The hype factor of digital technologies in AEC

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Abstract

Purpose – This paper aims to focus on 11 digital technologies (i.e. building information modeling, artificial intelligence and machine learning, 3D scanning, sensors, robots/automation, digital twin, virtual reality, 3D printing, drones, cloud computing and self-driving vehicles) that are portrayed in future trend reports and hype curves. The study concentrates on the current usage and knowledge of digital technologies in the Swedish architecture, engineering and construction (AEC) industry to gain an insight in the possible expectations and future trajectory of these digital technologies.

Design/methodology/approach – The study applies an abductive approach which is based on three different types of methods. These methods are a literature and document study which focused on 11 digital technologies, two workshops with industry (13 participants) and an online survey ($N = 84$).

Findings – The paper contributes to a current state analysis of the Swedish AEC industry concerning digital technologies and discusses the trajectory of these technologies for the AEC industry. The paper identifies hype factors, in which the knowledge of a digital technology is related to its usage. From the hype factors, four zones that show different stages of digital technology usage and maturity in the industry are induced.

Originality/value – The contribution of the paper is twofold. The paper shows insight into opportunities, the current barriers, use and knowledge of digital technologies for the different actors in the AEC industry. Furthermore, the study shows that the AEC industry is behind the traditional Gartner hype curves and

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contributes with defining four zones for digital technologies for the Swedish AEC industry: confusion, excitement, experimentation and integration.

Keywords Digital technologies, Hype curve, Future study, Hype factor, Technology knowledge, Usage and prioritization, Construction technology

Paper type Research paper

Introduction

Recently, an increased focus has been on digital technologies and trends toward digitalization in the architecture, engineering and construction industries (AEC). Digital technologies can be defined as advanced information and communication technologies and tools used in amplifying productivity across the construction life cycle (Chowdhury *et al.*, 2019, p. 2); others refer to innovations that support construction procurement, management and delivery of building projects (Ibrahim, 2013). Many perceive the new digitalization trends as possibilities to improve performance and productivity within the AEC industry (cf. Lavikka *et al.*, 2018), two parameters that have been discussed at length both in academic literature and in industry. Numerous digital technologies are currently being developed, and it becomes challenging for the AEC industry to select what kind of digital technology would be beneficial and what should be prioritized. Furthermore, research has also recognized that the industry is perceived as lagging in technology adoption and implementation (Chowdhury *et al.*, 2019; Sepasgozar *et al.*, 2016).

To gain insight in the adoption of new technologies for the AEC industry, several studies have performed future workshops and foresight studies to develop roadmaps (Lee *et al.*, 2007) and scenarios (Harty *et al.*, 2007; Lavikka *et al.*, 2018). These forecasting studies have focused on multiple topics such as environmental, human, economic and technological issues (The Government office for Science, 2017). Technological forecasting studies have discussed, among others, the use of 3D and virtual reality (CERF, 2000), 3D printing, the use of robots, intelligent robots, sensing (CERF, 2000; Edkins, 2000) and virtual prototyping (Hampson and Brandon, 2004). Furthermore, general studies point to several new technological possibilities (Gerbert *et al.*, 2016; The Government office for Science, 2017) from which the AEC industry could benefit. Digitalization is discussed as presenting opportunities to the AEC industry (Lavikka *et al.*, 2018). For example, digital solutions can support data-driven decision-making that is based on simulations and visualizations (Gerbert *et al.*, 2016) and can impact productivity improvement in terms of cost reduction engineering, ubiquitous digital access and decision-making of the life cycle of a construction (Chowdhury *et al.*, 2019). However, Lavikka *et al.* (2018) mention that digitalization can pose threats to the future of the current AEC industry in terms of new players on the market, and new business models. Therefore, it becomes relevant to look into what kind of new technologies and trends will affect the AEC industry.

Several trend reports and hype curves present future digital technology adoption for multiple industries. One of these is the Gartner Hype curve (Fenn and Raskino, 2008), which highlights new trends in upcoming and future technologies. While the AEC industry is known to lag in maturity and adoption of digital technologies, it is likely to expect that the industry will enter the different phases of the Gartner hype curve later compared to other industries. The hype studies are known to shape expectations in innovation processes (Borop *et al.*, 2006; Van Lente *et al.*, 2013). Van Lente *et al.* (2013) define these expectations as real-time representations of future technological situations and capabilities. These expectations guide innovative actors' activities in the form of setting agendas, providing legitimacy for additional funding and support, and can facilitate prototyping or pilot testing

(Van Lente *et al.*, 2013). The usage and development of the digital technology of building information modeling (BIM) can be seen as a technology that had high expectations in research (Dainty *et al.*, 2017), but it is not until now that it has entered the last phase of the hype curve (plateau of productivity) and is more applied in the AEC industry. As machine learning (ML) and AI currently attract an increased focus in research within the AEC field, it becomes relevant to understand how the industry relates to these new developments. Therefore, our research question examines the current usage and knowledge of new digital technologies in the Swedish AEC industry to gain an insight into the possible expectations and future trajectory of the promised hyped technologies. Clearly, the transformation of the construction sector cannot rely on technology alone but needs to be supported by an ecosystem of transformations including standards, vocational training, skills and management (Bock and Linner, 2015). However, this paper contributes to a current state analysis of the Swedish AEC industry concerning digital technologies and discusses the trajectory of these technologies for the AEC industry, and identified gap in the literature, thereby taking one step towards the necessary holistic transformation.

