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Published in:
Journal of Construction Engineering and Management

Link to article, DOI:
10.1061/(ASCE)CO.1943-7862.0001928

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Ernstsen, S. N., Whyte, J., Thuesen, C., & Maier, A. (2021). How Innovation Champions Frame the Future: Three Visions for Digital Transformation of Construction. *Journal of Construction Engineering and Management*, *147*(1), Article 05020022. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001928

Case Study

How Innovation Champions Frame the Future: Three Visions for Digital Transformation of Construction

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Abstract: Digital technologies are expected to create transformational change in the construction sector. Previous studies have either anticipated the impact of individual technologies or outlined a number of nontechnology-focused future scenarios. There is comparatively little work on how innovation champions frame the future by combining a range of digital technologies and trends (such as big data, the internet of things, and automation) to transform construction. Drawing on an interview-based study with UK construction professionals, this paper presents three emergent visions for digital transformation of the sector. *These visions are efficient construction, user-data-driven built environment, and value-driven computational design*. Arising in practitioner narratives, these visions all emphasize different technologies and are partially influenced, intertwined, and interconnected with technology, business, and policy discourses in the sector. Furthermore, the visions represent different trajectories for implementing digital technologies in the construction sector. This paper contributes to work on construction foresight and innovation discourses by articulating the multiplicity of visions for digital transformation of construction. This has implications for researchers, practitioners, and policy makers responsible for the digital transformation of construction toward possible, profitable, and desirable futures. **DOI: 10.1061/(ASCE)CO.1943-7862.0001928.**

Introduction

In a time of rapid change, construction companies need to innovate to remain competitive (Tatum 1989). Much construction research has studied the nature of innovation in construction (e.g., Gann 2003; Harty 2005; Ozorhon and Oral 2017; Slaughter 1998) and has regarded innovation as an important component in improving the performance of the construction sector (Gambatese and Hallowell 2011; Xue et al. 2014). According to Winch (1998), one of the most consistent findings in such research is that innovation requires champions. Innovation champions are described in the literature as individuals who are capable of promoting innovation despite opposition and who inspire others with regard to their vision for the future (Leiringer and Cardellino 2008). Moreover, these champions are willing to take risks and are capable of telling convincing narratives to gain the commitment of others (Sergeeva 2016).

In their study of examples of successful construction innovation, Nam and Tatum (1997) highlighted the importance of technically competent innovation champions. As technology has the power to transform existing construction-related products, services, and work processes, much construction research has studied the impact, adoption, and implementation of specific digital technologies in construction. For example, Dossick and Neff (2010) studied the implementation of building information modeling (BIM), Teizer et al. (2012) examined the potential of and barriers to nanotechnology, Whyte and Nikolić (2018) explored the practical use of virtual reality (VR), Li et al. (2019) investigated the role of blockchain, and Sawhney et al. (2020) recently proposed a framework for Construction 4.0. Several studies have anticipated that individual digital technologies will be able to change the competitive landscape for construction companies. Fewer studies have explored how innovation champions expect a combination of multiple digital technologies to affect the construction sector (a notable exception is Erdogan et al. 2010). Furthermore, construction practitioners remain unsure of what digital technologies to implement and how to implement change (Lavikka et al. 2018).

Nam and Tatum (1992) argue that construction companies can improve their innovation capability by taking leadership and applying a technology-push strategy with long-term perspectives, with later construction researchers articulating the benefits of long-term planning and foresight studies (Chan and Cooper 2011; Dixon et al. 2018). However, as a result of the unpredictability of the construction market, inadequate resources, and unstable employment, the capacity for long-term planning is low in construction practices (Soetanto et al. 2007). Questions arise about how futures are brought into being.

Innovation champions arguably play an important role, as they use narratives of the future to promote innovation and shape technological futures. To ensure internal and external credibility, innovation champions may align their narratives or visions with wider sectoral discourses (Leiringer and Cardellino 2008). Studying policy discourses of the UK construction sector, Smiley (2016) has argued for the need to explore multiple alternative futures:

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Note. This manuscript was submitted on August 28, 2019; approved on June 12, 2020; published online on October 30, 2020. Discussion period open until March 30, 2021; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Construction Engineering and Management***, © ASCE, ISSN 0733-9364.

"contemporary construction policy discourses are in danger of becoming increasingly myopic, with alternative perspectives and visions increasingly marginalised, and so any potential for the flexible adaptation or reimagining of future policies is reduced." (Smiley 2016, p. 4)

Sergeeva and Green (2019) have built on this argument and identified a need for understanding how construction practitioners interpret innovation and for comparing this to current policy discourses. In addition, they have emphasized the relevance of understanding construction innovation through the narratives of innovation champions.

This work contributes to the development of such an understanding. It explores construction practitioners' expectations for the future of digital transformation in the sector through interviews with 13 innovation champions from the UK. The work builds on the aforementioned previous studies that anticipate the impact of individual technologies or outline a number of nontechnology-focused future scenarios. It extends this work to focus on how innovation champions frame the future by combining a range of digital technologies and trends [such as big data, the internet of things (IoT), and automation] to transform construction. It situates the three visions that emerge in the narratives of innovation champions within wider technology, business, and policy discourses. The next section describes the theoretical background to the paper in the work on construction futures, and the following section then describes the research method used in the study. The subsequent section describes the three identified visions for digital transformation of construction, and the following section compares and contrasts the three visions. The next two sections describe a set of innovation discourses that span technology, business, and policy and discuss how the visions are situated within these. The article concludes by summarizing contributions to practice and future studies research by presenting three distinct visions for digital transformation of the construction sector. These visions may serve as a narrative reference point for debates and aid the development of research, long-term company strategies, and sectoral policy, thereby constructing futures that are possible, profitable, and desirable.

Theoretical Background: Construction Futures

Narratives may be used to shape the future. In this regard, scenario planning and visioning are two well-known foresight methods for communicating possible or preferred narratives of the future (e.g., Doericht 2013). Narratives in the form of scenarios or visions can motivate stakeholders to think about how they may respond to a range of potential future changes, thereby improving strategic decision-making (Dixon et al. 2018; Harty et al. 2007). Moreover, both visions and scenarios encourage construction stakeholders to disregard traditional organizational boundaries and consider a range of trends and technologies in their exploration of the future.

Scenario planning is a structured foresight method that typically builds on the identification of social, technological, environmental, economic, and political (STEEP) trends. Several researchers have facilitated the development of future scenarios for construction (Erdogan et al. 2010; Harty et al. 2007; Lavikka et al. 2018). For example, Lavikka et al. (2018) and Erdogan et al. (2010) have described well-executed scenario planning processes in the construction sector, resulting in four exploratory scenarios for the future. However, in both cases, the resulting four scenarios focus on key trends and downplay the impact of digital technologies in favor of other aspects such as interorganizational structures and business models. To address this issue, Erdogan et al. (2010) supplemented the four scenarios with a comprehensive vision for construction information technology (IT) in 2030. This vision was created from the perspective of IT experts, and Erdogan et al. (2010) proposed that further research could benefit from considering the perspectives of other construction professionals.

Visions, similarly to scenarios, are exploratory in nature; however, they are different from scenarios because they are inherently positive and desirable descriptions of the future (Levin 2000). This is beneficial as "the future can be influenced if we know what we want it to be" (Erdogan et al. 2010). Being narratives by nature, visions utilize the power of storytelling, which triggers the imagination required for devoted actions from stakeholders (Levin 2000). While narratives are considered accounts of the future formulated at an individual level, they are often rooted in discourses that are shared among different individuals, organizations, and institutions. Narrative visions are thus a way for innovation champions to promote innovation in the construction sector. This paper correspondingly presents findings from interviews with innovation champions by means of narrative visions for the future of construction.

Research Method

The method applied in the research is based on the five phases illustrated in Fig. 1. Phases 1–4 cover the main empirical research on how innovation champions envision the future of construction through (1) selecting innovation champions, (2) interviewing innovations champions, (3) identifying future aspects, and (4) synthesizing visions. Subsequently, it became clear that the visions should be understood in a broader sectoral context and, thus, the fifth phase on mapping innovation discourses was added.

