Technology Cards: *A Design Game for Navigating in a Future of Digital Technologies*

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Digitalisation has had a game-changing effect on society—but how will future changes unfold? In this paper, we introduce the *Technology Cards*—a novel dialogue-based design game that enables users to explore the impact of multiple technologies on their future business. We review 14 card-based design games that focus on emerging technologies or futures thinking and identify an unmet need for design games that will help business managers navigate in a digital future. We describe the iterative development of the *Technology Cards*, including their testing in 17 *Tech Session* workshops with 257 participants from 40 private and public sector organisations. The findings reveal that the *Technology Cards* are "instruments of inquiry" that aid users in a) framing current challenges, b) imagining how multiple technologies affect the future, c) identifying synergies between technologies, and d) facilitating constructive dialogue. We discuss the importance of involving non-technology-savvy stakeholders in envisioning digital futures and creating design tools to help stakeholders grasp the implications of technology. The paper contributes to practice through a detailed description of the design game development process and lessons learned in this process through its use in industrial practice, as well as agenda-setting impacts on the business strategies of the participating organisations. The paper contributes to research by demonstrating how a design game helps stakeholders anticipate the impacts of new technologies on the future of their business.

Keywords – Construction Sector, Design Game, Design Tools, Digital, Future, Technologies.

Relevance to Design Practice – The paper provides guidance to design game developers and demonstrates to practitioners more widely how design games help make complex topics—such as digitalisation—visible, tangible, and actionable. The *Technology Cards* design game facilitates constructive dialogue on how multiple technologies will affect the future.

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Introduction

Digital technologies have changed how we communicate, travel, interact, shop, entertain ourselves, and conduct business. For business managers, anticipating the potential implications of digital technologies is a critical challenge. This challenge is exacerbated by the speed of change and the vast number of technologies that are emerging and evolving. For example, the *Internet of Things* may provide companies with real data on user behaviour; *virtual and augmented reality* may be used to create immersive customer experiences; *artificial intelligence* may be used to optimise the operation of assets; *3D printing* may enable new production methods; and *robotics* may be used to improve efficiency in the supply chain. All of these technologies are evolving simultaneously—independently and collectively—creating new opportunities which span across traditional industry boundaries.

One sector that still struggles to reap the full benefits of digitalisation is construction. While the construction sector is one of the largest industrial sectors of society, constituting 9% of the EU's gross domestic product (European Commission, 2016), it also happens to be one of the sectors that utilizes digitalisation the least (Gandhi et al., 2016). The construction sector, which includes large infrastructure, is concerned with planning, procuring, designing, constructing, renovating, and operating physical structures in the built environment. Considering the complex stakeholder network, work processes, and contractual structures of construction, several industry analysts and researchers have highlighted the significant potential for enhancing the productivity of the sector, and have called for a digital transformation—even to the extent that such a transformation may be disruptive (Barbosa et al., 2017; Ernstsen et al., 2018a; World Economic Forum, 2016). Most construction projects are complex and involve a large number of stakeholders, including architects, engineers, contractors, suppliers, clients,

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and investors. Although construction stakeholders generally acknowledge the potential benefits of digital technologies, they struggle to understand which technologies to implement, and how to do so (Lavikka et al., 2018). To help construction stakeholders grasp the impact of digital technologies on the sector, we draw on design research.

In design research, the technological opportunities of digitalisation are often studied in connection with societal and contextual considerations. For example, Coskun et al. (2018) studied how smart home technology affects future user preferences. Joseph et al. (2017) studied how emerging smart textiles have induced a need for new methodological approaches that support functionality, fashion, and embodied interaction. Other design researchers have studied the intangible aspects of digital technologies. For example, Kleinsmann and Ten Bhömer (2020) proposed that designers should use new types of prototypes to grasp the intangible aspects of digital product service systems, and Nam and Kim (2011) proposed a new design method called 'Design by Tangible Stories', which utilises gamification elements to help designers create meaningful digital products. These studies found that design processes improve when digital aspects are made relatable and tangible. Here, it is clear that design games play an important role.

In this paper, we present a future-oriented design game, called *Technology Cards*. The design game presents 22 high-impact and predominantly digital technologies. To ensure that the technologies are relatable and tangible for the average user, we developed the *Technology Cards* with one specific application domain in focus: the construction sector. However, findings suggest that they are relevant across multiple sectors.

The paper is structured in the following way. First, we review 14 card-based design games that focus on new technologies and/or futures thinking. Second, we introduce the *Technology Cards*, a card deck that presents 22 important technologies for the construction sector. Third, we describe the iterative process of developing and evaluating the card game. Fourth, we highlight the findings drawn from testing the cards in 17 workshops (*Tech Sessions*) with 257 participants. The findings demonstrate how the *Technology Cards* may aid stakeholders in exploring the future, by a) framing current challenges, b) imagining how multiple technologies may affect the future, c) identifying synergies between technologies, and d) facilitating constructive dialogue. Fifth, we position the *Technology Cards* within design game research and provide additional guidance for other design game developers. Finally, we identify limitations of this research and point towards avenues for further work.

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Christian Thuesen is an associate professor in project and construction management at the Technical University of Denmark (DTU) and has been a Fulbright scholar at UC Berkeley and Stanford. He has worked in project management for over 20 years as a lecturer, researcher, and consultant in various engineering settings, including construction and IT. This experience has sparked his fundamental research interest in the role of projects as vehicles for industrial and societal change, and more broadly, in the role that projects play in modern society. In this pursuit, he co-founded DTUs ProjectLab (www.doing-projects.org), which he currently directs. His current research focuses on establishing a research agenda for transforming the construction industry towards sustainability by leveraging developing digital capabilities.

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Design Games—Theoretical Framing

Design games—particularly card-based design games—have become increasingly popular within the last decade (Peters et al., 2020). In this section, we review 14 card-based design games that focus on new technologies and/or futures thinking. We also identify areas of potential for creating new design games that help make digital technologies more tangible and relatable to stakeholders.

Design Games as Instruments of Inquiry

Researchers and practitioners have developed design games for a number of different purposes. Some design games focus on investigating a design problem (Belman et al., 2011) or influencing user behaviour (Lockton et al., 2010), while other design games focus on facilitating collaboration (Brandt & Messeter, 2004) or generating ideas (Friedman & Hendry, 2012). Acting as boundary objects between stakeholders in a design process, design games can set rules for collaborative activities and bring in new perspectives (Kwiatkowska et al., 2014).

The strength of design games includes their ability to 1) facilitate creative combinations of information or ideas, 2) summarise useful information, and 3) provide a common frame

of reference for communication among the participants (Roy & Warren, 2019). Furthermore, the physical gestures involved in holding, moving, and grouping cards can aid cognition and help simplify the complexity of a design problem (Clatworthy, 2011).

Design games fall within the category of design tools. Dalsgaard (2017) characterises design tools as *instruments of inquiry* that possess one or more of five basic qualities:

- Perception: revealing otherwise hidden facets of a design situation (while obscuring other facets)
- Conception: helping designers understand the problem(s) and examine possible solutions
- Externalization: making imagined design solutions part of the world to allow for evaluation
- Knowing-through-action: generating new knowledge through acting with an instrument
- Mediation: allowing actors and artefacts to exchange insights and coordinate actions

Accepting Dalsgaard's characterisation, we investigate to what extent the *Technology Cards* elicit perception, conception, externalization, knowing-through-action, and mediation.

Technology-Oriented Design Games

Reviewing 76 analogue design tools for collaborative ideation, Peters et al. (2020) found that the majority (72%) were—or included—card decks. They also found that the number of card-based design games had grown significantly within the prior 10 years. However, despite the increasing number of design games, only four out of 76 focused on digital technologies. We reviewed these four technology-oriented design games, identified by Peters et al. (2020) (see Table 1), and discovered a need for design games that explore combinatorial technology innovation.

The technology-oriented design games from Table 1 focus on ideation and the development of technological solutions for the future. The games are well suited for exploring how digital technologies can be applied in practice. As described by De Roeck et al. (2014), digitalisation has created an emerging need for these kinds of tools for ideation and conceptualisation to aid the design of connected products by helping designers consider and combine physical and digital aspects of a service. Each of the games listed in Table 1 reveal the potential of one of three digital technologies: *machine learning*, *Internet of Things (IoT)*, or *mixed reality.*

Although the four games provide a comprehensive overview of the opportunities provided by a specific technology, they do not take into consideration the combination of multiple technologies or include other emerging technologies such as *autonomous vehicles* or *generative design*. To aid business managers in grasping the implications of digitalisation, we strive to imagine how digital technologies in combination will affect the competitive landscape of their business. Instead of considering ideation games, we therefore focus attention on another branch of design games, namely those aiding futures thinking.