The paper is structured as follows: hype and technological innovation is presented in the second section; digital technologies are presented in the third section; the fourth section discusses the method of the study; and the fifth section presents the empirical results. Finally, the results are analyzed and related to literature in the sixth section.

The hype curve

The hype curve has been used for technology forecasting among practitioners but has in recent years received increased attention from the academic field as well (Dedehayir and Steinert, 2016). The hype curve is based on two curves, one representing human-centric expectations in the form of a hype level curve and the second one representing a technology S-curve for technology maturity (Fenn and Raskino, 2008). The hype curve shows five phases: innovation trigger; peak of inflated expectations; through of disillusionment; slope of enlightenment; and the plateau of productivity.

In the field of technology and innovation management, the hype curve has been studied in relation to expectations in the innovation process (Borop *et al.*, 2006; Van Lente *et al.*, 2013). Expectations can provide guidance towards emerging technical areas (Van Lente *et al.*, 2013) due to the fact that change agents or innovation agents can use them to set an agenda for technological innovation. When expectations concerning a specific technology are shared among several actors, promises related to these expectations can translate into requirements, guidelines and specifications for the technology (van Lente and Bakker, 2010). Expectations become performative and shape the path of an innovation trajectory through activities of innovating actors (Van Lente *et al.*, 2013). The hype curve is popular in industry but is also criticized in that it is difficult to understand the actual development of the curve. Furthermore, the expectations of technologies can be expressed by different actor groups which are not shown in the current hype curves. For the expectation curve of Gartner, it is unclear if all actor groups have similar expectations and Alkemade and Suurs (2012) as well as Dedehayir and Steinert (2016) suggest analyzing hype patterns for particular stakeholder groups.

The new digital technologies can create new expectations, but they can also disrupt traditional practices or become a threat for organizations that feel the investment in terms of innovation and knowledge is too much and, therefore, are less willing to adapt to new trends (cf. Lavikka *et al.*, 2018).

Digital technologies in the architecture, engineering and construction industry
Within the AEC field, many articles have discussed existing and new digital technologies (Chowdhury *et al.*, 2019; Ibem and Laryea, 2014; Ibrahim, 2013; Skibniewski, 2014). These articles review the adoption of digital technologies, barriers for adoption, as well as benefits for performance, innovation and the industry. Digital technologies are studied for different purposes such as procurement (Ibem and Laryea, 2014), collaboration in large construction projects (Ibrahim, 2013), construction safety (Getuli *et al.*, 2020; Skibniewski, 2014) or improving productivity (Chowdhury *et al.*, 2019). Other studies focus more on the specific technologies such as sensors and Internet of Things (IoT) (Chen *et al.*, 2020; Woodhead *et al.*, 2018), construction robotics (Adán *et al.*, 2020; Bock and Linner, 2015), unmanned aerial vehicles (UAV) or drones (Albeaino *et al.*, 2019), virtual, augmented and mixed realities (Lin *et al.*, 2020; Getuli *et al.*, 2020) or digital twins (Boje *et al.*, 2020). BIM is one of the technologies in which many studies have been performed on the adoption and usage of BIM (cf. Sacks *et al.*, 2018; Tang *et al.*, 2019; Zhao, 2017). According to Sepasgozar *et al.* (2016), a range of cultural, organizational and institutional barriers have been identified by numerous authors. A next generation BIM is viewed as managing information across diverse collaboration and interrelationship of the key stakeholders and process information modeling (PIM) is such an example (Pan *et al.*, 2018) to be successful in future construction management with digital technologies. The main objectives of PIM are to make sure that everyone understands data collected from different digital technologies in a correct way to predict what will happen in the future based, and to provide an automated process through accurate information flow from the design phase to the construction phase (Pan *et al.*, 2018). This is in line with other systematic approaches that focus on an integration of technologies, people and processes (cf. Ibrahim, 2013; Gu and London, 2010). Many of these studies present a review of adoption and use as well as research in specific digital technologies in the industry but focus less on new trends.

Methodology

The research applies an abductive approach. Data was collected with multiple methods to gain insight in digital technologies and their implications for the AEC industry:

- literature and document study;
- workshop; and
- survey.

For the literature study, knowledge was gathered concerning digitization and other technological trends relevant to AEC sector. The literature and document study focused primarily on digital technologies with a *close-to-market applicable technologies focus*, using the technology readiness level model (EU, 2014) and technologies that require basic research with a 10-year horizon are not taken into account. The focus is primarily on technologies geared towards future markets such as construction or technologies that have been applied in other industries but are not yet applied in construction. In addition to the Gartner hype curve and governmental trend reports for the industry, a selective search was performed in journals such as *Automation in Construction*, *IT-Con* and *Construction Innovation*. A list of 11 digital technologies have been identified from literature and trend reports (Table 1). In addition, we have also taken into account global trends in society that affect the AEC industry.