Selecting Innovation Champions (Sampling Approach)

In sampling a relevant set of innovation champions, the study drew on Leiringer and Cardellino's (2008) conceptualization of innovation champions. The interviewees' formal titles were, for example, *group innovation and knowledge manager and business development director*. The authors consider the interviewees to be innovation champions through the role they had in the companies they represented and by their peer recognition as thought leaders, framing industry understandings of digital futures. The size of the sample was defined by the initial identification of relevant interviewees by the researchers and by a snowballing strategy in which the initial selection of innovation champions identified innovation practitioners they considered their peers. Most of the interviewees were in charge of innovation, digitalization, technology development, or business development within their company, and the remaining interviewees had a similar role as change agents within the sector. The final sample included 13 UK construction professionals from 10 companies.

The interviewees represent 10 small and large companies in the UK construction sector. The companies operate in the infrastructure industry, the building industry, or both. Four companies are engineering consultancies, three are contractors and three are small enterprises. An overview of the companies is found in Table 1.

Interviewing Innovation Champions (Data Collection)

The interviews were semistructured (Kvale and Brinkmann 2009) and were conducted in September and October 2018. Each interview lasted approximately 1 h and was recorded and later transcribed.

The purpose of the interviews was to elicit how innovation champions envision the future of construction. However, as this

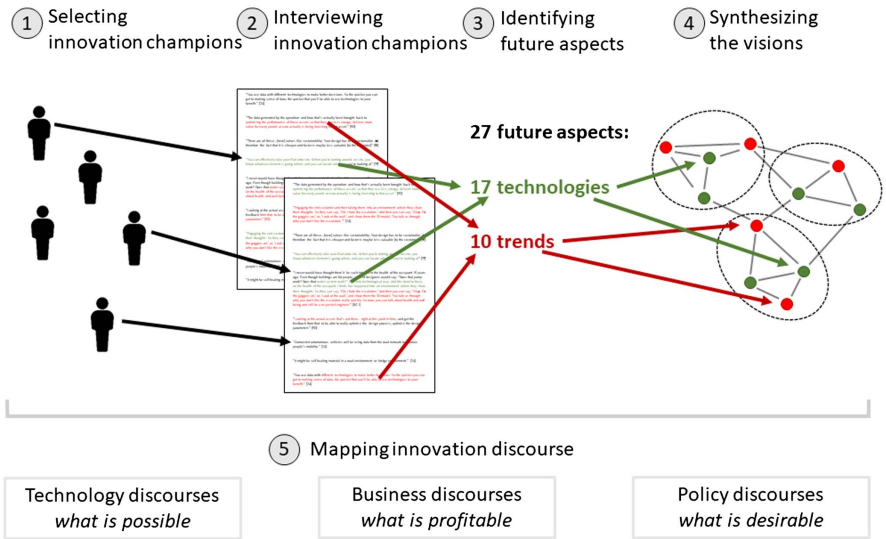

Fig. 1. Five phases of the research method. [Person icon by Universal Icons, under CC Attribution 3.0 (https://creativecommons.org/licenses/by/3.0/us/legalcode).]

is a rather difficult question, the interview guide was carefully developed to build up trust between the interviewer and interviewee (and get the interviewee talking) before discussing the difficult questions of what the future will look like. Correspondingly, the interviews started out with questions relating to how the company dealt with digitalization before the interviewer asked the interviewees about their personal opinions of digitalization and expectations for the future. The specific questions were intentionally open-ended to encourage the respondents to give long, narrative answers. This included several *how* questions intended to capture the interviewees' personal perspective of construction futures and the role of digital technologies. The central question that this paper primarily draws upon was the following: How do you envision the future of construction (e.g., how will we design and construct buildings 15 years in the future)?

The interviewer encouraged the interviewees to be specific and give concrete examples of the impact of technologies, including descriptions of work processes and stakeholder relations.

Table 2 shows an overview of the interviewees. Each interview has been assigned a unique identifier showing which company the interviewee represented. All interviews involved only one interviewee and one interviewer, except for Interview 8, which involved three interviewees from the same company. All interviews took place face-to-face, typically at the interviewee's workplace; the exception was Interview 11, which was conducted via Skype version 2019.

Table 1. Company sample

Company	Company size	Company type	Subsector
A	Large	Contractor	Infrastructure
B	Large	Engineering consultancy	Infrastructure
C	Small	Management consultancy	Infrastructure
D	Large	Engineering consultancy	Building and infrastructure
E	Small	Technology start-up	Infrastructure
F	Large	Contractor	Building and infrastructure
G	Medium/large	Engineering consultancy	Building
H	Large	Engineering consultancy	Building and infrastructure
I	Medium	Contractor	Infrastructure
J	Small	Innovation agency	Building and infrastructure

Identifying Future Aspects (Qualitative Coding)

All audio recordings were transcribed, summing to a total of 104,200 words. The authors read the transcripts and gained an impression that several interviewees shared similar visions for the

Table 2. Interviewee sample

Interviewee	Job title	Department/area	Length (hh:mm)
1A	Manager	Innovation and knowledge	01:38
2A	Manager	Sustainability	00:55
3B	Senior Engineer	Digitalization/ BIM strategy	00:55
4C	Independent consultant	Major projects	00:49
5D	Project Director	Major projects	01:22
6E	Cofounder and Chief Executive Officer	Technology development	01:02
7F	Engineer	Engineering excellence	00:55
8G1	Head of Department	Sustainability	00:56
8G2	Associate Director	Performance	
8G3	Consultant	Performance	
9H	Associate	Foresight	01:01
10I	Director	Business development	00:55
11J	Independent consultant	Digital transformation	01:07

Table 3. Overview of future aspects (technologies and trends)

Identified technologies	Identified trends
BIM	Lean processes
AI	Alliancing business models
Design automation	Standardization
Big data	Safety on-site
IoT asset management	No disruption
IoT energy consumption	Sustainability
AR on-site and maintenance	End user focus
VR and immersive design	Bespoke semiautomation
Future materials	Data-driven companies
CAVs and tunnels	Gig economy
Digital fabrication on-site	—
Design simulations	—
Blockchain	—
Digital twin of city	—
Distributed off-site production	—
Modularization	—
Off-site construction	—

Note: AR = augmented reality; AI = artificial intelligence; BIM = building information modeling; CAV = connected autonomous vehicles; IoT = internet of things; and VR = virtual reality.

future. The authors therefore imported the interview transcriptions into qualitative data analysis software (ATLAS.ti version 8.4.14) to allow for iterative coding of the content.

The analysis software was used to highlight parts of each interview in which the interviewees described an aspect of their envisioned future. The qualitative coding process was conducted iteratively to identify patterns across the interviews. Initially, the focus was on understanding what technologies the interviewees would find important and how the technologies would shape the future of the construction industry. Therefore, codes were assigned to the quotes that mentioned particular technologies. However, these technologies were not sufficient to describe the interviewees' visions of the future. The interviewees also described trends that they believed would affect the future, such as sustainability or standardization. To capture this dimension, 10 further codes were added. The 17 technologies and 10 trends represent 27 future aspects, see Table 3.

Synthesizing the Visions (Data Analysis)

To some extent, the interviewees shared a common vision for the future. Reading through the transcriptions, the authors gained the impression that the interviewees committed to one of three distinct visions for the future. To explore this further, the authors recognized a need for concretizing each narrative. Narratives of the future are by nature not very tangible—and describing to which extent different narratives overlap can therefore be difficult. To cope with this, the paper conceptualizes a narrative vision as a combination of several different future aspects.

Each interviewee mentioned several different future aspects when he or she described a narrative vision for the future. This paper considers two future aspects as connected if they were mentioned by the same interviewee. Consequently, the combination of future aspects can be visualized by means of network analysis.

The network analysis software Gephi version 0.9.2 was used for building a network graph (Fig. 2). The authors exported a data table from the analysis software (ATLAS.ti). This table, which connected each interviewee to a number of future aspects, was then imported into the network analysis software (Gephi). In total, 158 empirical statements were imported, connecting the 27 future aspects through 234 edges (links).