Design Games for Futures Thinking

Roy and Warren (2019) reviewed 155 card-based design tools and classified them into six categories: creative thinking and problem solving, domain-specific design, human-centred design, systematic design methods and procedures, team building and collaborative working, and futures thinking. Only seven card decks (4.5%) ended up in the category of futures thinking. A similar review by Peters et al. (2020) identified four card-based tools in the category of futures thinking, of which three were not listed by Roy and Warren (2019). This yields ten design games that aid futures thinking (see Table 2).

Although the ten games in Table 2 all fall within the category of futures thinking, they serve different purposes. Much like the design games in Table 1, the majority of the future thinking games focus on idea generation and conceptualisation (I, J, K, L, M). Another group of games focuses on promoting better designs or change (E, H), and a third group focuses on anticipating the impact of trends and technologies (F, G, N).

Table 1. Technology-oriented design games.

	Card deck	Year	Author	Content	Purpose	Activity
A	Intelligence Augmentation Design Toolkit	2017	Futurice (2020a)	60 cards of four types: channel/ touchpoint cards, machine learning interaction cards, customer segments cards, and unexpected bug cards. A map, two canvasses and a booklet.	To teach non-tech experts to design future smart concepts.	• Creating concepts for using machine learning. • Prototyping.
B	IoT Service Kit	2015	Futurice (2020b)	Five types of cards: sensors, interactions, service cards, open APIs, and user cards. Tokens that represent users, vehicles, and assets. Maps.	To co-create user-centric IoT experiences.	• Designing user journeys. • Mapping interactions.
C	KnowCards	2014	Aspiala & Deschamps-Sonsino (2014)	162 cards with simple descriptions of components in four categories: input, output, power, and connection.	To learn about IoT components and aid the design of new products.	• Learning about components. • Analysing current products. • Brainstorming new use cases.
D	Mixed Reality Game Cards	2016	Wetzel et al. (2017)	51 opportunity cards, 18 question cards, 24 challenge cards.	To create and develop ideas for mixed reality games.	• Generating ideas. • Developing ideas. • Documenting ideas.

Table 2. Design games on futures thinking.

	Title	Year	Author	Content	Purpose	Activity
E	Envisioning Cards	2002	Friedman & Hendry (2012)	28 cards in four categories: Stakeholder, Time, Values, Pervasiveness.	To consider human values during design processes.	• (Re)framing a design problem. • Exploring the solution space.
F	Drivers of Change cards	2006-9	Arup Foresight (2020)	An app and multiple physical card decks. 10 categories: climate change, convergence, energy, demographics, oceans, water, food, waste, poverty, and urbanisation.	To identify and explore leading factors affecting the future.	• Facilitating conversations about trends shaping the future. • Informing business strategy, brainstorming, and education.
G	Foresight Cards—STEEP Edition	2012	IVTO (2020)	125 cards in 5 categories: social, technological, economic, environmental, and political.	To identify and explore leading factors affecting the future.	• Understanding how developments in the external environment affect market conditions and business models.
H	Liberating Voices cards	2011	Public Sphere Project (2020)	136 pattern cards describing different aspects of social change.	To promote social change all over the world.	• Addressing information or communication problems.
I	The Thing from the Future	2015	Situation Lab (2020)	108 cards in four categories: Arc, Terrain, Object, and Mood.	To spark imagination about products of the future.	• Facilitating creativity and entertainment.
J	Design Fiction Product Design Work Kit	2012	The Near Future Laboratory (Girardin, 2015)	52 cards in three categories: Design action, Attribute, and Object.	To spark imagination about products of the future.	• Facilitating creativity.
K	Triggers: A powerful ideation tool—Innovation Deck	2016	Triggers (2020)	60 cards with trigger questions.	To facilitate idea generation processes.	• Collaborative brainstorming of ideas.
L	Human-centred Design prompt for emerging technologies	2017	Google Play + IDEO (2017)	20 cards with prompts for 4 technologies: virtual reality, augmented reality, digital assistant, ephemeral apps.	To facilitate idea generation processes.	• Brainstorming ideas from user scenarios and prompts.
M	FutureDeck	2015	Gerenwa (2020)	126 cards with growth markets, impacts, technologies.	To facilitate idea generation processes.	• Collaborative brainstorming of ideas.
N	IMPACT: A Foresight Game	2016	Bolton (2016)	A board game with 10 domains of society, a stack of impact cards with technological events, persona cards, and cubes.	To think critically about how emerging technologies can impact society.	• Learning about emerging technologies. • Imagining future implications of emerging change.

This third group contains three games: The *Drivers of Change Cards*, the *Foresight Cards–STEEP Edition* and *IMPACT: A Foresight Game*. The first two both present a number of trends by applying the STEEP framework (social, technological, economic, environmental, and political trends). The third game, *IMPACT: A Foresight Game*, is the only game in Table 2 which focuses on the combined future impact of new technologies and is also the only game that is not purely based on cards. Instead, it is a board game in which players compete to secure the future job of their persona, while multiple technological events occur. While this game provides an overview of the implications of different digital technologies, it is played with several hypothetical personas; therefore, the game does not challenge players to consider the technological implications potentially affecting their real-world business.

The *Technology Cards*, which we introduce in this paper, also fall within this third group of games, as they likewise anticipate the impact of trends and technologies. We found that there was a need for design games that allow users to explore the combined impact of multiple new technologies on the future of their business. In the following section, we present the *Technology Cards*, a versatile card game that can facilitate strategic dialogues on future implications of digital technologies.

Introducing the *Technology Cards*

The *Technology Cards* is a design game card deck presenting 22 technologies of importance for the construction sector. Although the cards are targeted at the construction sector, findings show that the *Technology Cards* are applicable, relevant, and useful across multiple industries.

Each card presents a technology in a straightforward manner by means of an image, short descriptive sentences, and a short list of benefits and challenges of the technology (see Figure 1). Moreover, a design element at the top of the cards

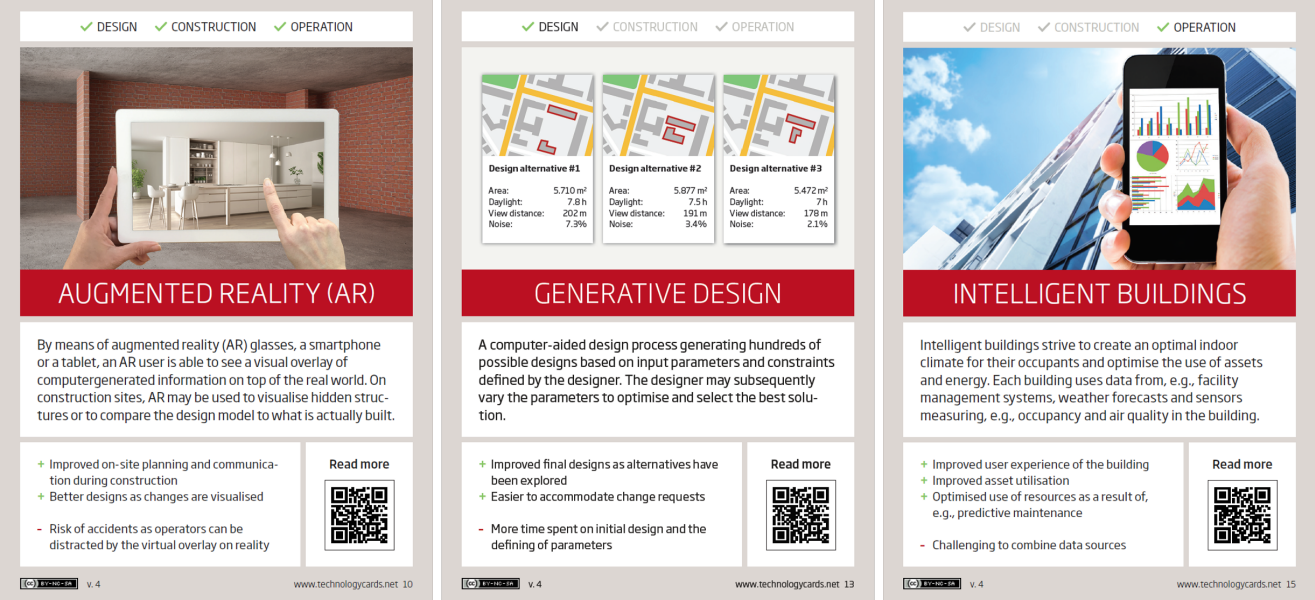

Figure 1. Three of the Technology Cards (www.technologycards.net).

shows the expected implications on a typical construction process, i.e., whether the technology contributes primarily to the design phase, construction phase, and/or operation phase of a typical construction project (Motawa et al., 1999). Users interested in obtaining additional information may use the QR code in the bottom right corner of a card to access to the webpage (www.technologycards.net), which contains detailed information on each technology. The *Technology Cards* present 22 technologies, which are listed alphabetically in Figure 2.