Two workshops were organized which dealt with digital technologies and their possible impact on two global challenges in society: sustainability and urbanization. The workshops

Digital technologies	Definition
1. BIM	Digital representation of physical and functional aspects of a building or facility (e.g. Ashworth and Perera, 2018; Sacks *et al.*, 2018; Gu and London, 2010; Woodhead *et al.*, 2018; Tang *et al.*, 2019)
2. Sensors/IoT	Device or plant that collects some form of signal or data. Sensors help us capture data from the physical world (e.g. Ashworth and Perera, 2018; Skibniewski, 2014), e.g. sensors for light, temperature, humidity, CO_2, etc. IoT in AEC is often related to connected and or automated sensors (Chen *et al.*, 2020; Woodhead *et al.*, 2018; Tang *et al.*, 2019)
3. Cloud computing	Calculations, analyzes, etc. (not as storage) that are carried out in the cloud (Woodhead *et al.*, 2018; Zhang and Issa, 2012)
4. VR, AR, MR	Virtual Reality (VR), Augmented Reality (AR) or Mixed Reality – various types of computer-generated interactive experiences that represent and visualize a real environment virtually (e.g. Getuli *et al.*, 2020; Johansson *et al.*, 2015; McMeel and Gonzalez, 2019; Lin *et al.*, 2020; Zaher *et al.*, 2018), e.g. head mounted displays
5. 3D scanning	Device that can read the shape of a three-dimensional object and save it as points/3 D coordinates (Guo *et al.*, 2020; Skibniewski, 2014)
6. Drones	Computer-controlled unmanned aircraft that can be used for various applications such as filming/photography/3 D scanning and other sensors (Albeaino *et al.*, 2019; Zhou and Gheisari, 2018)
7. Robots and automation	Robotization and automation means that manual, repetitive tasks are performed by a computer or machine instead of human (Adán *et al.*, 2020; Bock and Linner, 2015; Skibniewski, 2014), e.g. brick-laying machine, automatic generated design and automated quality control
8. 3D printing	Machine that produces three-dimensional material objects after drawings made in computer (Balasubramanian *et al.*, 2017; Marchment and Sanjayan, 2020)
9. Self-driving vehicles	Cars, buses or other vehicles that are controlled and driven automatically, by the vehicle sensing its surroundings and navigating without human input, e.g. self-driving cars, lawn mowers, vacuum cleaners, etc.
10. ML/AI	Machine learning (ML) deals with methods for computers to "learn" from data without being programmed for that particular task. Artificial Intelligence (AI) is a system of intelligent behavior that perceives its environment and takes action to achieve its set goal (e.g. Ashworth and Perera, 2018; Darko *et al.*, 2020; Nath *et al.*, 2020; Woodhead *et al.*, 2018), e.g. automated monitored construction site safety and risk management; automated production planning; predict and monitor facility management data
11. Digital twin	Exact digital image of a particular machine/building/construction or a city in the form of software (Boje *et al.*, 2020; Woodhead *et al.*, 2018), e.g. virtual Singapore, a digital copy of a machine, building

Table 1. Overview of 11 digital technologies

were inspired by the future workshop process of Jungk and Müllert (1987), in which the groups follow the process of:

- first identifying challenges and barriers;
- then discuss visions and opportunities; and
- concluding with a realization phase which focuses more on what needs to be done than on an action plan.

For the workshop, participants were specifically selected based on their role and expertise with digital technologies and their ability to think ahead. The participants were also chosen based on their role in the Swedish industry as known coordinators of research programs, researchers, speakers and industry/company change agents. The workshops focused on creating a joint picture of how digitization and future technology can influence and help solve the challenges of sustainability (Workshop 2) and urbanization (Workshop 1). Participants were invited through email, phone or face-to-face meetings.

During the workshop, an individual estimate of the 11 digital technologies was made by all participants with help of a survey (this survey was tested in the workshop and later sent out online). In the workshop, for every technology the participants mention examples for use cases in their organization as well as possible use cases in the future (some of these examples are mentioned in Table 1). After this estimate, the groups discussed first challenges and barriers, then opportunities and possibilities and finally what would need to be realized to achieve these opportunities (see the future workshop process from Jungk and Müllert, 1987). The workshop discussions were recorded and transcribed to enable analysis of the material. Workshop 1 (with five participants out of 15 invited) held in September 2018 focused on urbanization and workshop 2 (eight participants out of 17 invited) held in October 2018 focused on sustainability (Table 2). The data was coded thematically into the following themes: use areas of every technology, barriers, opportunities and what would be needed to achieve the opportunity with the new technologies. From the data analysis of the workshop, a list of needs to achieve the opportunity to use the technology in the future was found. This list contained the following needs for: industry collaboration, regulation, clear vision, learn of other industries, competence, standards, type of input data, communication, usefulness and think outside of the box. These needs were used in the online survey as an additional question and for every technology, respondents could state what was required to be able to use the technology in the future. The open questions of the survey were also coded. For example, for the use case per technology, we used the open answers from the survey and listed all use cases per technology and then categorized these into themes and counted how many mentioned this theme (see Table 3 in results). For instance, for drones, the following three statements were mentioned: "drones can inspect construction sites - good for safety issues"; "drones can support judgement of risks in the work environment on site"; and "drones can help to check or get data from locations that are difficult to reach and this implies less risks for employees". These three statements were combined into the code: work environment and safety.

Based on the results of the workshops, an exploratory online survey was further developed and sent out:

(1) via email to all invitees to the workshops (32 in total) who did not participate in the workshop (the participants of the workshop were not included in this email);

(2) via email to 118 participants that signed up for an industry seminar on the research project; and

(3) through the Centre for Management of the Built Environment (CMB), consisting of 60 Swedish AEC companies to their members via their LinkedIn page and their email newsletter.