Two nodes (i.e., future aspects) are connected if they are both mentioned by the same interviewee. In this way, the edges represent a direct account of the interviewees' understanding of how future aspects are connected. The following quote exemplifies how an

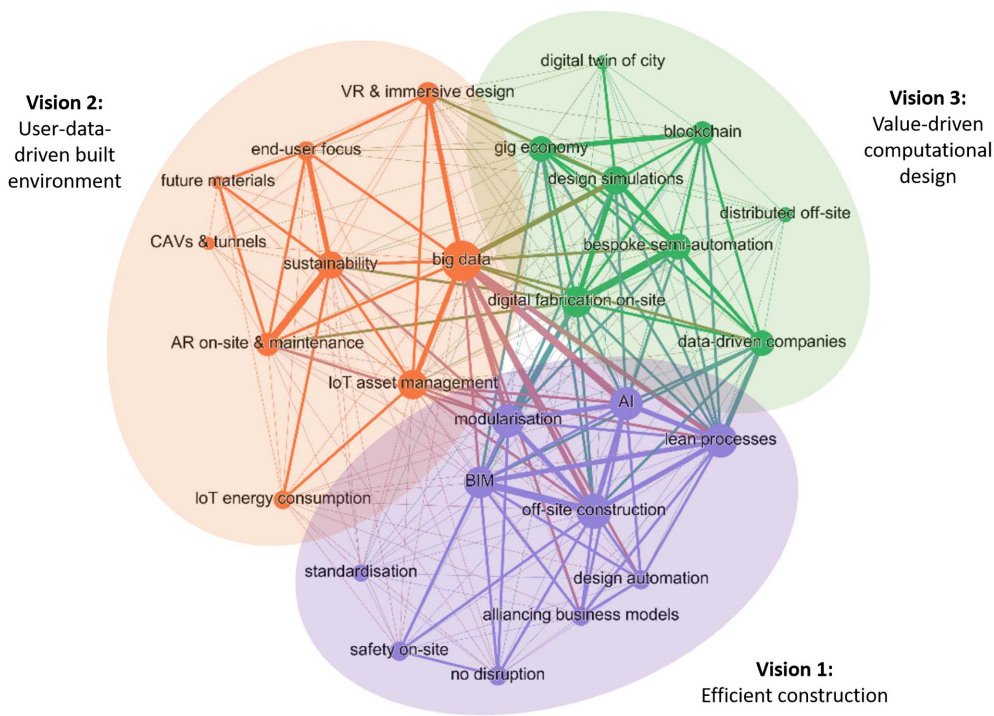

Fig. 2. Future aspects elicited through interviews are clustered to form three visions for the future: efficient construction, user-data-driven built environment, value-driven computational design. AR = augmented reality; AI = artificial intelligence; BIM = building information modeling; IoT = internet of things; VR = virtual reality; and CAV = connected autonomous vehicles.

interviewee connects the two future aspects big data and IoT asset management.

> "How can we think about connecting, for example, the traffic data to an office use, to public transport use, to weather data? It could be bringing a lot of these different functions of everything around us to optimize and deliver a better performance from the assets. Digital infrastructure is ... to get more of those IoT sort of stuff into our infrastructure." [Interviewee 5D—engineering consultancy]

Other interviewees also mentioned these two future aspects, suggesting that big data and IoT asset management (for example) are heavily connected aspects of the future. In other words, these two future aspects are often combined into one narrative of the future—and one might assume some degree of dependency between the two. To visualize to which extent future aspects are connected, the thickness of the connections represent how many unique interviewees have mentioned both of the connecting future aspects.

In some interviews, an interviewee would describe a certain aspect of the future [e.g., artificial intelligence (AI)] in great detail and then briefly mention another future aspect (e.g., off-site construction). To account for this, the size of the nodes represents the number of times this specific future aspect was mentioned by any interviewee (counting also the number of times it was mentioned by the same interviewee).

The authors applied a ForceAtlas algorithm in Gephi to ensure that heavily connected nodes were placed in the middle of the network. This helped identify future aspects that were often mentioned in the interviews, that is, highly likely aspects of the future (according to the interviewees). Correspondingly, the future aspects located far from each other in the periphery of the network do not necessarily align or support the same narrative vision for the future.

To explore how the future aspects combined to form different visions for the future, the authors used Gephi to identify clusters in the network. By means of the Louvain method (Blondel et al. 2008), the software analyzed the network density and identified three clusters, which were characterized by a high degree of internal compared to external connections. The authors analyzed the clusters and used the insights from the interviews to describe three distinct visions for the future of construction.

Mapping Innovation Discourses (Contextualizing the Findings)

During the empirical study, the authors also sought to compare and contrast emerging findings with research literature and industry reports on sectoral discourses that might influence the narratives of construction futures. Thus, secondary data was collated to understand the context of innovation discourses, and after establishing the visions, it was clarified how they relate and should be understood in a broader sectoral context. As this understanding of the visions developed, three wider discourses became seen as interesting: (1) technology discourses driven by researchers and innovators considering what is possible, (2) business discourses created and promoted by management consultancies considering what is profitable, and (3) policy discourses developed by governmental bodies considering what is desirable.

Three Visions for Digital Transformation of Construction

The interview data suggests that innovation champions frame digital transformation through multiple competing visions of the future. Through the synthesis, three visions for digital transformation in construction were identified. Fig. 2 illustrates how the 27 identified future aspects form three clusters representing the visions: (1) *efficient construction*, (2) *user-data-driven built environment*, and (3) *value-driven computational design*.

In the following subsections, the three visions are described and supported by quotes from the interviewees. To enable validation of the network analysis, Tables 4–6 document the future aspects comprising each vision by means of exemplary statements. Furthermore, the tables list the number of interviewees mentioning each future aspect. The tables are organized according to network centrality, so the most central future aspect is listed first.

Vision 1: Efficient Construction

The cluster in the lower part of Fig. 2 forms one vision for the future. Interviewees who outlined this future emphasized the need for making the construction process faster and more efficient. Due to the focus on efficiency, this future vision is labeled *efficient construction*. The vision is centered on aspects such as off-site construction, AI, modularization, BIM, lean processes, standardization, no disruption, safety on-site, alliancing business models, and design automation (Table 4).

In this future vision, BIM is central and fully implemented in all phases of construction projects, as it is vital that all information be fully digital. BIM is used to enable smooth transactions and information flow between the various parties in the supply chain:

> "BIM is really important. It's the interface between each of the parties and each of the phases of the life cycle, and making those as smooth as possible so that you can locate the information, you know what to do with the information when you have it, you know what permission you have for it, and then you can reuse it without having to retype it into a computer so we're not passing PDFs or unreadable information around we've got. That's going to be the real key." [Interviewee 3B—engineering consultancy]

Thus, efficient construction is seen as BIM-enabled, with all parties interfacing through the use of the same reusable information. Inspired by the principles of lean manufacturing processes, the majority of building components are now standardized by reducing complexity and removing unnecessary variability in construction designs:

> "Why do we have so many different types of pile holes we dump into the ground? So many different diameters.... Can we find ways to standardize that? ... We're going to have five different types, and they will be these diameters. Some areas might be slightly over-designed, but some areas will be optimized. And overall you get a better optimization in terms of costs and quantities." [Interviewee 5D—engineering consultancy]

Standardization increases efficiency through leveraging learning effects and economy of scale. It is furthermore supported by modularization of construction elements and off-site prefabrication, allowing for faster on-site assembly. This has implications for construction workers' tasks, which have changed as the need for manual handling of construction materials decreased. Consequently, safety for on-site workers is improved, and fewer people are now working on construction sites:

> "Most of the buildings these days can be modularized.... The details can be developed such that there is no huge need for people on the construction site to interact with construction

Table 4. List of future aspects forming Vision 1: efficient construction

Future aspect	Centrality	Mentioned by interviewee	Example of quote from an interviewee
Off-site construction	0.93	[3B] [5D] [7F] [10I] [11J]	"You will see lots of prefabricated long section corridors of MEPs, ductworks, and cabling, and stuff already prefabricated in the factory and delivered on-site" [7F]
AI	0.91	[3B] [5D] [9H] [11J]	"[AI] will make it very much faster to make the initial estimates of how a design will affect the cost and the size, the time it takes to build the building" [9H]
Modularization	0.91	[5D] [7F] [9F] [11J]	"[A building] can be modularized as a volume or it can be modularized in component parts." [7F]
BIM	0.89	[3B] [4C] [5D] [7F] [10I]	"The BIM thing is all about handing over digital information to the contractor so that they can do their piece, and that the contractor hands over digital information to the maintainer and the operator so they can do their piece." [3B]
Lean processes	0.86	[3B] [4C] [5D] [11J]	"I think the role of technologies are to simplify the interface between the different parties and to ... limit the barriers between organizations ... in kind of the larger sense, how does design speak to construction, speak to maintenance?" [3B]
Standardization	0.67	[5D] [8G1]	"The type of beam we might use in a housing project probably should not be more than three, four, five, different types." [5D]
No disruption	0.65	[5D] [7F]	"So we believe that disruption doesn't exist in reality. In reality, it's just the slow pace needs to be managed." [7F]
Safety on-site	0.65	[5D] [7F]	"We started talking about putting sensors and locators on hardhats or high-definition cameras that can analyze the work of the workers to see if they're doing anything risky." [7F]
Alliancing business models	0.56	[3B] [5D]	"I think generally, the contracts are moving much more into alliancing models and we're thinking more about integrators and delivery partners, rather than designer and constructor." [3B]
Design automation	0.56	[3B] [5D]	"The aim ... is not to replace the creative aspects of design, but merely to automate the completion of those aspects for which standard processes, designs, and templates already exist." [5D]

Note: MEPs = mechanical, electrical, plumbing systems.