These technologies were selected with the objective of representing all the technologies relevant to the operation of construction companies. However, the relevance of a technology is greatly dependent on the context. Therefore, we incorporated two empty cards into the deck to allow users to add additional technologies of their own. To complete the deck of *Technology Cards*, a box and two instructional cards (explaining the purpose of the cards and how to use them) were also included. The cards are A6 size (105 × 148 mm) and printed on thick paper (300 g), similar to a traditional deck of cards.

Methods

The *Technology Cards* were designed through an iterative process, in which the cards were tested and redesigned several times. Figure 3 illustrates the design process in three phases: 1) exploring the potential for a design game; 2) scoping the game and developing the *Technology Cards*; and 3) testing and validating the card game. This section describes the main activities involved in each of the three phases. The Methods section ends by describing the data evaluation strategy.

Phase 1: *Exploring the Potential for a Design Game*

In phase 1 of the design process, we explored the potential for creating a design game that could help construction industry stakeholders anticipate the implications of emerging technologies. At this stage, we thought it would be important for the construction industry stakeholders to consider technologies beyond their own specific domains; therefore, the *Technology Cards* should include

- Agent-based modelling and discrete event simulations
- Artificial intelligence predictions
- Augmented reality
- Autonomous construction vehicles
- Big data analytics
- Blockchain
- Building information modelling (BIM)
- 4D, 5D and 6D BIM
- Cloud-based construction management
- Construction 3D printing
- Construction robots
- Drone survey
- Generative design
- Industrial exoskeletons
- Intelligent buildings
- Linked data for buildings
- New building materials
- Prefabrication and modular construction
- Reality capture
- Smart cities
- Smart construction site
- Virtual reality

Figure 2. The 22 technologies depicted on the *Technology Cards*.

emerging technologies from across all industries, in order to prepare the construction sector for potential disruptive entrants from other sectors (Karimi & Walter, 2015).

Identifying Technologies for Version 1

To get a cross-industrial overview of emerging technologies, we initiated the development process with a horizon scanning (Ernstsen et al., 2018b), which involved reviewing 11 reports about future technologies and participating in nine conferences/seminars to identify emerging technologies. The horizon scan resulted in a list of 133 cross-sectoral technologies, which was taken as the point of departure for the creation of the first version of the *Technology Cards*. At this point in time, we were not aiming for the cards to be an exhaustive list of all possible technologies relevant to the construction sector; instead, technologies were chosen based on curiosity and a desire to have as many different domains represented on the cards as possible. This resulted in 26 *Technology Cards* representing technologies from six sectors: construction and transportation, digital economy, healthcare and biogenetics, information technology, manufacturing and robotics, and space. During the development of version 1, we focused on designing *Technology* Card prototypes, which could help us understand if and how a design game might help construction companies handle digital technologies.

Testing the Card Design through Interviews

To test the initial card design, we conducted seven 30-minute interviews with construction sector practitioners. The semi-structured interviews were split into two parts. In the first part, we laid out ten *Technology Cards* in front of the interviewee and asked him or her to give their first impression of the cards without reading the text in detail. We used an interview guide to ask for opinions about different parts of the card (e.g., "Do you like the layout?", "How do you interpret the symbol here?", "What do you think about the amount of information in each card?", etc.). In the second part of the interviews, we showed the interviewees five different designs of a *Technology Card* and asked them to design the perfect card, e.g., by choosing one of the five designs or by combining parts of the different designs into one card. We audio recorded the interviews and took notes.

Building on the responses from the interviews, we redesigned the cards and created version 2. Some of the most noticeable changes from version 1 to version 2 included reducing the amount of text on each card, adding arrows to the graphics (to clarify that the four categories at the top of each card are consecutive phases), introducing background colours on cards (to illustrate which sector each technology stems from), and renaming certain card titles from product-specific names to technology-related names. We also used these initial user insights to inform later redesigns of the cards.

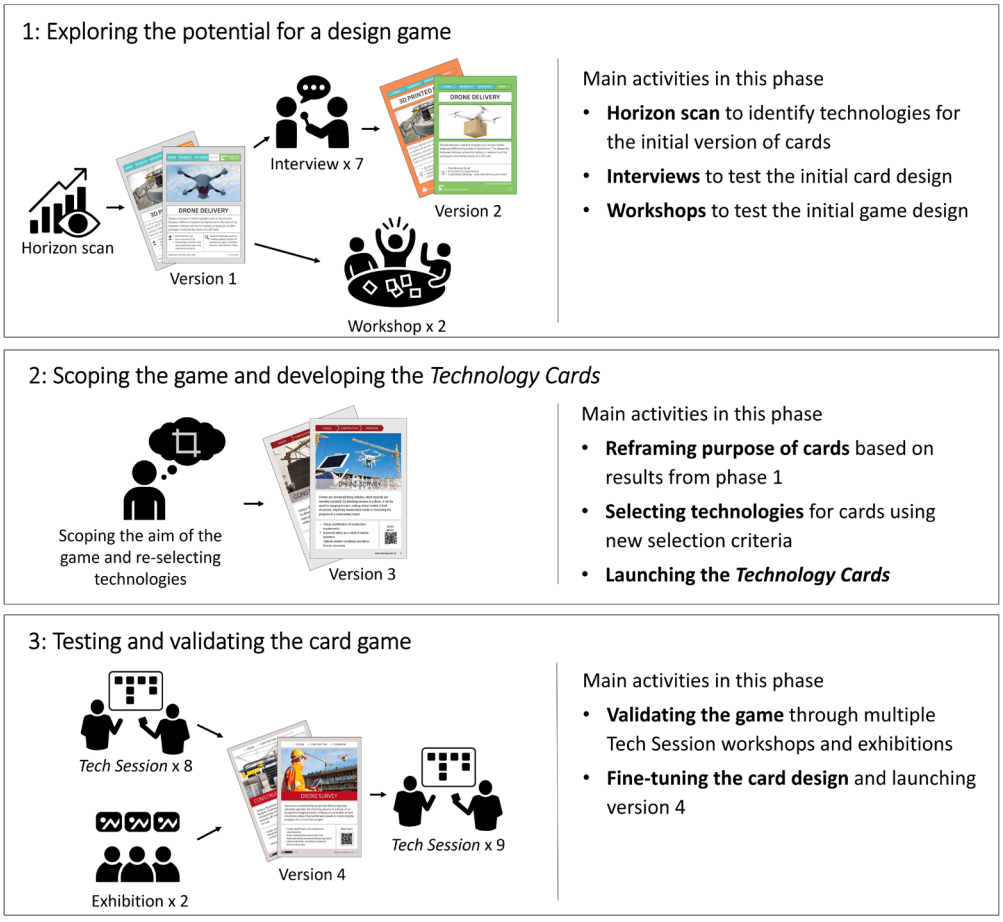

Figure 3. The *Technology Cards* were designed through an iterative process.

Testing the Use of the Cards through Workshops

To test the usability of the cards, we held two workshops with 11 participants in total, including seven construction practitioners and four engineering students. The purpose of both workshops was to create ideas for how a construction company could benefit from applying the cross-sectoral technologies depicted on the cards. The first workshop lasted 45 minutes, and was a condensed version of the second workshop, which lasted two hours.

Both workshops followed the same overall agenda. First, we asked the participants to create *domain cards* representing their own fields of work, a step inspired by Halskov and Dalsgård (2006). Second, we divided the participants into groups and had them identify the main technological principles on one or more *Technology Cards*. Third, the groups created new ideas by transferring the technological principles from the cards into their own domains. Fourth, the groups presented their ideas in plenum and evaluated the workshop. To guide the participants through the workshop, we designed four self-facilitating templates (Phaal et al., 2016), which we asked the participants fill out. To document the results and reflections from the workshop, we used the templates, the results from an evaluation survey, pictures from the workshop, and audio recordings in which verbal feedback was provided.

The feedback from the workshops revealed that the participants were intrigued and inspired by the concept of the cards. However, they found the ideation exercises difficult, as it was hard to extract the main principles from one domain and apply it in another. For example, participants struggled to imagine how the technological principles of gene editing (CRIPR/Cas9) technology or small satellites could be useful in the construction sector, and this constrained the ideation activity. Furthermore, we observed an urge among the participants to combine several cards instead of working with one at a time.

Phase 2: *Scoping the Game and Developing the Technology Cards*

Reframing the Purpose of the Technology Cards

The interview results and the workshop evaluations led us to reframe the purpose of the *Technology Cards* to focus on strategic dialogue rather than on creativity. We had assumed that the main advantage of the cards would be to facilitate ideation, when in fact the cards were better suited for stimulating dialogue and gaining an overview of how various new technologies may affect the future. This represented a major turning point in the cards' development and way of playing.