The selection of possible respondents was focused on company representatives that are interested in management and strategy questions as well as digitalization questions which can have implications for the result and generalizability of this study. The survey was used exploratory, and not for hypotheses testing, and is applied to gain an understanding of the current use, knowledge and needs for new digital technologies. Questions were first pilot tested in the workshops. The survey was sent out during the period January 2019-March 2019 and reminders were sent twice through email and through the Centre for Management of the Built Environment. In total, 84 survey responses were received. Survey questions

Workshop 1 Urbanization	Role	Experience WS1	Workshop 2 Sustainability	Role	Experience WS2
1 Contractor (male)	R&D	18 y	2 Contractor (male/female)	BIM strategist/ Environmental manager	23/20 y
1 Lead Engineer firm (male)	Digitalization expert	23 y	2 R&D (male/male)	Circular economy experts	10/25 y
2 Architects (male/female)	Digitalization expert/ City planning experts	10/32 y	1 Supplier (female)	Waste/recycling expert	10 y
1 Private client (male)	development and R&D	27 y	1 Consultant (female)	Digitalization and sustainability expert	29 y
1 Public client (female)	Infrastructure, digitalization expert	23 y	1 Architect (female)	Environmental expert	30 y

Table 2.
Participants from the two workshops

were answered on a scale of 1–5. The survey dealt with the level of perceived knowledge of all 11 technologies (scale 1 = no knowledge – 5 = very much knowledge), the use of the technologies (scale 1 = no usage – 5 = very much usage); time needed for a particular technology to be used throughout the respondent's company as well as the Swedish AEC industry (scale 0–2 y; 2–5 y; 5–10 y, >10 y, never), which technology will your organization invest in the coming 5 years (only three could be selected) and what would be needed to implement these technologies. The needs were defined based on the data analysis of the two workshops as mentioned above. The results of the survey provide an insight on the state of knowledge in the Swedish AEC industry regarding the selected digital technologies. Respondents were owners/clients (16%), lead design engineering firms (27%), architects (11%), contractors (26%), suppliers (1%) and others (19%). The survey was analyzed descriptively, focused on means and standard deviations and answers to open questions. The data was analyzed per respondent's role (contractor, client and design engineers/architects), and if there were differences between the three actor groups, this is mentioned in the result section. For the questions concerning knowledge of all digital technologies (11 technologies), usage of the digital technologies in the organization and the time to full use in the organization of the respondents which we analyzed, a Cronbach's alpha of 0.71 (N is 33 items) was measured for the internal consistency. The level of 0.7 is often mentioned as being sufficient for reliability of the data.

Workshop results

The workshop result section is divided into the results concerning barriers and opportunities for future use of digital technologies.

Barriers and opportunities for future use of digital technologies. From the workshops, 15 barriers towards the future implementation and usage of the 11 digital technologies were discussed. The following main barriers were discussed:

Codes/ Technologies	1	2	3	4	5	6	7	8	9	10	11	Total
Improve effectiveness production	7	1				4	11	12		11		46
Traceability, circularity, sustainability	9	4	1	1		1		7	4	2	2	31
Work environment and safety		2	1	2		6	4	4	5	2		26
Analysis support		1	15							3	3	22
Control, real-time measurements		15								1	5	21
Data collection/generation		9				14						23
Basis for decision-making	2		1	1	5					7	1	17
Understanding by using visualization				10								10
Digital documentation/digital twin	8										2	10
Information on existing buildings					9							9
Development of new areas for use								4	5			9
Optimizing transports									7			7
Information full life cycle	5											5
Improve effectiveness FM	4											4
Increased quality, security, predictability				4								4
Waste and material handling							3					3
Supporting sales				2								2
Plan and improve processes											2	2
Other	4	1	2		3		5	4		3		22
Total	39	33	20	20	17	25	23	31	21	29	15	273

Table 3.
Possible use case codes per technology (technologies 1 = BIM, 2 = sensors, 3 = cloud computing, 4 = VR, AR,MR, 5 = 3 D scanning, 6 = drones, 7 = robots/automation, 8 = 3 D printing, 9 = self-driving vehicles, 10 = AI/ML, 11 = digital twins)

- Lack of competence (19%): during the workshop, participants mentioned the lack of competence and the need for training in the digital technologies as well as new competence that would need to be introduced from different disciplines and industries to incorporate these new technologies.
- The industry's current way of working (18%) was seen as a major hinder towards the use and implementation of new digital technologies. The fragmentation of the industry, the fact that the work is often performed in different silos, as well as the current business models in the AEC industry were perceived as a hinder to be able to use the new digital technologies. Many participants of the workshop viewed the new digital technologies as a way to interlink different disciplines, data sets and expertise across the industry.
- Many of the workshop members expressed barriers in terms of data security, lack of trust in the collected data and how this data could then be analyzed and interpreted for the right context and in the right way (14%). Furthermore, managing large amounts of data was perceived as a barrier.
- Another barrier mentioned was the current business models in the industry as well as the lack of digital strategies and supporting leadership for implementing and using the new technologies (12%).
- The focus on construction projects combined with a short-term focus (12%) was seen as a major barrier for the possibility to test and experiment with new technologies and the necessary investments would often need a long-term perspective.
- Legal as well as ethical (10%) issues concerning usage, collection of user and behavior data and integrity issues were discussed during the workshops as a hinder due to the current lack of laws, guidelines and rules in ethics and integrity in relation to new digital technologies in the industry.
- Finally, it was stressed that there is a need for communication (5%) concerning the changes that must take place in terms of ways of working, practices and processes as well as what kind of benefits these new technologies can offer for the industry – at the moment these were unclear.