> materials.... You will effectively build every section using technology that is already developed and used in manufacturing lines." [Interviewee 7F—contractor]

This vision includes no big bang type of disruption in the sense of new entrants managing to gain large market shares. On the contrary, the established construction companies have managed to make a slow and steady transition to a digital and lean way of working. The various parties in the supply chains now interact and collaborate digitally by means of strategic collaboration contracts:

> "I think generally, the contracts are moving much more into alliancing models and we're thinking more about integrators and delivery partners, rather than designer and constructor.... So what we'll see is shared liability and shared risk and opportunity across project deliveries or program delivery" [Interviewee 3B—engineering consultancy]

These longer-term alliancing business models and strategic collaborations allow construction companies to optimize solutions and processes, not just in single projects but also at the portfolio and program level. They create a fruitful context for organizational learning by which the efficiency of construction is improved.

Long-term business models further enable investment in automation of design tasks, thus eliminating the most repetitive work and making the design process more efficient:

> "[If] we know that there's not [just] one single water supply project or drainage project, there's going to be 25 of them over the next three, four years... we could actually invest time into getting that standardized design automated. And then the contractor can standardize their manufacturing or installation process. So you start getting efficiency out of that." [Interviewee 5D—engineering consultancy]

As certain design tasks are automated, construction designers begin utilizing AI technologies, such as generative design and parametric design, to vary the input parameters and consider hundreds of design alternatives from an early stage in the project:

> "Generally [today], when you have a new project coming in, let's say a stadium, we say, 'Let's do a steel stadium'. That decision is a massive decision. It has a huge implication on cost. It has a huge implication on looks, ... on carbon, etc. But it's made like that. Right? But could we actually explore ... 'What if I do the stadium in timber or in concrete?' That is very exciting." [Interviewee 9H—engineering consultancy]

In this vision, AI not only expands the solution space for construction design, it also increases the efficiency of construction planning processes by exploring and evaluating a number of alternative construction schedules.

Vision 2: User-Data-Driven Built Environment

The cluster in the upper left corner of Fig. 2 forms a second vision for the future, named *user-data-driven built environment*. Interviewees outlining this vision for the future emphasized the importance of ensuring that construction projects be based on actual user data gathered, for example, through sensors in the built environment. Furthermore, interviewees emphasized optimizing the built environment to suit the end user in a sustainable way.

Table 5. List of future aspects forming Vision 2: user-data-driven built environment

Future aspect	Centrality	Mentioned by interviewee	Example of quote from an interviewee
Big data	1.00	[2A] [3B] [5D] [6E] [7F] [9H] [11J]	"You use data with different technologies to make better decisions. So the quicker you can get to making sense of data, the quicker that you'll be able to use technologies to your benefit." [2A]
IoT asset management	0.98	[2A] [5D] [8G3] [11J]	"Looking at the actual assets that's out there . . . right at this point in time, and get the feedback from that to be able to really optimize the design process, optimize the design parameters." [5D]
Sustainability	0.81	[1A] [2A] [7F] [8G1] [8G3] [9H]	"There are all these . . . [new] values like sustainability. Your design has to be sustainable. And therefore the fact that it is cheaper and faster is maybe less valuable [to the customer]." [9H]
Virtual reality and immersive design	0.76	[2A] [6E] [11J]	"Engaging the end customer and then taking them into an environment where they share their thoughts. So they can say, 'Oh, I hate the escalators.' And then you can say, 'Okay. Put the goggles on,' or, 'Look at the wall,' and show them the 3D model, 'You talk us through why you don't like the escalators.'" [2A]
Augmented reality on-site and maintenance	0.69	[1A] [2A] [7F] [9H]	"You can effectively take your iPad onto site. When you're turning around on-site, you know whatever element is going where, and you can locate whatever you're looking at." [7F]
IoT energy consumption	0.65	[1A] [2A] [5D] [6E] [8G3] [11J]	"The data generated by the operation and how that's actually been brought back to optimizing the performance of those assets so that they use less energy, delivers more value for every pound or euro actually is being investing to that asset." [5D]
End user focus	0.50	[1A] [2A] [6E] [8G1]	"I never would have thought there'd be such interest in the health of the occupant 15 years ago. Even though buildings are for people, a lot of designers would say, 'Does that pump work? Does that water system work?' in a very technological way. And this trend to focus on the health of the occupant, I think, has happened really quickly. So now, you can talk about health and well-being and still be a respected engineer." [8G1]
Connected autonomous vehicles and tunnels	0.42	[2A] [10I]	"Connected autonomous vehicles will be using data from the road network to improve people's mobility." [2A]
Future materials	0.32	[1A] [2A]	"It might be self-healing material in a road environment or bridge environment." [2A]

The vision is organized around aspects such as big data, the IoT asset management, sustainability, virtual reality and immersive design, augmented reality on-site and maintenance, IoT energy consumption, end user focus, connected autonomous vehicles and tunnels, and future materials (Table 5).

This future vision focuses on the built environment rather than the construction process. Here, construction companies focus on designing and optimizing the built environment to suit the needs and behavior of users. IoT sensors are installed ubiquitously in the built environment to gather data such as user movement patterns and air quality. The gathered data is combined with other data sources (e.g., weather or climate) in big data sets and used to optimize the utilization of built structures:

> "There's capacity issues. And there are ebbs and flows in the way the system operation. Whether it's raining, or it's not raining, or whether certain trains are in maintenance or in operation. So we can bring it all together to get better insights to an extent that you might be able to say, 'Well, maybe do not schedule a meeting 9:00 AM on a Monday morning in the Fleet Place office, because there's a half chance that six of your invitees might be delayed.' That's the sort of insights that we can generate." [Interviewee 5D—engineering consultancy]

Collected information can be stored in data pools, which create a much more elaborate knowledge base for designing and operating buildings. Instead of relying on building codes and standard information, designers now use the actual use data to dimension built structures to fit specific site conditions and user preferences:

> "For example, when we designed this building, we assumed that if we're going to have, let's say, 55 people on this floor, each of them will use this much water every day, and that means this is the system we need to design for. That's what we do in our [Eurocodes] rule books. No one has actually looked at, actually, in this area with this type of demographic, this type of office use, that actually, we have data that the water usage is this. . . . That's where our design will be informed by much more real data than actually empirical standard information." [Interviewee 5D—engineering consultancy]

User needs are considered as central to the design and new design criteria have emerged. One important design criterion is sustainability, which certain customers consider more important than price and construction time. Sustainability is used to describe not only initiatives aimed at reducing energy consumption and carbon emission of built assets but also the extent to which a built asset

Table 6. List of future aspects forming Vision 3: value-driven computational design

Future aspect	Centrality	Mentioned by interviewee	Example of quote from an interviewee
Digital fabrication on-site	0.81	[4C] [7F] [8G3] [9H] [11J]	"There's still some things that you have to do on-site, but maybe you could get some automation in there, such as robotics or even additive manufacturing, 3D printing." [11J]
Gig economy	0.79	[4C] [8G1] [10I] [11J]	"I just think that we should be more willing to join the specialists together to deliver a project as opposed to trying to capture them into organizations." [4C]
Design simulations	0.77	[4C] [6E] [9H] [11J]	"This is how people are moving around in this area. How will those people exit? If there is something that happens, that means that we need to get people out within 25 s. And, fundamentally, when we do buildings and when we do design, those are the key issues that we start looking at." [11J]
Blockchain	0.77	[4C] [8G1] [11J]	"They're not [supply] chains anymore. They're webs of suppliers, which designers are part of . . . I think you could with blockchain technologies, potentially." [11J]
Bespoke semiautomation	0.74	[4C] [8G2] [9H] [11J]	"Semiautomization is really interesting, the idea that you can decide as you go along on the right construction methodology . . . I think when you standardize, you remove options, whereas . . . actually, at each point, we could decide which bits we'd put on a CNC machine or a laser cutter and which bits we'd just do in-house [based on the] availability of our carpenter." [4C]
Data-driven companies	0.72	[3B] [4C] [11J]	"If we actually had a Google-like company enter this market, you'd end up with . . . your fabricators, and your assemblers, and your architects, and your engineers, and your clients all working inside a virtual world to design it all." [4C]
Distributed off-site production	0.59	[11J]	"Can you design your own home and then send that to your local factory, which could be a couple of miles away or in the local city? And then they will have a CNC cutter, and they will cut that." [11J]
Digital twin of city	0.47	[4C] [6E]	"I want a digital twin of London already built and ready to go so that you can do proper analysis of: 'If you put a new Aldi in here, what's the impact on the traffic?'" [4C]