Reframing the purpose of the cards, we identified three design criteria to guide our development of the workshop format and the cards for version 3:

- Aim for facilitating discussions about the future (rather than facilitating ideation)
- Design a game that encourages browsing through and combining several cards
- Ensure that all cards only describe technologies that appear immediately relevant to stakeholders from the construction sector

To guide the selection of relevant technologies for version 3 (and 4) of the *Technology Cards*, we iteratively developed some selection criteria. Formulating the selection criteria, we consulted foresight, disruption, and innovation management literature (Christensen, 1997; Gans, 2016; Henderson & Clark, 1990; Phaal et al., 2011). We wanted to ensure that the card deck included all technologies that could be potentially disruptive to the construction sector. At the same time, we also wanted to ensure that a deck of *Technology Cards* had a manageable number of cards, so that players would view all the cards over the course of one game. By balancing these design intentions with our insights from the literature and our experiences from practice, we formulated the following four selection criteria (described in detail in the following four sub-sections):

- Impact: technologies with a game-changing potential
- Domain relevance: technologies that may replace current construction products
- Applicability: technologies with a concrete application in construction
- Timing: technologies that have recently been demonstrated to have applications in the construction sector

Whether or not the technology was digital was not a part of the initial selection criteria. However, the final selection of technologies revealed that only one out of 22 technologies was not (fully or partially) digital: *New building materials*. This suggests that digitalisation is indeed important when considering the impact of new technologies on the future. The four selection criteria are described in detail below.

Selection Criteria

1. Impact: Technologies with a game-changing potential

To foresee major changes (e.g., disruption) in the construction sector, we were especially interested in identifying technologies that can act as game-changers. Christensen (1997) defines disruptive technologies as "very much different" from the existing alternatives. Henderson and Clark (1990) argue that architectural innovations are especially powerful, as they can reconfigure the relationship between components, thereby restructuring the relationship between organisational units. We used the term "game-changers" to encompass both of these descriptions of novelty. We looked for game-changing technologies that differ considerably from existing value propositions offered by construction companies and/or that reconfigure sectoral structures by combining existing components in a new way.

2. Domain relevance: technologies that may replace current construction products

To ensure that the selected technologies are relevant to construction stakeholders, we looked for technologies that have the potential to replace other products or services currently offered by construction companies. Adopting a new technology that replaces an older technology often induces switch-over costs to established companies. According to Gans (2016), this

replacement effect can make established companies reluctant to adopt new technology, leaving them vulnerable to disruption. When selecting technologies for the *Technology Cards*, we therefore disregarded technologies that do not threaten to replace current construction products and services.

For example, we did not include connected autonomous vehicles (CAVs) in the current deck of *Technology Cards*. CAVs will likely change the design of the built environment (e.g., so that hop-on/hop-off spots are preferred over parking lots), but they do not directly replace any of the existing construction products and processes.

3. Applicability: technologies with a concrete application in construction

To ensure that the *Technology Cards* were playable and relatable, we searched for concrete applications of each technology. Rather than letting a card present an abstract technology such as *Internet of Things*, we specified three cards that present concrete applications of *Internet of Things*, i.e., *intelligent buildings, smart construction site*, and *smart city.*

4. Timing: technologies that have been demonstrated applicable in construction lately

All technologies evolve over time. According to Phaal et al. (2011), this evolutionary process can be split into four phases: science, technology, application, and market. A new science becomes a technology when it is "sufficiently robust to be integrated into a functional system" (Phaal et al., 2011, p. 221). However, at such a point in time, the performance and commercial applicability of the technology is still uncertain. To ensure that we selected technologies applicable within the construction domain, we defined a selection criterion that favoured technologies mature enough to have passed the threshold of *application demonstrator* (Phaal et al., 2011).

Selecting and Scoping Technologies for Version 3 and 4 of the Cards

As a point of departure for the technology selection process, we used a recent report from the World Economic Forum's (2018) Future of Construction Initiative, which lists ten of "the most promising digital technologies for improving productivity in the industry" (World Economic Forum, 2018, p. 5). We investigated the characteristics and potential of each of the ten technologies cited and found that many of them actually described several technologies; therefore, we investigated them in further detail, and this provided us with a solid starting point for selecting technologies for the cards.

Next, we consulted the original list of 133 technologies from the horizon scanning to ensure that no important technology was overlooked. We used the selection criteria to guide our search and found that many technologies from the horizon scanning (e.g., DNA sequencing and brain-computer interfaces) did not qualify for the *Technology Cards* due to a lack of domain relevance or applicability within construction.

As many technological terms tend to overlap, the selection process was also a scoping process. For example, we needed to decide whether a specific card would be referred to as machine learning, deep learning, artificial intelligence, or some other related term—and to decide this, the differences and similarities between the various terms needed to be better understood. Often, we sought to scope the technologies in a way that highlighted a concrete application area. In one particular case, we decided that a card should be named *Artificial Intelligence Prediction* to emphasise how the technology utilises data to predict a certain outcome.

To ensure coherency between all the cards and create a sense of balance in the final card deck, we furthermore engaged in a negotiation process. If one card was to be called *Reality Capture* and another called *Drone Survey*, how could we explain the differences—and to what extend do these technologies overlap? In many cases, we renamed and scoped the technologies to clarify how they were different from (or related to) other cards in the deck. This negotiation process turned out to be critical for ensuring the consistency and coherency of the final card deck.

All the authors contributed to the process of iteratively selecting, scoping, and negotiating the final list of technologies for the cards. The five authors include construction domain specialists, digitalisation experts, and design researchers. We believe that our diverse backgrounds helped to ensure that all relevant technologies were considered, and that they were presented in the most relevant way possible.

The selection process resulted in a final list of 22 technologies we considered potentially disruptive to the construction sector. The *Technology Cards* versions 3 and 4 present the following 22 technologies (see also Figure 2): Agent-based modelling and discrete event simulations; Artificial intelligence predictions; Augmented reality; Autonomous construction vehicles; Big data analytics; Blockchain; Building information modelling (BIM); 4D, 5D, and 6D BIM; Cloud-based construction management; Construction 3D printing; Construction robots; Drone survey; Generative design; Industrial exoskeletons; Intelligent buildings; Linked data for buildings; New building materials; Prefabrication and modular construction; Reality capture; Smart cities; Smart construction site; and Virtual reality.

Phase 3: *Testing and Validating the Card Game*

Testing the Reframed Card Concept through Interactive Exhibitions

To ensure that the *Technology Cards* were applicable in an industrial setting, we launched the cards (version 3) within a construction consultancy, which we will refer to as company A (Figure 4). The launch event was held in the company innovation room and attracted 15 visitors. Posters, screens, whiteboards, and banners in the room encouraged the visitors to try out one of three different games, and if they documented the results of their games, they could participate in a competition. This interactive exhibition of the *Technology Cards* was active for 1.5 months. We also exhibited the cards in another office location.

Based on the number of names in the guest book and the number of participants in the competition, at least 33 people visited one of the innovation rooms and interacted with the *Technology Cards*. Factoring in observations of additional people who did not leave their names yet interacted with the exhibitions, we estimate the actual number of visitors to be much higher. We collected written and verbal feedback from the visitors by speaking with them and reading the comments they provided in the guest book.

Designing Tech Sessions

To test the applicability of the *Technology Cards*, we designed a new workshop format called *Tech Sessions*. The purpose of a *Tech Session* workshop is to help the participants:

- gain an overview of important technologies entering the construction sector
- collectively imagine what the future of the sector will look like
- prioritise technologies according to their importance (in a specific context)
- engage in strategic discussions with the aim of deciding on appropriate action

The *Tech Session* agenda was designed and refined through several iterations with different game formats. Following the launch event, we held three drop-in *Tech Sessions* that were open for all employees to attend, before settling on a *Tech Session* agenda (see Figure 5).

This paper reports on the results from 17 *Tech Sessions*. We played game 1 in all *Tech Sessions*. Game 1 invites the participants to prioritise the technologies in relation to their (case) company. We typically split the workshop participants into groups of 3-6 people and provided each group with a whiteboard, which had one of two headlines on either end of the board: *Very important* or *Less important*. We asked the participants to take turns selecting a card from the pile (non-randomly) and placing it on the board, arguing for why they thought that this particular technology was important or not. Typically, this game initiated rewarding discussions on how their (case) company could benefit from specific technologies—in the short term and in the long term.

Figure 4. (a) A box of *Technology Cards*; (b) Participants in a *Tech Session* moving around enlarged *Technology Cards*.

Introduction to the *Technology Cards*

- Brief introduction to all technologies by the facilitator.
- The participants can create extra cards if they want to add technologies.
- Division of the participants into groups of e.g., 3-4 people.

Game 1: Which technologies do we find most important?

- The most important technologies are placed in one end of the board and the least important technologies on the other end.
- The groups are encouraged to write down their thoughts/justifications/ideas next to the *Technology Cards* in either end of the board.

Game 2 (optional): Select a combination of 2-4 technologies that represent an idea for digitalisation

- The groups fill out a template with their initial thoughts on the potential, value, and maturity of the idea.