During the workshops, the respondents mentioned the different opportunities for the selected digital technologies. The main opportunities (out of 10 opportunities) that were mentioned were new possibilities to work with data such as testing, simulations, identify patterns and work with different scenarios (25 %), support for sustainability (19%) and the possibility to involve society in decision-making – i.e. urban planning (17%) and improvements of the construction process (12%).

Survey results

The survey results section is divided into subsections discussing the potential usage areas of the technologies in the AEC industry, the current knowledge and usage in the Swedish industry, the prioritization of technologies for organizations, and finally the hype factor.

Potential use areas. In the workshop survey and the online survey, we asked, in an open question format, for every technology, what future possibilities do the respondents see (not everyone answered the question). From the data, we found three main usage areas that were mentioned by many respondents, out of 19 possible use cases in total (Table 3). The first area was *productivity improvement* of the production phase: several respondents mentioned the usage of 3 D printing, AI/ML and the usage of robots as the main technologies that can increase and improve the productivity of construction production. For 3D printing (26% of respondents) and the use of robots (24% of respondents), respondents mentioned resource efficiency, locally produced and production on-site, and a 24 h working place as examples. For AI/ML (24%), the focus was on the optimization of processes as well as optimization of transport and logistics. BIM was mentioned by 15% of the respondents to support productivity in production. Drones and sensors were mentioned in this respect as well in connection to logistics and traceability of materials on site.

The second area of use was within *sustainability, circular economy and traceability of materials*: respondents viewed the usage of BIM (35% of respondents) to support sustainability as well as traceability of information concerning materials, i.e. "connect the right information on products to the object in the 3 D model" and "relate to more effective management of resources". The second technology that was viewed to support sustainability was 3 D printing (22%) in which "an increase of possibilities for recycling of materials" was deemed possible as well as a reduction in waste. Sensors, ML/AI, digital twins as well as self-driving vehicles were also perceived to support sustainability and traceability.

The final category that was mentioned by many respondents was the *working environment and security*. Drones were mentioned by 23% of respondents to "support safety", "to get to areas that are difficult to access" or '"to make risk judgements". 19% of respondents view the use of self-driving vehicles to diminish working environment risks and a reduction of accidents on site. Also, the usage of robots and 3D printing (15%) is perceived to support a better working environment. In the case of robots, these can take over heavy lifting, risky and dangerous work.

Current knowledge and usage. In the survey, questions were asked regarding the current level of the respondent's knowledge of all 11 technologies (scale 1= no knowledge – 5= very much knowledge) and current level of usage in his/her organization (scale 1= no usage – 5= very much usage). From the survey results, it becomes clear that the respondents have limited knowledge about the different technologies, except for BIM, which has a mean of 3.8 (Table 4). Most technologies have a mean of three (3) which implies that one has knowledge to a certain extent. Concerning the current usage of these technologies in the respondents' own companies and work, only BIM is used with a means on 3.6 implying usage to a certain or relative

Mean	Knowledge on the technology	SD	Usage of the technology in their own company	SD
BIM	3,8	0.819	3,6	1.4
Sensors	3,2	0.747	2,5	0.963
Cloud computing	2,9	1.07	2,1	1.09
VR, AR, MR	3,4	0.775	2,6	1.04
3D scanning	3,3	0.951	2,5	1.16
Drones	3,3	0.731	2,3	1.13
Robots, automation	3,1	0.648	1,8	0.804
3D printing	3,2	0.709	1,9	1.02
Self-driving vehicles	3,0	0.760	1,3	0.679
AI/ML	3,1	0.824	1,7	0.855
Digital twin	2,8	1.23	1,9	1.15
Average	3,19		2,2	

Table 4. Means of knowledge and usage of digital technologies (scale is 1 = no knowledge/usage 3 = to a certain extent and 5 = very much knowledge/usage)

extent, while all other technologies are hardly used (with means below 2.5). Regarding knowledge of technology, there was only a deviation in answers when it came to cloud computing between the three actor groups (client/owner, design engineer/architecture and contractor). For this technology, the knowledge was found lower for the client/owner group compared to the design engineer/architecture and contractor groups. When it came to usage of technologies, there were some differences for the technologies BIM, cloud computing and VR which all scored lower for the client group compared to the two other groups. Sensors were mainly used by contractors and clients while drones were primarily used by contractors.