Note: CNC = computer numerical control.

improves the quality of life of users (i.e., social sustainability). Construction companies are increasingly interested in the health and well-being of end users, and several companies apply a business-to-consumer (B2C) rather than a business-to-business (B2B) business model:

> "I don't think we'll be building that many roads [in the future]. I think we'll be providing services on the road. So the connected autonomous vehicles will be using data from the road network to improve people's mobility. I think we'll see [Company A] go from a B2B business to maybe a B2C, so we'll be providing services to our clients." [Interviewee 2A—contractor]

Further, the actual interaction with users changes. Construction companies often engage with users by means of VR. The virtual three-dimensional (3D) model of a construction project helps users and designers understand each other during the design phase, as design criteria, suggestions, and alterations are visually tangible within the virtual environment. Consequently, the public hearing phase of construction projects results in far fewer petitions than earlier:

> "If you engage people in the place where you want to innovate, hopefully they'll feel more inclined, hopefully they can see the benefit and hopefully . . . you can actually say, 'Thank you very much for the research.' Even if it's five years later, you'll feed back to them and say, 'Your innovation was implemented at Euston Station. Come back and rate it.'" [Interviewee 2A—contractor]

VR not only enables involvement of the broader stakeholder landscape, VR experiences can also help users and designers understand highly specific details of the project, such as noise-related aspects of a built structure:

> "When you're in an immersive environment, we can now make it so you can hear how the room will sound based on the different wall coverings, or glass, or ceiling height, or whether the ceiling is exposed, or the floor coverings, or whether there's furniture in there, or whether there are more people in there, and we can model that. So that's when you start getting into the comfort bit." [Interviewee 11J—innovation agency and freelancer]

Finally, the virtual 3D models are also used for augmented reality (AR). Construction professionals on-site use AR glasses or handheld devices (e.g., a tablet) to compare the construction site to the virtual model. Furthermore, AR is used to visualize hidden structures (e.g., water pipes or electricity installations) on-site:

> "Every time there is a problem with a pipe, or any small problem on-site . . . via the [augmented reality glasses] HoloLens, . . . you are able to see what's the problem." [Interviewee 1A—contractor]

Consequently, the user focus of this vision is not just targeting end users but includes all users that are a part of the built environment.

Vision 3: Value-Driven Computational Design

The cluster in the upper right corner of Fig. 2 forms the third vision, named *value-driven computational design*. Interviewees outlining this vision for the future emphasized the need for embracing the bespoke nature of construction projects by creating digital designs that simulate the consequences of different design choices and enable changes during the construction process. Moreover, they anticipated a fundamental shift in the organization of construction professionals and profiles of a typical construction company. The vision is comprised of aspects such as digital fabrication on-site, gig economy, design simulations, blockchain, bespoke semiautomation, data-driven companies, distributed off-site production, and digital twin of city (Table 6).

In this vision of the future, all construction projects are bespoke by choice. Construction professionals utilize computational design tools based on AI to simulate the consequences of different design options. Design simulations aid many types of decisions, including not only how the designed structure should look but also how to get materials to the site, how to construct certain parts, and how the project is expected to impact congestion:

> "All the risk sits as soon as you physically buy something, as soon as you physically dig a hole in the ground, all the money sits there. If you can de-risk that and put all of that in the computer, then actually that completely and utterly changes the model for the industry." [Interviewee 4C—management consultancy]

The basic idea is that a digital representation fundamentally changes the way physical infrastructure is developed. Where both the digital and physical can be developed and updated in parallel (in near real time), practitioners talk about a digital twin. A common digital twin of entire cities assists construction professionals in anticipating the impact of built structures on citizen behavior and preferences. Gaming engines and digital twins are used to simulate, for example, evacuation behavior and transport patterns. As user behavior and preferences can be simulated reasonably accurately, the actual end users are disconnected from the design process:

> "We know the way sound will move, and we can pretty much make assumptions about what is uncomfortable and what is comfortable.... I mean involving users is great, but most of the time, we involve people so they don't get pissed off that we haven't involved them. They don't actually necessarily give consistent or valid answers." [Interviewee 11J—innovation agency and freelancer]

In this vision, the user is not just involved in the construction process but rather modeled. Despite being modeled, the inconsistencies of actual user needs make construction professionals strive to create flexible designs to cope with changing design criteria and customer preferences during the construction process. This enables the client to commit to design decisions as late as possible. As the client does not need to decide on construction methods until a few days before construction begins, these choices can be based on practical issues, such as site conditions or the availability of workers and machinery on the day in question:

> "You've got to give people the flexibility to take into account the available expertise that's there at that moment in time, to make the decision on what you do next. And to say that we're going to go down a fully automated way, that constrains you just as much as we are now. I think you've got to allow for all the shades in between, and to be able to make a sensible decision." [Interviewee 4C—management consultancy]

The flexibility of design and construction furthermore changes company profiles fundamentally toward more data-driven profiles. Digital skills are now at least as important as traditional construction skills, and the most successful companies are those who have understood how to integrate the two and digitally transform their business model:

> "You want people with a digital skill set working alongside cross people who understand how stuff goes together. And it's all being done in a virtual world. It's not necessarily going to be the contractors of today because their skill set is contracting, setting up contracts, and that's not the skill set we really need. We have that skill set because of the disjunct between how well we can design and how well we can build. And so they can fill that gap, whereas actually, if he can solve all those problems on a computer, the contracting side becomes really easy." [Interviewee 4C—management consultancy]

This vision challenges the existing archetypes of companies involved in construction. Instead, the construction sector is characterized by networks of smaller enterprises and freelancers that collaborate on specific construction projects. Typically, each construction stakeholder is hired on project terms for the duration of each project, according to his or her individual contract. In some cases, blockchain-based solutions are used to coordinate between individuals and reduce the need for intermediaries, thus cutting overheads and overall project costs:

> "Why don't we do fixed term contracts? Why don't you hire me for two years to do a piece of work? Why do you feel the need to have me on your books as an employee, and why do I need to work for you five days a week? If the piece of work I'm doing only requires me to do two days per week with you, then I'll do two days a week with you and I'll do two days a week with somebody else. And actually, huge numbers of people would want that flexible way of working." [Interviewee 4C—management consultancy]

This vision is, thus, heavily influenced by the gig economy and the project society, in which people define themselves by the projects they have contributed to rather than the companies they work for. The distributed and flexible workforce is further mirrored in local production facilities spread across the country, providing easy access to, for example, computer numerical control (CNC) machines or laser cutters. By sending a digital BIM model to the nearest production facility, construction stakeholders can create unique items on demand and exploit quick delivery times, thus speeding up the construction process:

> "You would have an individual with a facility, and that facility has a CNC machine, a cutting machine, and additive manufacturing, and... can make all sorts of different things. And that individual is local to where you are building. And so you have hundreds of these individuals all around the UK. And when you have your design, you send that to your local person who will create your flat-pack building or your I-beams or your ductwork or whatever, your modulated system, and ship it to you. And that person, at the same

time, could be . . . printing plastic Christmas trees for a local toy shop. Because all they need is the equipment, and the information is handled digitally, so you're not having these centralized factories that do a specific thing." [Interviewee 11J—innovation agency and freelancer]

The local production is further supported by new digital fabrication methods such as additive manufacturing and robotics. This changes the way in which construction elements are fabricated. Due to the faster and cheaper fabrication technologies, the limitations for what may be designed is changing:

"So, our kitchen in our house, we've done what's called box in box. There's no hardware. So, there's no runners on our drawers, which is how they used to make cupboards. But they stopped doing it because carpenters couldn't afford to have someone who could make it that precise. A machine can make it that precise. So, we can go back to that style of making things. But we've designed so many things in our world based on the limitations of the industrial process. . . . 'We can only make plywood this size because our machine is only this big.' Well, actually we get to rethink all that and say, 'This is the right solution.'" [Interviewee 4C—management consultancy]

Thereby, the flexibility of the production systems enables the bespoke nature of construction projects characterized by this vision.