Game 3 (optional): How does the future look like and what should we do to get there?

- The groups create a common vision for the future (e.g., 2035) by selecting and combining cards.
- Backcasting: The groups discuss which (technological) steps are necessary to reach their common vision. They facilitate the discussion using the cards and a timeline, e.g., 2023-2035.

Presentation of the results and plenary discussion

- Plenary discussion: Did the groups select similar technologies to be important? Where do the groups differ—and why? Which ideas did they come up with?
- Evaluation and discussion of next steps.

Figure 5. A typical *Tech Session* agenda.

In about half of the *Tech Sessions*, we used the results from game 1 to play game 2. The optional game 2 asks the participants to create ideas for digitalisation by combining multiple *Technology Cards* and exploring their market potential. In three out of 17 *Tech Sessions*, we also played game 3, which asks the participants to create a vision for the future (2030) and identify the necessary steps to reach that vision by placing the cards on a timeline ranging from 2020 to 2030.

Validating the Technology Cards through Tech Sessions

The initial *Tech Sessions* were well received, and we subsequently received requests for *Tech Sessions* from various departments within company A (see Table 3). Surprisingly, construction-related stakeholders were not the only individuals who were inspired by the *Technology Cards*; employees and managers working within areas as diverse as environmental impact assessments, soil management, ground pollution, and working environment also expressed interest. Having tested the *Tech Session* concept within company A, we updated the design of the *Technology Cards* for version 4. The changes included making the titles of the technologies easier to read and the design element at the top of the cards more intuitive.

In total, we tested the *Technology Cards* and the *Tech Session* concept on 257 participants by means of 17 Tech Session workshops. The participants represented 40 unique organisations, mainly from the construction sector, but with other sectors also represented, including manufacturing, education, services, and transportation.

The duration of the events varied. A short *Tech Session* in which game 1 was played lasted approximately 45 minutes, whereas a long *Tech Session* to play game 1 and 2 lasted approximately three hours. Often, the *Tech Sessions* were incorporated into a strategy seminar or a digitalisation workshop to prompt free ideation about digitalisation. In these instances, the technologies that participants selected as most important in game 1 were sometimes used as the point of departure for additional exercises or discussion. Subsequent workshop activities allowed the participants to transition strategic dialogue into concrete, actionable plans. When the sessions ended, participants typically held on to a deck of cards, allowing them to read more about each technology and easily recall the *Tech Session* discussions.

As a result of the coronavirus pandemic, some of the *Tech Sessions* were conducted as virtual workshops. In the virtual *Tech Sessions*, group work was conducted via video meetings with an

Table 3. Detailed list of *Tech Sessions*.

ID	Date	Event	Card version	Participants	Number of participants	Games
A	13.06.19	Launch party	3	Open invitation to all employees in company A	15	1,2,3
B	21.06.19	Drop-in *Tech Session*	3		3	1
C	24.06.19	Drop-in *Tech Session*	3		6	1,3
D	26.06.19	Drop-in T*ech Session*	3		3	1
E	03.07.19	*Tech Session*	3	Department managers from environment management departments in company A	7	1
F	06.09.19	*Tech Session*	3	Market managers in construction departments in company A	6	1
G	23.09.19	Strategy course	3	Director and managers in a public facility management organisation	5	1
H	11.10.19	*Tech Session*	3	Employees from work environment department in company A	7	1
I	22.10.19	*Tech Session* and workshop	4	The board of directors at a contractor	6	1+2
J	30.10.19	*Tech Session* and workshop	4	Chief executives in a research and technology organisation	9	1+2
K	30.10.19	High Tech Summit 2019	4	Members of an innovation network in a cleantech cluster and conference participants	45	1
L	24.01.20	Lean Design Forum 2020	4	Participants in a construction seminar on Lean Design	20	1+2+3
M	05.03.20	*Tech Session* and workshop	4	Employees from a work environment department at company A	11	1+2
N	25.03.20	Virtual *Tech Session* class	4	Engineering students from the Technical University of Denmark	45	1+2
O	24.03.20	Virtual *Tech Session*	4	Employees from the Centre for Regional Development in a Danish region	40	1+2
P	18.05.20	Open, virtual *Tech Session*	4	Open invitation via LinkedIn. 18 organisations represented	22	1+2
Q	25.06.20	*Tech Session*	4	Director and department heads at a property management company	7	1
In total 17 *Tech Sessions* with 40 unique organisations represented					**257 participants**	

appointed moderator who shared the screen. The moderator moved pictures of the *Technology Cards* around on a presentation slide to reflect what the group was discussing. Although individuals within the groups could not touch or move the physical *Technology Cards*, the virtual *Tech Sessions* nonetheless worked surprisingly well. Participants engaged in the group discussion and welcomed the format as an interactive alternative to traditional webinars.

Data Evaluation Strategy

We documented the *Tech Session* workshops with notes and photos, and for virtual workshops, through video recordings. Afterwards, we used a bottom-up approach to find patterns in the data and compared this to our own reflections about how we had managed to stimulate beneficial discussions.

As described by Peters et al. (2020), the outcome of a card game workshop can be difficult to evaluate without a controlled testing procedure, which is often impractical in real world contexts. Reflecting on how to evaluate the results of a design game, Clatworthy (2011) describes the challenges of distinguishing between the workshop format and the cards. With this in mind, we evaluated the *Technology Cards* and the *Tech Session* format collectively through observations, interviews, and feedback from the participants in the workshops and *Tech Sessions* with respect to the proposition of cards as tangible *instruments of inquiry.*

Facilitating the group discussions, both physically and virtually, we found that prioritisation of technologies was highly dependent on the groups' interpretations of the cards. The same card represented different technological applications to different groups, and therefore, we do not compare the prioritisation of technologies across different *Tech Sessions* or groups. However, we found that the *Technology Cards* enabled lively future-oriented discussions among the participants, and we note this as the most important outcome of the sessions. The following section documents the process-related findings from the *Tech Sessions*, with a particular focus on the empirical validation of the theory-frame adopted: design games as *instruments of inquiry.*

Findings: *Technology Cards as Tangible Instruments of Inquiry*

As described earlier, Dalsgaard (2017) proposes that design tools (so-called "instruments of inquiry") possess five qualities: perception, conception, externalization, knowing-through-action, and mediation. Our evaluation of the *Technology Cards* as empirical validation of the propositions suggests that the cards possess four of these five qualities: framing current challenges (aiding perception), imagining how multiple technologies may affect the future (aiding conception), identifying synergies between technologies (facilitating knowing-through-action), and facilitating constructive dialogue (mediating between the participants). We did not find evidence to confirm or disconfirm the fifth proposition proposed by Dalsgaard (2017), which concerns externalisation. That is, our findings neither confirm nor disconfirm whether instruments of inquiry in the form of card-based design games support making imagined design solutions part of the real world to allow for evaluation. In what follows, we present empirical evidence for the presence of the four qualities (perception, conception, knowing-through-action, and mediation) in the utilization of the *Technology Cards.*

Framing Current Challenges: Aiding Perception

When participants prioritised the technologies in game 1, they typically justified their viewpoints by means of examples. These examples often took current challenges experienced by the participants as their point of departure, e.g., "I think Generative Design is important because it can eliminate tedious design tasks" *or* "I find Virtual Reality (VR) important as it can help us improve our communication with the client". In this way, the participants used the *Technology Cards* to identify design challenges, such as tedious design work or suboptimal communication with a client.

Scoping the example cases turned out to be important. For example, *Tech Session* P featured a case in which a group was working with hospitals. This group struggled to decide whether or not a technology was important until they agreed on defining their case as *the operation of hospitals*, rather than *the construction of hospitals*. Another *Tech Session* (D) hosted construction employees from company A, who decided that Construction 3D printing and Construction robots were less important technologies, because they were considered "relevant to the contractor, not us". Therefore, the participants did not only prioritise the technological solutions, but they also negotiated a common perception of what the case company could and should offer. Referring to Dalsgaard (2017), our findings corroborate that the *Technology Cards* support perception, as the participants used the cards to focus on facets of the (design) situation that could be improved by means of technology.

In some *Tech Sessions* (I and N), the participants did not have a clear idea of the challenges they faced in advance. In these instances, the participants struggled when playing game 2, which entails the concretisation of an idea and specifying how it will create value for the customer. We found that the technology-focused approach of game 2 was difficult when the participants did not have in-depth knowledge of the problem domain. We would therefore suggest that game 2 be supplemented with other approaches that explore the problem domain, e.g., by means of a SWOT analysis or Porter's *five forces* (Meyer et al., 2008).

Imagining How Multiple Technologies May Affect the Future: *Aiding Conception*

We observed that the images and concrete use cases depicted on the cards helped the participants to gain a quick understanding of the (often abstract) technology, and several participants commented that they liked the straightforward format of the cards. For example, Participant 1 in *Tech Session* P, group 3, stated, "Of course we could have spent much more time on this, but that wasn't the assignment. We tried the cards and I think they worked surprisingly well as an object for discussion on what is possible."