Current prioritization of technologies of Swedish companies. Figure 1 shows the outcome of the answers to the question concerning which technologies Swedish AEC companies are prioritizing or will invest in the coming 5 years (respondents could select up to three technologies). Based on the answers, the Swedish AEC companies are expected to invest in the following digital technologies:

- BIM (70%);
- AI and ML (42%);

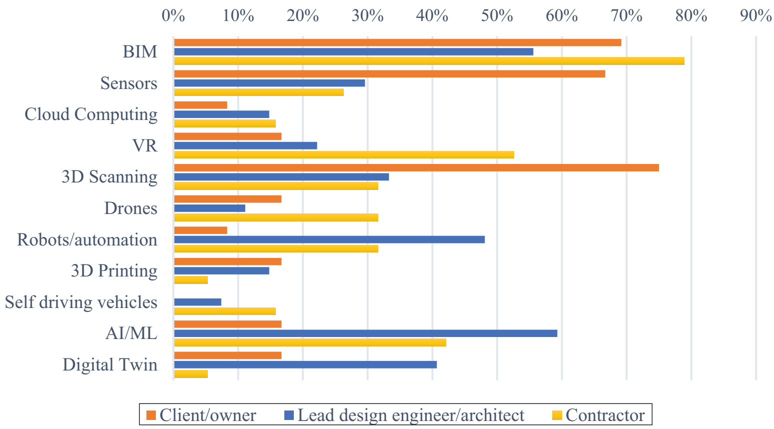

Figure 1. Which technologies will your company invest in for the coming five years (divided per actor) – Respondents selected the three main priorities for their company

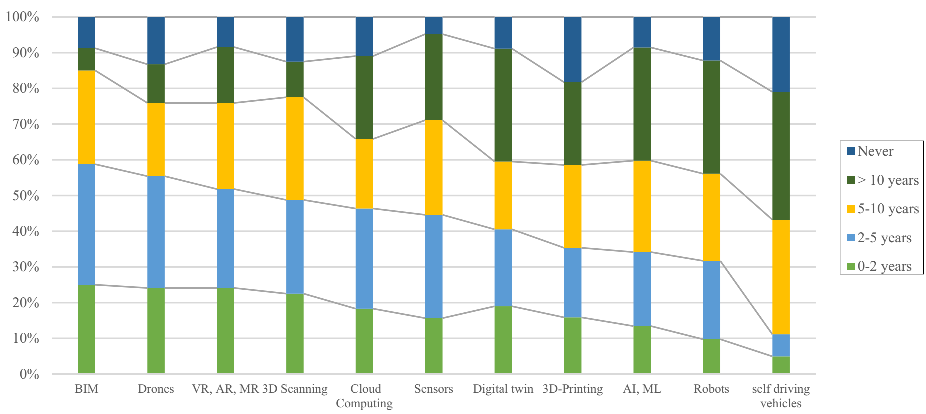

Figure 2. Time for the usage of digital technologies in your company – data is ranked from 0 to 5 years' time

- 3D scanning (38%);
- sensors (37%);
- robots and automation (34%); and
- digital twin (32%).

However, there is a clear difference in prioritization in digital technologies for the different actors in the industry. Contractors will focus primarily on BIM (79%), VR (52%) and AI/ML (42%), all of which are closely related to the construction process. Lead design engineering companies and architects plan to focus on BIM (79%), AI/ML (59%), Robots and automation (48%) and Digital Twins (41%), technologies which can be connected to the design phases and analysis of design data. Clients and owners plan to invest in 3D scanning (75%), BIM (69%) and sensors (69%). For clients and owners, the prioritizations of sensors and on 3D scanning are connected to the challenges related to facility management.

One survey question asked how long it would take for the respondent's company to use a technology to its full extent. Most respondents (60%) believe that BIM will be used fully in their company within 0–5 years (Figure 2). Subsequently, drones, VR, 3 D scanning, cloud computing and sensors, will be implemented in the near future. When it comes to self-driving vehicles, the full adoption will take a much longer time.

In the workshop and survey, we also asked about what would be needed for companies to realize the opportunities of the technologies in the future. In the workshop, ten needs were expressed. However, the data in the survey related to these needs did not deliver a specific significant pattern as per technology and is, therefore, not discussed in this article.

Hype factor. To estimate a hype factor for each one of the investigated technologies, the ratio between the experts' knowledge about a certain technology and the actual use of that technology in the company has been evaluated. We calculated the hype factor as follows: *hype_factor = knowledge_of_technology/actual_use_of_technology*. This idea is based on the assumption that for a mature technology, such as mobile phones, the ratio between knowledge and actual use should be close to one (1). For an emerging technology, on the other hand, the perceived knowledge should be rated much higher compared to the actual use, and hence, the ratio will be much higher, and, thus, is a representative metric of the hype factor. This metric will fail when both the knowledge and use is considered to be low, as the ratio then will approach one (1) and becomes equal to that of a mature technology. However, as we are investigating technologies that are expected to have broad usage within industry in 5 to 10 years and – as our data shows – already familiar to our respondents, there is no risk in crossing that threshold. In fact, as illustrated in Figure 3, the calculated hype factors are in line in comparison to similar estimates taken from the literature (Gartner hype curve 2018). In addition, four distinct zones based on the clustering are identified. After analyzing the different clusters/zones and revisiting the qualitative data from the workshops, it was recognized that it was difficult to pinpoint the zones back to the different phases in the Gartner hype curve (i.e. peak of inflated expectations, trough of disillusionment and slope of enlightenment). However, by analyzing the workshops' qualitative data related to the different technology and clusters/zones it was recognized that renaming the zones into *Confusion, Excitement, Experimentation, Integration,* made it easier to identify the different clusters/zones from the qualitative data and the results.