Comparing the Three Visions

The visions differ as they emphasize different primary design criteria, highlight the future potential of different technologies, describe different enabling work processes, and aim toward different overall goals for the sector. Table 7 summarizes the characteristics of each of the three visions for the future of the construction sector. This section will compare and contrast the visions and discuss their implications.

Centrality of Future Aspects

As can be seen from the network graph in Fig. 2, some future aspects are more highly connected than others. Consequently, these future aspects are found in central locations of the network. The eigenvector centrality measure can be used to calculate the relative importance of each future aspect. The centrality measure considers an aspect important if it is linked to other important aspects. Tables 4–6 rank the future aspects for each vision according to their eigenvector centrality. The future aspect big data turns out to be the most central. This finding is consistent with the general view that implementation of digital technologies relies on good data management. The aspects IoT asset management, off-site construction, AI, modularization, and BIM are also located centrally in the network. All of these future aspects represent Visions 1 and 2, perhaps signaling that the aspects of these two visions are more frequently mentioned (i.e., are better known to the interviewees).

Table 7. Comparison of the three visions

Theme	Vision 1: efficient construction	Vision 2: user-data-driven built environment	Vision 3: value-driven computational design
Task assessment	*BIM:* BIM models are used to contain all relevant data on a construction project to enable seamless transitions between stakeholders.	*Big data:* User data is combined with other data sources to understand user needs and preferences. *IoT:* Data is collected through sensors in the built environments to optimize asset performance.	*Digital twin of city:* Data is compiled in a common city-wide digital twin to enable simulations of the impact of a new construction project.
Design	*Standardization:* Modular and standardized elements are building blocks for design. *Design automation:* Repetitive design tasks have been automated. *AI:* New design tools predict the cost and time of a construction project from an early stage.	*VR and immersive environments:* Stakeholders and end users explore design solutions in immersive environments. *Sustainability:* User-defined design criteria like sustainability are often regarded as more important than time and cost.	*Design simulations:* Computer-simulated scenarios are used to predict user behavior. *Bespoke semiautomation:* Rather than committing to decisions from an early stage, designers strive to keep open several options for manufacturing and assembly.
Construction methods	*Modularization and off-site construction:* Modular construction leverage the benefits of prefabrication and off-site construction. *Safety on-site:* Sensor technology enhances the safety of on-site workers.	*Future materials:* New materials improve the expected life-time of built structures. *AR on-site:* On-site workers use augmented reality to compare the virtual model to the actual built structures.	*Distributed off-site production facilities:* Produce construction elements alongside other manufactured goods. *Digital fabrication methods on-site:* Robots and 3D printing technology are used on-site and enable customized designs.
Stakeholders and other topics	*No disruption:* Companies are not new entrants but have years of experience from within the sector. *Alliancing business models:* Companies engage in long-term strategic collaborations. *Lean processes:* The work flows are optimized to ensure smooth transactions between construction professionals.	*End user focus:* Construction companies target end users using B2C business models. *Connected autonomous vehicles and tunnels:* New types of transportation dominate the built environment.	*Data-driven companies:* Data flows and data management structures form successful construction companies. *Gig economy and blockchain:* Construction workers are organized in project-based networks and hired individually rather than as part of a large company.
Primary aim	Reducing time and cost of construction.	Enhancing the performance of the built environment.	Customizing designs to fit the context.

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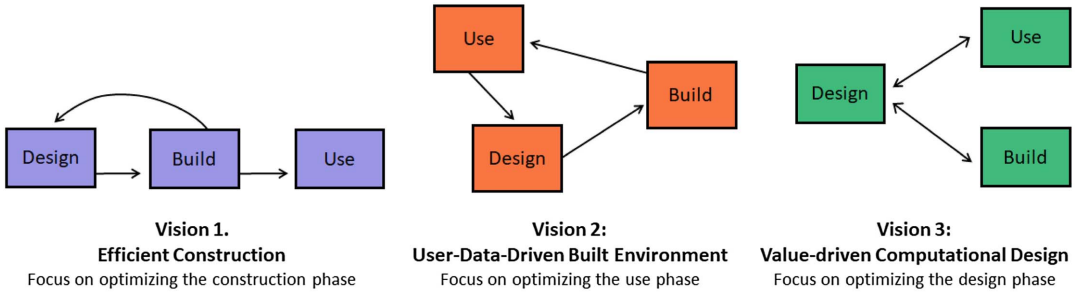

Fig. 3. Visions place emphasis on different parts of the three main phases in a construction project.

Table 8. Percentages of the interviewed companies that mentioned aspects from each vision by company type

Company type	Vision 1: efficient construction (%)	Vision 2: user-data-driven built environment (%)	Vision 3: value-driven computational design (%)
Contractors	66	100	66
Engineering consultancies	100	100	75
Small companies	66	66	100

Focus Areas of Each Vision

The three visions are not mutually exclusive, although they have different focus areas (Fig. 3). Whereas Vision 3 focuses on optimizing the design of a construction project, Vision 1 focuses on optimizing construction, and Vision 2 focuses on optimizing for the use phase.

Correspondingly, one might think that the interviewees representing contractors are committed to the construction-related aspects of Vision 1, while engineering consultancies are focused on the design-related aspects of Vision 3. However, as can be seen from Table 8, this is not the case.

In Table 8, the interviewed companies are differentiated into three company types: contractors, engineering consultancies, and smaller companies (management consultancy, innovation agency, and start-up). Each of these three groups consist of three or four interviewed companies. Contractors and engineering consultancies alike mentioned aspects from all three visions, especially Vision 2. Moreover, smaller companies more consistently mentioned aspects from Vision 3 than contractors and engineering consultancies.

Interdependencies Between Visions

The visions emphasize the potential of various technologies differently. Vision 1 emphasizes the impact of BIM, AI, and off-site manufacturing technologies; Vision 2 emphasizes the impact of big data, IoT, and mixed reality (i.e., VR or AR); and Vision 3 emphasizes the impact of digital twins, design simulation tools, robotics, and 3D printing. Although the visions are in principle self-sufficient, elements from one vision may support or contribute to another vision. For instance, the sensor data described in Vision 2 may be used to improve the design simulations described in Vision 3. In other cases, certain elements from one vision may not be compatible with elements in another vision. For instance, the customized construction elements described in Vision 3 stand in contrast to the modular and standardized construction methods found in Vision 1.

To some extent, it may be difficult to see one vision emerge without future aspects from other visions, as the technological future aspects are dependent on each other. For instance, how would one use virtual reality environments (as described in Vision 2) without a BIM model of the built structure (as described in Vision 1)? In addition, how can a digital twin of entire cities (as described in Vision 3) be created without an immense amount of (big) data from the existing built environment (as described in Vision 2)?

Focusing on similarities between the visions, readers may find it appealing to combine the three visions into one large vision for the future of the sector. Likely, the future will entail a combination of elements from all three visions. However, it is important to keep in mind that the purpose of the visions is not to establish agreement. Instead, the purpose is to explore how different trends and expectations for the future support or conflict with each other, while acknowledging that the future is uncertain.

A company implementing BIM to create lean supply-chain processes will arguably make very different managerial decisions compared with a company implementing BIM to improve its interactions with the client through VR. Similarly, a company seeking to improve its management of big data to optimize the performance of built assets may behave very differently from a company seeking to improve its management of big data to create a city-wide digital twin. Consequently, the authors argue that a company may benefit from clarifying the goal of applying a digital technology. Is the primary aim of implementing new technologies to reduce cost and construction time? To enhance the performance of the built environment? Or to ensure that each design is optimized for its context? Committing to one of the digital visions outlined in this paper could be a way for construction companies to explicate their primary aims.

