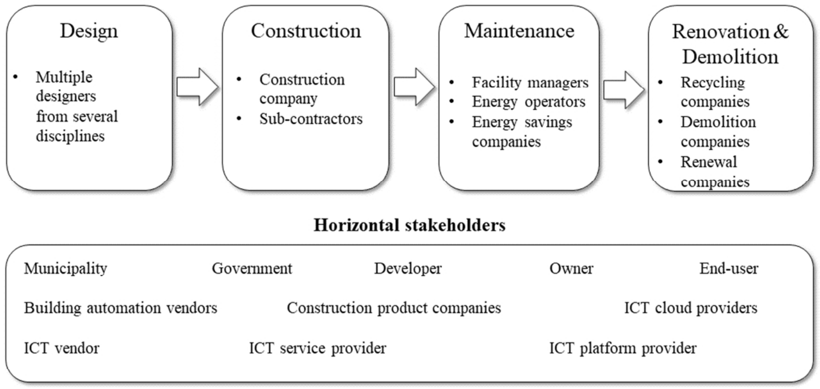
- U1: The openness of cloud platforms in the built environment
- U2: Distributed and participative decision-making
- U3: Role of platform economy increases
- U4: (Municipal regulatory) push towards open standards and data
- U5: Blockchain
- U6: De-regulation
- U7: Disruptive new entrants, business models

Figure 1: An interrelationship matrix of the main uncertainty forces.

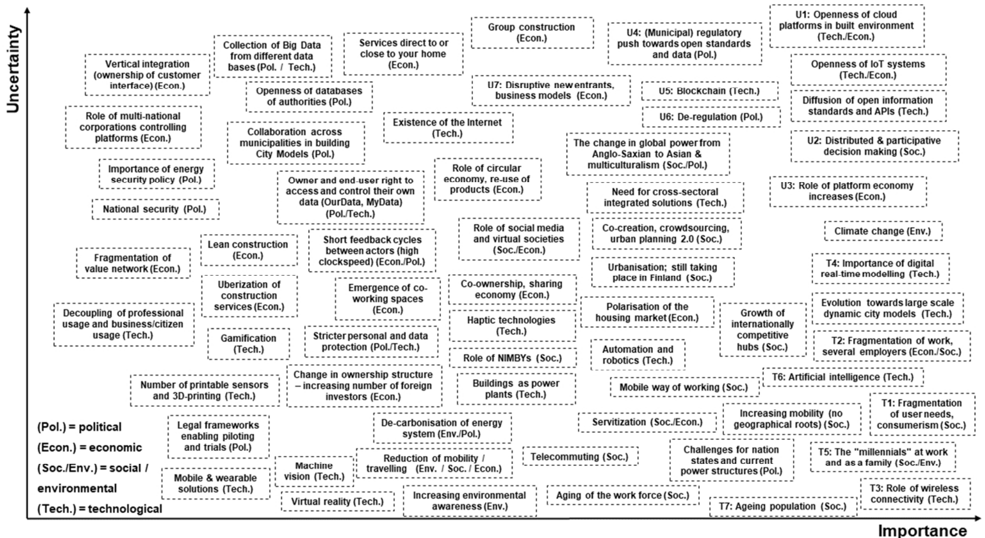
An interrelationship matrix of the main uncertainty forces.



Four technology-oriented scenarios for development paths in the AEC industry.



Appendix 1: The major stakeholders involved in the various phases of a construction project.



Appendix 2: A summary of identified key forces in terms of importance and uncertainty.

Appendix 3: A description of forces.