The first zone, *Confusion*, has a high hype factor (knowledge is low, but still higher than actual usage). Self-driving vehicles can be found in this zone, due to a very low current usage (reported in Table 2 with a 1.3 score). A few workshop participants mentioned that they were part of research projects in which some kind of self-driving vehicle is studied. Self-driving

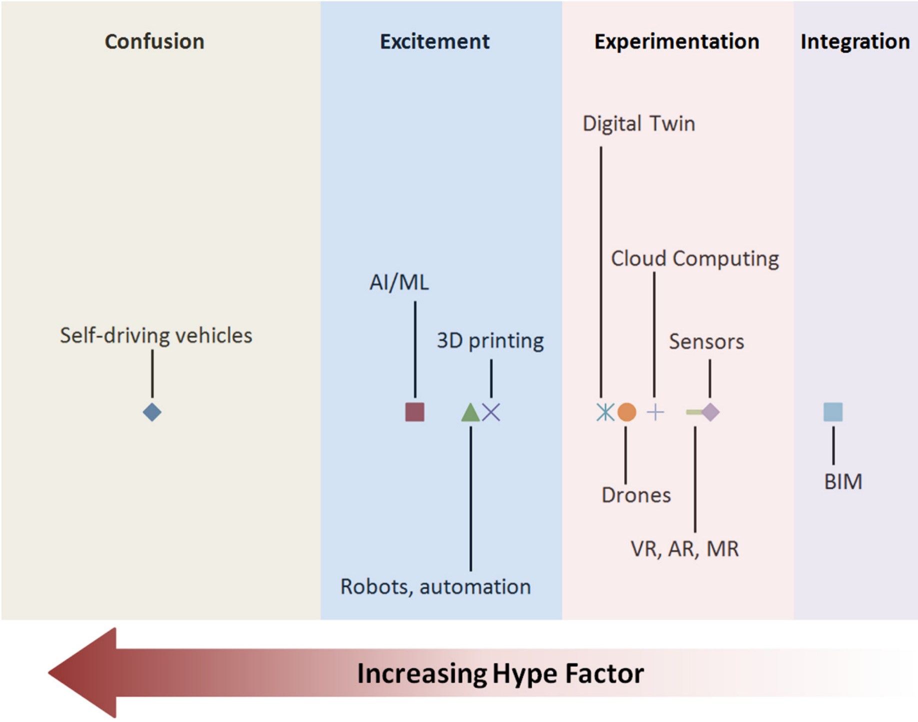

Figure 3. The calculated hype factor and corresponding identified zones for the 11 digital technologies as known and used in the Swedish AEC industry

vehicles were not discussed during the workshops which could be due to little knowledge, no usage and confusion concerning the use cases. A different trend may have emerged if suppliers or representatives from the transport sector had been included in the study.

The next cluster is viewed with anticipation and *Excitement*. These are technologies many have heard of, but few have yet used. However, there is a buzz around these technologies and people are excited and full of expectation on their future possibilities. The technologies that fall within this cluster are AI/ML, 3D printing, Robots and Automation. Some quotes from the workshop are:

> But machine learning can identify patterns from large datasets that we cannot make and maybe it sees patterns much earlier than we can do with the current data analysis of today.

> The technologies we discuss most are AI and deep learning which we cannot use yet today, that is a bit further ahead in the future.

The third cluster consists of technologies that the AEC industry has started to test and to experiment with, i.e. *Experimentation*. These tests and experiments are often performed in pilot projects and are not yet scaled to multiple projects. The technologies that fall into this cluster are VR, sensors, drones, cloud computing and digital twins. In the workshop, one person confirms testing VR in a single project:

> We have now started to test VR in one project in the production. Another quote concerns digital twins: But the difference is that we are starting to work with digital twins, even though it is just on a very small scale, but in a test object.

The final cluster concerns technologies that are already integrated and applied in the AEC industry: *Integration*. In the Swedish AEC industry, the technology BIM has reached this stage. One quote from a lead engineering company representative states the following: "*We use BIM almost throughout the whole construction process*."

Discussion and conclusion

In this article, the current opportunities, barriers, usage and knowledge of 11 digital technologies in the Swedish AEC industry is studied, to gain insight into possible expectations and future trajectories of these technologies. From the above-mentioned results, the current knowledge and use of 11 digital technologies are found. However, the results also present insight regarding the strategic choice of different actors in the Swedish AEC industry in which technology they will prioritize or invest in the coming five years, as well as the time needed to adopt the technology in the organization. The combination of results gives insight into future trajectories of digital technologies in the industry and can be related to other forecasting studies in the AEC field (cf. Lee *et al.*, 2007; Hampson and Brandon, 2004; Harty *et al.*, 2007; Lavikka *et al.*, 2018) or forecasting studies focusing on one specific technology such as 3D printing (Balasubramanian *et al.*, 2017).

Concerning the hype factor of the different technologies related to the Swedish AEC industry, it becomes clear from our results, that these do not follow a traditional Gartner hype curve and the industry is a bit later in these trajectories. This might be due to the fact that the industry is lagging in terms of digitalization (Sepasgozar *et al.*, 2016), or also that the hype curve is a rather generic approach and not really applied to particular stakeholders (Alkemade and Suurs, 2012; Dedehayir and Steinert, 2016), therefore, might not always represent the trajectory of new technologies in a clear and understandable way (Dedehayir and Steinert, 2016). From the result of the analyses of the hype factor and its clusters/zones together with the analyses of the qualitative data of the workshops, it became clear that renaming the zones into *Confusion, Excitement, Experimentation, Integration*, made it easier to represent the trajectory of new technologies in a clear and understandable way. Furthermore, compared to many other industries, it seems that the hype curve of the AEC industry follows a similar pattern (see, for example, the zones in Figure 3) but is shifted backwards and technologies are applied and adopted later in time in relation to general hype curves.