When prioritising the technologies, some groups started by exploring the whole deck of cards in sequence, whereas other groups let participants take turns selecting an interesting technology and arguing for its importance. This difference in approach turned out to have a great influence on the flow of the discussion. We observed how groups that allowed discussions to be driven by curiosity engaged in creative discussions about how the technologies might be applied. We refer to this state of mind as the "design thinking mindset." In contrast, the groups that went through the card deck from one end to the other approached the prioritisation exercise with a more analytical or evaluative mindset, which facilitated discussions about whether or not a technology was relevant.

In one case, the evaluative approach entailed that one of the group members (a domain specialist) behave as if he possessed the *correct* answer about where a technology should be placed on the board. This was path-setting, and at the time deemed unfortunate, considering that the *Tech Session* was intended to facilitate exploratory discussions about an uncertain future. In contrast, the curiosity-driven approach ensured that all the group members were given speaking time and kept an open-minded attitude which facilitated creativity.

We observed that the concrete use cases depicted on the cards did not prevent participants from thinking about other, related use cases. For example, participants used the *Drone survey* card to describe other drone-related activities, such as transportation or mapping. As intended, the *Technology Cards* were used as a point of reference in the discussion, and during the *Tech Sessions*, the specific contextual meaning of each card was negotiated between the participants. Take, for example, the *Augmented reality (AR)* card: one group used this card to discuss how public hearing procedures could change if citizens experienced a planned construction project in AR, while another group used the same card to discuss how design consultants could use AR to compare design drawings with what is actually built on site. This example emphasises that both groups considered this technology very important—but for different reasons. Again referring to Dalsgaard (2017), we conclude that the *Technology Cards* aid conception by helping people examine and obtain an overview of different technologies that could improve their business.

Identifying Synergies Between Technologies: *Facilitating Knowing-Through-Action*

In most of the *Tech Sessions*, we noticed that the participants—unprompted—began clustering technologies that they considered to be related or interdependent. During discussions on how to prioritise the technologies, the participants would identify relationships between different *Technology Cards* and group them together on the board. For example, one group clustered *Reality capture* and *Drone survey*, since both of these technologies are considered useful for mapping as-built structures. This group also clustered *VR, AR*, and *Building Information Modelling (BIM),* arguing that BIM is a prerequisite for implementing AR and VR. In this way, the *Technology Cards* facilitated discussions on the synergies between different technologies: "We quickly identified a number of cards that were very relevant. Finding something that was less relevant was more difficult. And then we discovered the synergies that emerged" (Participant 2 in *Tech Session* P, group 4).

Typically, the clustering of technologies occurred as an unintended side effect of the discussions, and the participants seemed delighted to have identified these relationships. Drawing on Dalsgaard (2017), we consider these incidences as instances of knowing-through-action.

Facilitating Constructive Dialogue: *Mediating Between the Participants*

In some of the *Tech Sessions* (e.g., D, H, O), the participants shared very similar fields of knowledge, sometimes even working as colleagues within the same organisation. In these sessions, the discussions of technological possibilities were concrete and actionable, and typically referenced actual challenges experienced by the participants. In other *Tech Sessions* (e.g., K, L, N, P), the participants represented different domains and/or different organisations. In these sessions, we found that the participants were curious to learn and gain inspiration from each other. Whether or not the participants possessed detailed knowledge about the technologies or the case company turned out to be less important than we had expected. For example, one of the participants, who was from a publicly-owned environmental data organisation, joined a group that worked with an e-mobility company. He stated, "I think the cards worked surprisingly well, [because] we quickly began discussing some relevant things. I knew nothing about e-mobility before, but now I know a bit more" (Participant 3 in *Tech Session* P, group 1).

Several participants suggested that we create new editions of *Technology Card*s that target other sectors, such as the environmental sector or healthcare. Such feedback suggests that the *Technology Cards* are applicable and inspiring to participants from sectors other than construction. Therefore, in September 2022, the authors launched a new deck of *Technology Cards* targeted at the process manufacturing industry (NIRAS, 2023). We also see potential for applying the *Technology Cards* in other contexts, such as in municipalities or hospitals.

We found that the game-like format of the *Technology Cards* encouraged the group members to take turns joining the discussion, as is typical when playing traditional card games for the purpose of entertainment. We also observed that the rather simple game rules encouraged discussions that quickly focused on relevant aspects of the future: "I think that the *Technology Cards* are great for illustrating how you easily—within a short timeframe—can boil down what is important to focus on in your company" (Participant 4 in Tech Session K). This observation suggests that the *Technology Cards* lowered the entry barrier for participants joining technology-related discussions about the future, and confirms that the *Technology Cards* serve as tangible instruments of inquiry that also work well as a mediation tool facilitating cross-disciplinary dialogue between participants (Dalsgaard, 2017).

Discussion

The contribution of this paper is two-fold. First, the paper contributes to research by demonstrating how a design game (the *Technology Cards*) helps stakeholders anticipate how new technologies may impact their future business—which to date has not been done. Second, the paper contributes to practice by describing the process of developing a novel card-based design game, hereby providing guidance for other design game developers.

To further expand on the paper's contribution to research, we compare the *Technology Cards* to other design games, which we reviewed in the beginning of this paper. To expand on our contributions to practice, we present additional lessons learned.

Implications for Research: *Positioning the Technology Cards Among Design Games*

A review of future- and technology-oriented design games revealed a need for design games that explore the combined impact of several new technologies on the future of a business. In this section, we compare the *Technology Cards* to three other design games that are also concerned with anticipating trends and technologies:

- Game F: *The Drivers of Change Cards* (Arup Foresight, 2020)
- Game G: *The Foresight Cards–STEEP edition* (IVTO, 2020)
- Game N: *IMPACT: A foresight game* (Bolton, 2016)

We discuss three characteristics of the *Technology Cards*: 1) The ability to engage a diverse group of stakeholders, 2) the focus on technologies as opposed to trends, and 3) the focus on narrating the future.

An Inclusive Approach to Discussing the Future

The *Technology Cards* are, in many ways, similar to games F, G, and N (see Table 2). All four design games strive to a) teach the players about new technologies or trends and b) kickstart discussions about how these trends/technologies will affect the future. All four games share a playful appearance that invites people from various backgrounds to participate in discussing difficult topics.

One of these difficult topics is technological futures. In our experience, discussions about the impact of technologies on the future can easily become nerdy. When this happens (e.g., participants start discussing the difference between deep learning and machine learning), the discussions tend to exclude participants without in-depth knowledge of the topic. We consider this situation unfortunate, as the future is, by nature, unknown to everyone. To ensure that we plan for a desirable future for all, it is important to include multiple viewpoints and consider not only what is technologically possible—but also what is desirable—from a societal point of view. We find that design games are particularly well-suited for addressing these needs.

In the findings section, we reported how the gamification element of the *Technology Cards* encouraged people—including non-tech-savvy people—to experiment with different combinations of the cards and envision different possible futures. This confirms what other design games studies have also found: participatory design tools, such as design games, can encourage stakeholders from multiple backgrounds to participate, promoting equalised power relations between the participants (Bratteteig & Wagner, 2012; Kensing & Blomberg, 1998). This being said, power relations between participants still exist. When playing the game, facilitators should be aware—and perhaps intervene—if the *Technology Cards* are used to establish or reinforce power relations (Eriksen et al., 2014). Since *Tech Session* workshops are situations involving negotiation, we consider it inevitable that the flow and results of the game will depend greatly on the relations and dynamics between the participants.

Focusing on Technologies Rather Than Trends

Technologies and trends are closely related terms. Whereas technologies create new ways of doing business, trends describe changes to the business environment. The *Technology Cards* and game N focus on technology, whereas both games F and G focus on present trends.

In the field of futures studies, trends are used to describe the future, and trends can be clustered into five overarching themes according to the STEEP framework: Social, Technological, Economical, Environmental, and Political (Szigeti et al., 2011). The *Technology Cards* are mainly useful for understanding technological trends; however, there are other themes which are equally important (e.g., urbanisation or sustainability), as trends may change a client's preferences or affect legislation.

To account for non-technology-driven changes affecting the market, users of the *Technology Cards* may supplement the technology-driven approach with a trend-driven approach, for example, by playing game F or G. Users may also choose to combine technology and trend-driven approaches, e.g., by designing a new workshop format which uses the *Technology Cards* to explore certain trends in detail. We took the initial steps in this direction in *Tech Session* L, where we asked the participants to identify how technologies could transform construction practices towards sustainability by 2030. This *Tech Session* was framed using sustainability challenges in construction and concluded with a discussion on the role of technologies as the means towards sustainable futures.