Contrasting the Visions to Aid Strategic Discussions

The narrative elements of the visions make them useful reference points for discussion. This was demonstrated in Interview 8, which coincidentally had two interviewees who did not share the same vision for the future (although they worked together in the same company). One interviewee (8G1) underlined the importance of standardization and described a future resembling Vision 1, whereas another interviewee (8G2) argued that the future of the sector would include more customized solutions and described a future resembling Vision 3. During the interview, these two

interviewees began debating their opposing views on the need for standardization and realized that they had different views on the future of the sector:

> "Imagine if screws and bolts were just random diameters. It'd be crazy . . . All our references to engineering assembly is based in German standards. So, manufacturing has got to be about standard dimensions. You could still have freedom about how it's put together, but let's not play with some of the standardizing principles of manufacturing." [Interviewee 8G1—engineering consultancy]

> "My point is that if the future of manufacturing is going to be customization, . . . Sure, you might start off by standardizing small bits of it, like the screws and the nuts and the bolts. But then get to a point where there are certain aspects of that standardization, which will constrain what you're doing and if that constraint is so defining that you end up with all student bedrooms looking like exactly the same thing, the market won't accept that." [Interviewee 8G2—engineering consultancy]

By contrasting Visions 1 and 3, stakeholders may find that the future of the sector entails a trade-off between standardization and customization. Arguably, standardization may lead to improved efficiency but also path dependency, thus creating unnecessary constraints for the design. Standardization is typically considered inevitable because it enables automation. However, the current development within AI and digital manufacturing technology may challenge this assumption, as described in Vision 3.

According to Harty et al. (2007), construction futures studies should appreciate the ability of stakeholders to influence some aspects of the future and not others. Comparing the three future visions, construction stakeholders can clarify what parts of the future seem inevitable (e.g., BIM and big data) and what parts are negotiable (e.g., standardization). Comparing the visions, construction professionals may also find it beneficial to discuss when they expect a given future to occur. Some may argue that Vision 1 is likely to happen before Vision 2, or that Vision 2 will be a stepping-stone toward Vision 3. These discussions can be beneficial for construction companies striving to create a resilient long-term strategy.

Innovation Discourses

When envisioning the future, innovation champions are influenced by innovation discourses. These discourses are present in technology-related research exploring what is possible, business-related reports on what is profitable, and policy-making debates on what is desirable. To contextualize the visions, this section will provide an overview of current innovation discourses.

Technology Discourses: What Is Possible?

Most research on the impact of technology on construction tend to focus on single technologies or a group of related technologies and their potential applications. This is the case in, for example, the review by Dainty et al. (2017) of a BIM revolution discourse. Research publications presenting the specific configuration of a technology and its applications may be interpreted as discourses of construction futures. As it is outside of the scope of this article to include all potential technologies, a few categories of emerging technologies were selected based on recent and highly cited articles: automated construction technologies (e.g., Bock 2015), big data (e.g., Bilal et al. 2016), and IoT (e.g., Woodhead et al. 2018).

As an exemplary account of construction futures, Bock (2015) outlines how technologies for automating construction will improve the efficiency of the construction process and transform how buildings are designed. Furthermore, pervasive construction automation technologies will be integrated into the built environment (e.g., in the form of service robots). This, however, imposes disruptive changes on products, processes, organization, management, stakeholders, and business models of the construction sector. Construction automation further connects to other technologies like BIM, 3D scanning, 3D printing, and IoT.

Much research anticipates that big data will have a large impact on the future of the construction sector [e.g., Bilal et al. (2016)]. Mansouri and Akhavian (2018) outline a large number of application areas for big data, including productivity, lean construction, safety, building life cycle management, and sustainability. Madanayake and Egbu (2019) specifically identify sustainability as an umbrella term for organizing the application of big data. In all cases, the implementation of big data entails fundamental changes to either design, production, and/or operational processes (Bilal et al. 2016). Furthermore, the successful implementation of big data connects to the implementation of other technologies like BIM, cloud computing, smart buildings, AR, and IoT.

Focusing specifically on IoT, Woodhead et al. (2018) argue that technologies are typically conceived as singularly focused point solutions and that this perception is counterproductive for the realization of future opportunities. Woodhead et al. (2018) take the point of departure in a future narrative conceptualized as Industry 4.0 and incite that technologies like IoT are seen as an integrated layer—an ecosystem—spanning different parts of construction, processes, organizations and connected systems, and technologies. Specifically, they see IoT connected to topics as BIM, robotics, blockchain, AI, digital twins, and prefabrication. According to Woodhead et al. (2018), a broader mindset of IoT will lead to the introduction of new companies; new smart products; new services; new processes; new ways of working; new expectations; new business models; and new relationships.

Based on this brief review of some on the most cited and recent academic publications on construction technologies, it can be concluded that narratives of construction futures (1) target multiple use cases and areas of applications, (2) are leveraged by connecting multiple different technologies, and (3) entail transformational changes to the industry.

Business Discourses: What Is Profitable?

Over the last five years, an increasing number of highly profiled business publications have articulated a change agenda for construction, arguing that the sector is ripe for disruption (Ernstsen et al. 2018). Inspired by the research by Teicholz et al. (2001) on productivity, the McKinsey Global Institute (Barbosa et al. 2017) argue that the productivity of construction is "remarkably poor" and could be increased by over 50%. The World Economic Forum (2016) adds to this by claiming that the construction industry's significant economic, societal, and environmental impact creates a substantial case for digitally transforming the sector. Both industry analysis reports highlight the fact that construction may benefit from rethinking regulatory and contractual structures, standardizing work processes, and implementing new technologies. A subsequent article from McKinsey identified rising investments in construction technology firms amounting to $10 billion from 2011 through early 2017 (Blanco et al. 2017). Building upon this insight, Blanco et al. (2018) mapped the existing and emerging applications of digital technologies in a network graph. Their graph revealed four clusters of emerging digital technology in construction: (1) supply-chain

optimization and marketplace, (2) 3D printing, modularization, and robotics, (3) artificial intelligence and analytics, and (4) digital twins. Furthermore, Blanco et al. (2018) used the network graph to visualize how the emergence of new digital technology clusters connects to the existing applications of digital technology in construction. While the network graph clearly illustrated the connections and interdependencies between technologies, the analysis did not explore how technology clusters integrate with different visions for the future of the sector.

Policy Discourses: What Is Desirable?

Governments facilitate the adoption of digital technologies in construction through various policy instruments and strategies (Blanco et al. 2019). In the UK, a widely accepted policy narrative describes the construction sector as lagging behind other sectors and needing modernization. The corresponding improvement agenda, which was introduced by the *Rethinking Construction* report (Egan 1998), has been discussed in the literature as a performative discourse that seeks to promote improved competitiveness and sectoral efficiency (Green et al. 2008; Sergeeva and Green 2019).

From this perspective, construction policies are shaped in a dynamic negotiation and competition between multiple discourses (Green 2011). The dominant performative discourse exists as it positions itself in contrast to other discourses. A significant, concurrent counterdiscourse may, for example, describe the need for promoting sustainability of the built environment (Akadiri and Fadiya 2013; Pomponi and Moncaster 2017). This counterdiscourse focuses on minimizing the negative environmental side effects of production and consumption, and draws on the concepts of circular economy and sustainable supply-chain management (Nasir et al. 2017). Other counterdiscourses emerge and consolidate or disappear over time. Research has, for example, also articulated and discussed an adaptive architecture discourse (Cheng and Bier 2016).

Recently, Sergeeva and Green (2019) highlighted a need for introducing nuance into the dominant construction sector narrative. Furthermore, they identified a need for empirical research that explores how construction practitioners interpret innovation. Through qualitative analyses of interviews with innovation champions, two studies have found that champions draw on sectoral narratives or discourses in their descriptions of past and present innovations (Leiringer and Cardellino 2008; Sergeeva and Green 2019). Consequently, researchers studying construction innovation can benefit from considering innovation to be a constituent part of wider discourses in the sector (Leiringer and Cardellino 2008). The three visions for digital transformation of construction should be seen from this perspective.

Situating the Visions in Current Innovation Discourses

The following section will put the visions *efficient construction, user-data driven built environment, and value-driven computational design* into perspective by investigating their alignment with current technology, business, and policy discourses.

Alignment with Technology Discourses

The visions connect to broader technology discourses on what is technically possible. Three dominant technology discourses were presented in the previous section: construction automation, big data, and IoT. It is thus interesting to investigate how the visions align with the existing discourses on technology in construction.

The technology discourse on construction automation presented in, for example, Bock (2015) connects construction automation to Visions 1 and 3 through the future aspects design automation, standardization, digital fabrication on-site, and bespoke semiautomation. While this is in line with the predominant discourse on automation, it is challenged by Bock's (2015) idea that automation is not just about improving the efficiency of construction but targeting the broader built environment (Vision 2).

The technology discourse on big data claims that big data implementation entails a large number of changes to construction sector processes and points out that big data connects to a large number of other technologies (Bilal et al. 2016). The centrality of the big data node in the network in Fig. 2 supports this claim, stating that implementation of big data seems to play a pivotal role in most visions for the future of construction.