While our data does not present a new hype curve for AEC, there are some patterns that have become clear (Figure 3) and four different zones or clusters are recognized and defined which can to some extent be related to the Gartner hype curve or to other innovation diffusion and technology maturity models. The four zone's names are inspired by change management models. The first zone of *confusion* was based on a technology with a high hype factor and participants did neither know much about this technology nor for what purpose the technology could be used in their work and industry, i.e. the self-driving vehicles. In the second zone, which is defined as *expectation*, the technologies of AI/ML as well as robots/automation and 3D printing are found. In the workshops and survey, confirmed by literature and secondary data, these technologies are not yet applied to a large extent, but there are high expectations and excitement on possible opportunities of these technologies. These technologies could also be related to the Gartner curve of inflated expectations. There is a lot of attention on AI/ML in the Swedish AEC industry and there are high expectations in the field which, as research related to hype curves confirms, support the prioritization of research, funding and strategic focus (Van Lente *et al.*, 2013; Van Lente and Bakker, 2010).

In the third zone, which is defined as *experimentation*, technologies are found that are tested to some extent in small scales and pilot projects. These technologies can be related to Gartner's hype curve in terms of being in between the ending phase of The Through of Disillusionment and on the Slope of Enlightenment. Our results in this *experimentation phase* predict that in the near future there will be more use of VR, drones, sensors, cloud computing and digital twins because of their location in the hype factor curve. This is also reflected in the literature that reports on adoptions of these technologies. Our data, however, also showed digital twins in zone three, while the digital twins technology is in many cases perceived as further behind in the hype curves. Digital twins were the sixth prioritized digital technology, primarily mentioned by architects and lead design engineering company representatives. The knowledge concerning digital twins as well as its current usage was rather low. According to the Gartner curve (2018), the digital twin technology is currently at the top of the hype curve in the Peak of Inflated Expectations, but this does not fully seem to be the case for the AEC industry in Sweden based on our data. The knowledge as well as usage of digital twins was low and digital twins are based on the usage of sensors (Internet of Things), drones and VR (Woodhead *et al.*, 2018). However, the position of digital twins in this stage might be related to how digital twins are defined by our respondents in which a BIM model might be a first phase needed for a digital twin.

The final zone is defined as *integration* and implies that a technology, in this case BIM, has been integrated in the industry and is applied. This can also be seen in the large number of studies on BIM adaptation and review articles on specific aspects of BIM. This integration zone could be related to the Plateau of Productivity level of the Gartner hype curve. BIM is perceived by many of the actors (except by the clients) to be in this particular zone. Due to the fact that BIM is maturing, it is also clear that the needs and requests for standards and rules become more relevant for the industry. To reach the next maturity level, cooperation across disciplines and fields is needed, and best practices and methodologies are currently being developed and implemented.

The contribution of the paper is twofold. The paper shows insight into opportunities, the current barriers, use and knowledge of digital technologies for the different actors in the AEC industry. Furthermore, the study shows that the AEC industry is lagging behind the traditional Gartner hype curves' predictions. The paper identifies hype factors, relating the knowledge of a digital technology to its usage. From the hype factors we contribute with defining four zones that show different stages of digital technology usage and maturity in the Swedish AEC industry: *Confusion, Excitement, Experimentation* and *Integration*. The four patterns/zones found can contribute to supporting a model specifically developed for the AEC industry, as the traditional hype curves are often not developed for particular industries or stakeholders.

The results presented above give insight in the digital technologies that will be implemented within the next 5 to 10 years within the AEC industry. The findings can support strategic agenda setting, as well as provide legitimization to invest in or prioritize particular digital technologies for the different actors in the AEC industry. The data is limited to only presenting an insight into the Swedish AEC industry and the trajectory of certain technologies could differ slightly for other countries. It would, however, be relevant to proceed with digital innovations and trend studies for future research so that the industry can develop digital strategies on how to progress in the future.

From our study on digital trends, it becomes clear that the AEC industry will focus more on digitalization and automation in the near future. However, this also implies that these digital technologies should not be viewed only in isolation, but as part of a larger ecosystem in which design, management, standards and training need to be adapted to support digitalization (Bock and Linner, 2015) and in such a way overcome the fragmentation of the industry, which has been mentioned in this study as one of the barriers for digitalization. Therefore, it becomes relevant to also take into account the socio-technical aspects of digital technology and how new technologies affect the current work practices, standards, processes, business models and ecosystems, as well as how technology can support demographic challenges. Additionally, models for how the digital technologies and data can support the life cycle of a project across all stakeholders become relevant to study, e.g. the conceptual model of process information modeling (Pan *et al.*, 2018). According to Lavikka *et al.* (2018), the future is uncertain and AEC practitioners face difficulties in what should be implemented. Therefore, gaining insight in possible trends and scenarios can give us guidance to what measures and capabilities are needed to be better prepared for the future of the AEC industry.

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Further reading

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