According to Peters et al. (2020) and De Roeck et al. (2014), there is a need for ideation tools that consider newer technologies, such as mixed reality and Internet of Things. The *Technology Cards* address this need, as they provide users with an overview of multiple technologies and allow users to explore the synergies between different technologies. Keeping in mind that digital technologies have the potential to transform entire sectors of society, we propose that this type of holistic, combinatorial view of technological potential is needed.

Focusing on Narrating the Future

The *Technology Cards* and game N both focus on technological change, and both games strive to teach the users about the possible disruptive implications of technology. The games differ

in format—as game N is a board game with intricate rules and hypothetical personas, whereas the *Technology Cards* is a deck of cards that can be used or played with in a variety of ways. The two games are similar in the sense that they encourage players to create imaginative narratives about the future. Such narratives are important, as they (deliberately or not) affect present-day strategic choices (Ernstsen et al., 2021). For example, a construction company that focuses on environmental sustainability may choose to invest in Internet of Things-related technologies that improve energy consumption in the built environment. In contrast, a construction company that believes in a future of fully automated design and construction processes may choose to invest in technologies that support this vision, i.e., generative design technology or robotics. These differences in strategic choices not only affect the competitive position of the company, but they also actively contribute to shaping the future of the sector. Therefore, we find that there is a need for design games such as the *Technology Cards* that allow businesses to verbalize their expectations for the future, using this activity as a starting point for strategic work.

Implications for Practice: *Lessons Learned During Card Game Development*

During the development process of the *Technology Cards*, relevant insights were collected which can be of benefit to other researchers and practitioners creating design games. This section presents some of the lessons learned and recommendations for other design game developers.

Designing Appealing, Informative, and Playable Cards

As described by Li et al. (2021), card game developers need to strike the right balance between overwhelming amounts of information and overly simplified cards. While developing the *Technology Cards,* we rephrased and shortened the description of each technology several times. Although this was a time-consuming process, we believe it was worthwhile. During the *Tech Session* workshops, we observed how the flow of the game improved when the cards were self-explanatory, and when the participants did not have to spend time reading the cards while playing (Clatworthy, 2011). In one of the early workshops, the participants requested that we begin the workshop with a quick introduction of all the cards before splitting into groups. In subsequent *Tech Session* workshops, we found the plenary introduction to all the cards to be worthwhile, as it relieved the participants of the task of reading the cards themselves. Moreover, we observed how the participants remembered the content of each card simply by looking at the headline, picture, and perhaps a few key words in the text. Drawing on that experience, we recommend focusing on the visual appeal of the design game and spending time on selecting appropriate pictures that are representative of the cards in play.

Iterations in the Development Process is Key

The iterative development process is long but rewarding. As described in the Methods section, we ended up completely reframing the purpose of the cards. Rather than designing cards to stimulate ideation activities, we decided to develop cards that facilitated discussions about the future. Additionally, we recommend testing design games over many workshops with different participants, rather than letting a single workshop define how a game should be (re)designed.

Gamification is A Powerful Process

In our opinion, a design game comes alive when people start playing with it and making it their own. Therefore, we recommend being mentally prepared for the likelihood that some participants will not follow the rules of the game and will modify the rules to fit within their own particular context. This process demands that the facilitator be flexible, maintaining a focus on the overall target of the discussions while simultaneously allowing participants to guide the discussions in new directions as they see fit. Twisting the rules or changing the game in certain respects does not mean that the game has failed. On the contrary, we believe that participants taking ownership of the process and outcome of the game indicate that the design game is both relevant and valuable to the stakeholders.

Outlook, limitations, and Further Work

Like any other design tool, the *Technology Cards* are well-suited for certain situations and less (or not) suitable for others. In the following section, we reflect on limitations of the *Technology Cards* and the *Tech Session* concept, as these are central to understanding the applicability and versatility of the design game as a tool (Dalsgaard, 2017). We also provide suggestions for further research.

Limitations

The *Technology Cards* present 22 technologies of importance to the construction industry. As described in the Methods section, the selection, scoping, and description of these technologies was the result of an iterative design process which included all of the authors. Nevertheless, another game developer may have scoped the technologies differently, added some technologies, and/or removed others. Although we aimed to include all important technologies, it is not unlikely that something was omitted. To mitigate this risk—and to encourage users to contribute to the game—we included two blank cards in the deck. However, we found that the blank cards were seldom used, and that users in general found the selected technologies to be appropriate and adequate.

The *Technology Cards* encourage a technology-driven approach. Such an approach entails a risk of letting the 'gadget factor' drive development of new products and services (De Roeck et al., 2014). In other words, participants may be tempted to say "VR sounds fascinating, let's do that" without having a clear picture of the fit within market conditions or business applications. To avoid this, users may benefit from supplementing the *Technology Cards* with a market-oriented approach that identifies needs in the problem space, for example, by utilizing a SWOT analysis or a customer journey (Meyer et al., 2008).

Successful implementation of technology is a complex undertaking. It depends on several factors, such as business models, customer segments, funding options, or collaboration possibilities. Timing is also critical. While a new technology may sound promising, the technology may need to mature before it is applicable in a specific business application. While the *Technology Cards* are suitable for identifying and selecting technologies to invest in, we suggest that users consult other tools when it comes to the actual implementation of selected technologies.

Further Work

This paper reveals how a design game involves participants from multiple disciplinary backgrounds and across multiple organisations from private and public sectors. Moreover, the paper demonstrates how design games make discussions about difficult topics more accessible and democratic. As a result, we postulate that design games in general help stakeholders from multiple disciplinary backgrounds engage in the discussion of difficult topics such as digitalisation and emerging technologies. Moreover, we suggest that the work reported here provides a platform for the development of further design games targeting other complex challenges, such as climate change, decarbonisation, future advanced manufacturing or future health care systems.

Digitalisation will have an enormous impact on society in the years to come, and there is large potential for further research on the topic. Design involves creating socio-technical solutions that satisfy complex networks of stakeholders. As such, we believe that design researchers and design practitioners are particularly well-equipped to investigate the future implications of digitalisation. Further research might explore how digitalisation can help leverage societal aims, such as those explicated by the Sustainable Development Goals. Further research might also investigate how design methods can contribute to discussing and designing digital futures.

The development of the *Technology Cards* demonstrates how research from the fields of futures studies and design connect and overlap. Futures studies excels in identifying trends and outlining multiple possible futures, and the field of design excels in turning abstract problems into tangible solutions, while taking into account the needs and wants of stakeholders. The *Technology Cards* bridge the gap between these two research fields by facilitating participatory, long term-oriented design thinking activities. We see great potential for further research connecting these two fields of study in order to explore the implications of digitalisation.

Conclusion

Digital technologies such as artificial intelligence, big data, virtual reality, robots, and Internet of Things will have a massive impact on the future. But what kind of change will they create? And how will that affect businesses?

In this paper, we introduced the *Technology Cards*—a novel design game that enables users to discuss the impact of multiple digital technologies within their own business contexts. We developed and tested the *Technology Cards* in 17 *Tech Sessions* with 257 participants from 40 private and public sector organisations. We thoroughly described the iterative design process of creating the cards and provided guidance for designers interested in developing design games.

With the new perspective of the *Technology Cards* as instruments of inquiry, we found that the cards aid users in a) framing current challenges, b) imagining how multiple technologies may affect the future, c) identifying synergies between technologies, and d) facilitating constructive dialogue. We also found that the *Technology Cards* engaged a diverse group of stakeholders and provide evidence for the importance of involving both technology-savvy and non-technology-savvy stakeholders in discussions about the future.

Digital technologies are likely to create even more profound changes for our society in the coming years. Correspondingly, we see a growing need to make the implications of digital technologies visible, tangible, and actionable to stakeholders. In this paper, we demonstrated how a design game helps stakeholders explore the impact of digitalisation and articulate their expectations for the future.

By introducing the *Technology Cards*, we presented an agenda-setting dialogue-based design game that highlights the implications of multiple technologies on the future of business strategy and organisation and assists business managers in navigating in a digital future.