Force (type)	Description
Servitization (Social/Environmental)	Servitization is arising from the increasing trend where, especially young people prefer services over ownership, e.g. not getting a driver's license and buying a car, but rather using mobility services.
Climate change (Social/Environmental)	Increasing environmental awareness and the corresponding actions to battle climate change. Major efforts for de-carbonisation of the energy system are ongoing and making mobility and travelling more sustainable.
The change in global power from Anglo-Saxian to Asian & multi-culturalism (Social/Political)	The financial crisis in the European Union has changed the global power from the Anglo-Saxian to Asian (Chinese) cultures. In general, multiculturalism is increasing.
Role of NIMBYs (Social)	The role of NIMBYs (Not in my backyard people) could affect the evolution towards new kinds of built environment concepts driven by digitalisation.
Role of social media and virtual societies increases, service replaces premises (Social/Economic)	Replacing traditional offices and work practices with social media and virtual societies is increasing. The alternative workplaces can reduce costs, e.g. office rents, and increase productivity while eliminating typical office routines. Furthermore, the services replacing premises reduce commuting and increase sustainability.
The existence of the Internet (Technological)	Current technological solutions, such as cloud platforms, rely heavily on the existence of the Internet. There will be a challenge if the Internet does not exist in its current form in the future.
Robotics (Technological)	Robotics refers to the interdisciplinary engineering and science that involves design, manufacture, and operations of robots, as well as software for their control and data processing (Bock, 2015). Recent advances in artificial intelligence, communications, and sensors have made more intelligent, capable, and sensing robots possible. In practice, these advances enable robots to replace human labour in manufacturing tasks and a growing number of service jobs.
Decoupling of professional usage and business/citizen usage (Technological)	Digital technologies are evolving fast. Computers and robots will learn to do new things and replace human workforce. By contrast, big data, analytics, and high-speed communication have increased the demand for people with engineering, design, and innovation skills.
Haptic technology (Technological)	Haptic technology recreates the physical sensation of touch and sense by applying forces, vibrations, or motions. When touching virtual objects, electronics give their users feedback, and objects seem real and tangible.
Virtual reality (Technological)	Virtual reality is a computer-generated realistic experience of a different reality, typically generated by a virtual reality headset.
Mobile & wearable solutions (Technological)	Smartphones and wearable devices, such as activity trackers, can communicate and exchange data through the Internet without human intervention. These solutions allow monitoring and tracking of people and objects, as well as real-time services.
Machine vision (Technological)	The ability of computers to identify objects, scenes, and activities in images. Machine vision includes methods for acquiring, processing, analysing, and understanding digital images.
3D printing (Technological)	The idea of 3D printing is to go directly from a 3D design file to a finished part or product (Berman, 2012). The advantages of 3D

	printing include on-demand production and reduction of waste materials. On-demand production has implications for supply chains and storage costs, which are the major costs for manufacturers.
Gamification (Technological)	The use of game design elements in non-game contexts.
Short feedback cycles between actors, high clock speed (Economic/Political)	Feedback cycles between actors could become substantially shorter, i.e. higher clock speed for the sector, where buildings and the related services rapidly adapt to changing end-user needs. When it comes to the AEC industry, this could further fuel lean construction methods where construction services could increasingly be provided over global digital platforms (i.e. uberization of construction services).
Group construction (Economic)	New collaborative ways of conducting construction and sharing resources could also emerge. We are already witnessing new models on how to conduct so-called group construction, which enables co-ownership and applies the principles of the sharing economy frameworks (e.g. Airbnb) for apartments.
Role of the circular economy, re-use of products (Economic/Environmental)	In the last few years, the circular economy has received increasing attention as a way to overcome the current production and consumption based on continuous growth. The circular economy focuses on keeping materials and products in use as long as possible and on preserving their value by creating added value through services and smart solutions.
Polarisation of the housing market (Economic)	Concomitantly, at least in Finland, the housing market is becoming more polarised between growing urban and sparsely populated regions. Changes are also happening regarding ownership structure with an increasing number of foreign investors being active especially in urban regions.
Services directly to the home, virtual places and showroom concepts (Economic)	Shortly, the most services will include home delivery. Customers are already more and more ordering goods or food from online stores directly to their home.
Vertical integration (Economic)	Vertical integration is a company strategy to expand business operations into different steps in the production chain.
Fragmentation of value network (Economic)	Fragmentation of value network is the use of different suppliers and component manufacturers in the production of goods, which is becoming more and more common. Suppliers do not necessarily have to be located in the same geographical locations.
Owner and end-user right to access and control their data (Political)	Owner and end-user rights to access and control their data (*i.e.* OurData, MyData) are also politically important. Stronger data trust, privacy and security, and stricter personal and data protection are issues that can become major political trends.
National security and energy security policy (Political)	Digitalization of the built environment might introduce infrastructure vulnerabilities that could be exploited, e.g. by hackers, and therefore governments could start paying more attention to national security and energy security policy. Broader themes are the current challenges for many nation-states and current power structures. As global digital platforms are increasingly gaining influence, power could gradually transition from nation states to these digital platforms and large cities, reducing the role of nation-states.
Collaboration across municipalities in building city models (Political)	A building city model is a digital representation of the buildings and infrastructure. 3D building city models might be developing into a major collaboration platform as collaborative actions towards

	compatibility are increasing across municipalities.