The current technology discourse on IoT is primarily connected to Vision 2, as it entails the collection of data through sensors in the built environment to optimize asset performance. However, the broader conceptualization proposed by Woodhead et al. (2018) also connects this technology discourse to Vision 1 (BIM and robotics) and Vision 3 (blockchain, AI, digital twins, and prefabrication).

These accounts of technological discourses suggest that technologies are much more interdependent than what is usually considered. The technologies connect to a wide range of complementary technologies and areas of application. The network graph (Fig. 2) confirms this. The technology discourses on IoT and construction automation articulate a broader area of application than what is currently formulated by the innovations champions. This suggests that visions can be further informed by technological possibilities. Conversely, the visions establish a framework of potential (desirable) futures, which can inform further research into technological possibilities.

Alignment with Business Discourses

The visions also connect to global business discourses. The network graph developed by McKinsey (Blanco et al. 2018) provides an overview of the many existing and emerging technology solutions provided by IT companies in construction. A comparison of this network and the network presented in Fig. 2 reveals a number of shared nodes (future aspects), including BIM, off-site fabrication, automation, and AI. The similarities between the two networks suggest that the future narratives of innovation champions affect (or are affected by) emerging application examples of digital technology within the sector. However, it is important to note that the two networks represent different perspectives on the transformation of the construction sector. The overview identified by McKinsey explicitly targets the productivity challenge in construction. While this fits very well with Vision 1 and the pursuit of construction efficiency, it only represent a subset of potential futures as highlighted by the focus of Visions 2 and 3.

In a larger perspective, the previous comparison and the identified similarities and differences suggest that there is room for further research into the configuration of technologies, organizations, and visions.

Alignment with Policy Discourses

Finally, the visions have implications for policy makers. This research suggests a multiplicity of coexisting visions for digital transformation of construction that are more or less represented in, and aligned with, policy discourses. The interviewees' notions of the future are shaped by, and also shape, this wider ecology of practice,

with each interviewee's view on the future informed and inspired by conversations with other construction professionals. In this way, the three visions represent overlapping and competing agendas, which are, to some extent, accommodated within the negotiated policy discourses in the UK construction sector.

The notion of *efficient construction* (Vision 1) is a theme in post-Egan policy discourses in construction, which treat the sector as poor in productivity, and compare it unfavorably with the car industry. The targets in the *Construction 2025* document (HM Government 2013) suggest the need for a 33% reduction in the cost of construction and the whole life cost of assets; and a 50% reduction in the time taken from inception to completion of new build—targets that suggest the need for efficient construction.

Vision 2 connects to a rising sustainability discourse in the UK construction sector. Construction represents one of the most resource-intensive sectors, accounting for 50% of the UK's carbon emissions and 50% of its water consumption (Akadiri and Fadiya 2013). Striving to reinforce better management of resources, researchers and policy makers have acknowledged the potential for reducing the environmental impact of the sector by reducing energy use and waste production of the built environment (Pomponi and Moncaster 2017). The industry has set ambitious targets for a 50% reduction in greenhouse gas emissions in the built environment—supporting the Industrial Strategy's Clean Growth Grand Challenge (HM Government 2017). This is further supported and challenged through the growing adoption of certification schemes and circular economy (Pomponi and Moncaster 2017).

Vision 3 connects to the work of the National Infrastructure Commission report on *Data for the Public Good*, which set out the idea of a national digital twin (National Infrastructure Commission 2017). However, it also challenges some of the established truths that currently drive innovation in construction, proposing, for instance, that standardization is not a necessary condition for obtaining efficient production processes and that user involvement is not needed to create user-centered value. The elements of Vision 3 represent one or more emerging counterdiscourses, such as the one Cheng and Bier (2016) call adaptive architecture. These emerging discourses can challenge policy makers and construction practitioners to think differently about the future and explore alternative, uncharted ways of getting there. The findings from this study (Table 8) suggest that small companies are more likely to commit to emerging counterdiscourses (corresponding to those of Vision 3). In contrast, the larger companies interviewed tended to refer to established discourses connected to Visions 1 and 2. The multiplicity of visions illustrates how counterdiscourses can challenge or consolidate current policy development while stimulating discussions about the preferred future of construction. When visions are incompatible, Jensen et al. (2011, p. 665) suggest that the "most productive governance response may be to recognize and accept their conflicting strategic implications." Policy makers may compare and contrast the visions to understand how regulatory instruments may support or hinder various preferred outcomes. This may support reflective policy making, which acknowledges the ambiguity and conflicting interests involved in transforming the sector to what is desirable for society.

Directions for Further Research

This study reveals multiple visions that innovation champions have for the future of digital construction. From the interview data, three visions have been identified. As such discourses are in flux, further research may build on and extend this work to identify additional, or differently configured, visions for the future.

The three visions describe unknown futures and are therefore inherently difficult to validate. It may be appealing to strive for validation, for example, by asking construction stakeholders to select the most plausible, desirable, or likely future. However, it is important to note that the results of such a ballot would not reflect the actual likelihood of each future occurring. On the contrary, the results of a ballot might divert construction stakeholders to consider, discuss, and plan for only one possible future. To be resilient in a changing market, construction professionals and policy makers should instead strive to consider several possible future outcomes. The three visions may constitute a narrative reference point for this kind of strategic discussion.

As innovation champions, and therefore promoters of innovation, the interviewees are likely to be affected by pro-innovation bias. As a result of such a bias, the interviewees may—more or less deliberately—emphasize positive elements of the future and downplay potentially negative side effects. Similar interviews with late adopters of innovation would presumably change the outcome of the study significantly.

By creating visions, this study presents positive descriptions of the future that may be used as guidance when construction stakeholders seek to create change in the sector. However, to operationalize the visions, these stakeholders may also benefit from identifying the potential barriers and pitfalls involved in implementing the visions. Further research could identify these implementation challenges and propose ways to mitigate related risks.

Whereas foresight methods are useful for exploring the future, the subsequent implementation of a desired future is better described by innovation management research. To operationalize the visions, further research could therefore benefit from connecting practitioner's expectations for the future to theory on construction innovation. The literature on systemic innovation may, for example, be used to investigate how rapidly various technologies can be expected to diffuse in the sector, and the literature on disruptive innovation may qualify discussions about how construction companies could and should respond to this. The presented visions provide a platform for further research on how digital technologies may aid transformative changes in construction.

Summary and Conclusion

To improve the performance of the construction sector, innovation is essential. Previous studies have demonstrated that innovation champions are vital drivers of innovation, as these individuals influence other stakeholders by means of compelling narratives or visions for the future. This paper has explored possible futures of the construction sector from the perspective of construction innovation champions and their narratives around digital technologies. Interviews with 13 innovation champions revealed three distinct future visions: (1) efficient construction, (2) user-data-driven built environment, and (3) value-driven computational design. The three identified visions are not exclusive but show that multiple visions emerge and are negotiated by innovation champions in envisioning the future. A theme shared by all visions is that digital technologies play an important role in all of these envisioned futures of construction, although the technological potential manifests in different ways. The visions illustrate how a combination of multiple digital technologies may change the way in which structures are designed and fabricated, who the main stakeholders of construction are, how professionals collaborate, and how important various design criteria are.

This study contributes to construction future studies, as it describes multiple ways in which a combination of technologies

and trends affect the sector. Furthermore, the study contributes to the literature on innovation discourses, as it connects the visions of innovation champions to the concurrent sectoral debates of construction. The findings suggest that innovation champions' narratives for the future are influenced by wider innovation discourses. These discourses consider what is technologically possible, profitable in a business context, and desirable on a societal level. The paper thus contributes to research, practice, and policy, as a holistic understanding of possible futures may help construction professionals in deciding how to stimulate transformational change that is possible, profitable, and desirable.

Data Availability Statement

Some or all data, models, or code generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions. Interview transcriptions contain anonymized information about the names and company affiliation of interviewees.

Acknowledgments

The authors wish to thank all interview participants for their contribution and time, Christopher McMahon from the University of Bristol and the Technical University of Denmark for supporting sampling of interview participants, and Sebastiano Piccolo from the University of Copenhagen for assistance in creating the network graph. Contributions of the journal-nominated reviewers and the journal editorial team are also gratefully acknowledged. This work was partially funded by the Danish Innovation Foundation under Grant No. 5189-00173B.

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