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References

1. Arup Foresight. (2020). *Drivers of change*. Retrieved November 10, 2020, from https://foresight.arup.com/our-tools/drivers-of-change
2. Aspiala, T., & Deschamps-Sonsino, A. (2014). *Know cards*. Retrieved March 10, 2023 from https://www.designswarm.com/know-cards/
3. Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M. J., Sridhar, M., Parsons, M., Bertram, N., & Brown, S. (2017). *Reinventing construction: A route to higher productivity*. McKinsey Global Institute.
4. Belman, J., Nissenbaum, H., Flanagan, M., & Diamond, J. (2011). Grow-a-game: A tool for values conscious design and analysis of digital games. In *Proceedings of the 5th international conference of Digital Game Research Association* (pp. 1-14). Digital Games Research Association. http://www.digra.org/wp-content/uploads/digital-library/11310.10534.pdf

5. Brandt, E., & Messeter, J. (2004). Facilitating collaboration through design games. In *Proceedings of the 8th conference on participatory design* (pp. 121-131). ACM. https://doi.org/10.1145/1011870.1011885
6. Bratteteig, T., & Wagner, I. (2012). Disentangling power and decision-making in participatory design. In *Proceedings of the 12th conference on participatory design* (pp. 41-50). ACM. https://doi.org/10.1145/2347635.2347642
7. Christensen, C. M. (1997). *The innovator's dilemma: When new technologies cause great firms to fail*. Harvard Business Review Press.
8. Clatworthy, S. (2011). Service innovation through touch-points: Development of an innovation toolkit for the first stages of new service development. *International Journal of Design, 5*(2), 15-28.
9. Coskun, A., Kaner, G., & Bostan, İ. (2018). Is smart home a necessity or a fantasy for the mainstream user? A study on users' expectations of smart household appliances. *International Journal of Design*, *12*(1), 7-20.
10. Dalsgaard, P. (2017). Instruments of inquiry: Understanding the nature and role of tools in design. *International Journal of Design*, *11*(1), 21-33.
11. Eriksen, M. A., Brandt, E., Mattelmäki, T., & Vaajakallio, K. (2014). Taking design games seriously: Re-connecting situated power relations of people and materials. In *Proceedings of the 13th conference* on participatory design (pp. 101-110). ACM. https://doi.org/10.1145/2661435.2661447
12. Ernstsen, S. K., Maier, A., Larsen, L. R., & Thuesen, C. (2018a). Is construction ripe for disruption? In *Proceedings of the 34th annual conference of Association of Researchers in Construction Management* (pp. 22-31). ARCOM.
13. Ernstsen, S. K., Thuesen, C, Larsen, L. R., & Maier, A. (2018b). Identifying disruptive technologies: Horizon scanning in the early stages of design. In *Proceedings of the 15th international design conference* (pp. 1833-1844). The Design Society. https://doi.org/10.21278/idc.2018.0105
14. Ernstsen, S. K., 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), 1-16. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001928
15. European Commission. (2016). *The European construction sector: A global partner.*
16. Friedman, B., & Hendry, D. G. (2012). The envisioning cards: A toolkit for catalyzing humanistic and technical imaginations. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 1145-1148). ACM. https://doi.org/10.1145/2207676.2208562
17. Futurice. (2020a). *The intelligence augmentation design toolkit*. https://futurice.com/ia-design-kit
18. Futurice. (2020b). *IoT service kit*. https://iotservicekit.com
19. Gandhi, P., Khanna, S., & Ramaswamy, S. (2016, April 1). Which industries are the most digital (and why)? *Harvard Business Review*. https://hbr.org/2016/04/a-chart-that-shows-which-industries-are-the-most-digital-and-why
20. Gans, J. (2016). *The disruption dilemma.* The MIT Press.
21. Gerenwa. (2020). *FutureDeck: Game design thinking.* https://gerenwa.com/wordpress/project/futuredeck/
22. Girardin, F. (2015). Our approach of design fiction. *Medium*. https://medium.com/design-fictions/our-approach-of-design-fiction-3ac0b1ae81f0
23. Google Play + IDEO. (2017). *Human-centered design prompts for emerging technologies.* Retrieved from https://services.google.com/fh/files/blogs/ideo_design_prompts_emerging_tech.pdf
24. Halskov, K., & Dalsgård, P. (2006). Inspiration card workshops. In *Proceedings of the 6th conference on designing interactive systems* (pp. 2-11). ACM. https://doi.org/10.1145/1142405.1142409
25. Henderson, R., & Clark, K. (1990). Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly, 35*(1), 9-30. https://doi.org/10.2307/2393549
26. Bolton, R. (2016). Notes on Designing IMPACT: A Foresight Game. *Medium.* https://medium.com/@arowbe/notes-on-designing-impact-a-foresight-game-4b9b523a13d0
27. IVTO. (2020). *Tool: Foresight cards.* https://ivto.org/foresightcards/
28. Joseph, F., Smitheram, M., Cleveland, D., Stephen, C., & Fisher, H. (2017). Digital materiality, embodied practices and fashionable interactions in the design of soft wearable technologies. *International Journal of Design, 11*(3), 7-15.
29. Karimi, J., & Walter, Z. (2015). The role of dynamic capabilities in responding to digital disruption: A factor-based study of the newspaper industry. *Journal of Management Information Systems*, *32*(1), 39-81. https://doi.org/10.1080/07421222.2015.1029380
30. Kensing, F., & Blomberg, J. (1998). Participatory design: Issues and concerns. *Computer Supported Cooperative Work*, *7*(3-4), 167-185. https://doi.org/10.1023/A:1008689307411
31. Kleinsmann, M., & Ten Bhömer, M. (2020). The (new) roles of prototypes during the co-development of digital product service systems. *International Journal of Design*, *14*(1), 65-79.
32. Kwiatkowska, J., Szóstek, A., & Lamas, D. (2014). (Un) structured sources of inspiration: Comparing the effects of game-like cards and design cards on creativity in co-design process. In *Proceedings of the 13th conference on participatory design* (pp. 31-39). ACM. https://doi.org/10.1145/2661435.2661442
33. Lavikka, R., Kallio, J., Casey, T., & Airaksinen, M. (2018). Digital disruption of the AEC industry: Technology-oriented scenarios for possible future development paths. *Construction Management and Economics*, *36*(11), 635-650. https://doi.org/10.1080/01446193.2018.1476729
34. Li, H., Khan, A. H., Hurtig, K. M., Jarusriboonchai, P., & Häkkilä, J. (2021). Flexi card game: A design toolkit for unconventional communication systems for long-distance relationships. In *Proceedings of the 15th international conference on tangible, embedded, and embodied interaction* (pp. 1-16). ACM. https://doi.org/10.1145/3430524.3440650

35. Lockton, D., Harrison, D., & Stanton, N. A. (2010). The design with intent method: A design tool for influencing user behaviour. *Applied Ergonomics, 41*(3), 382-392. https://doi.org/10.1016/j.apergo.2009.09.001
36. Meyer, E., Ashleigh, M., George, J., Jones, G., & Afuah, A. (2008). *Technology, economics, management and organisation* (Technical University of Denmark ed.). McGraw-Hill Custom Publishing.
37. Motawa, I. A., Price, A. D. F., & Sher, W. D. (1999). Implementing construction innovations. In *Proceedings of the 15th annual conference of Association of Researchers in Construction Management* (pp. 65-74). ARCOM.
38. Nam, T. J., & Kim, C. (2011). Design by tangible stories: Enriching interactive everyday products with ludic value. *International Journal of Design*, *5*(1), 85-98.
39. NIRAS (2023). *Digital advice and business development.* Retrieved March 15, 2023 from http://www.niras.com/techsession
40. Peters, D., Loke, L., & Ahmadpour, N. (2020). Toolkits, cards and games–A review of analogue tools for collaborative ideation. *CoDesign, 17*(4), 140-434. https://doi.org/10.1080/15710882.2020.1715444
41. Phaal, R., Kerr, C., Ilevbare, I., Farrukh, C., Routley, M., & Athanassopoulou, N. (2016). On self-facilitating templates for technology and innovation strategy workshops. https://www.ifm.eng.cam.ac.uk/research/ctm/ctmpublications/ctmworkingpapers/on-selffacilitating-templates-for-technology-and-innovation-strategy-workshops/
42. Phaal, R., O'Sullivan, E., Routley, M., Ford, S., & Probert, D. (2011). A framework for mapping industrial emergence. *Technological Forecasting and Social Change, 78*(2), 217-230. https://doi.org/10.1016/j.techfore.2010.06.018
43. Public Sphere Project. (2020). *Liberating voices pattern language.* http://www.publicsphereproject.org/patterns/lv
44. De Roeck, D., Stappers, P. J., & Standaert, A. (2014). Gearing up! A designer-focused evaluation of ideation tools for connected products. In *Proceedings of the 8th NordicCHI conference on human-computer interaction* (pp. 521-530). ACM. https://doi.org/10.1145/2639189.2639204
45. Roy, R., & Warren, J. P. (2019). Card-based design tools: A review and analysis of 155 card decks for designers and designing. *Design Studies, 63*, 125-154. https://doi.org/10.1016/j.destud.2019.04.002
46. Situation Lab. (2020). The thing from the future. http://situationlab.org/project/the-thing-from-the-future
47. Szigeti, H., Messaadia, M., Cesi, G., & Eynard, B. (2011). STEEP analysis as a tool for building technology roadmaps. https://www.researchgate.net/publication/301295850_STEEP_analysis_as_a_tool_for_building_technology_roadmaps
48. Triggers. (2020). Tools for modern teamwork. https://www.trytriggers.com
49. Wetzel, R., Rodden, T., & Benford, S. (2017). Developing ideation cards to support the design of mixed reality games. *Transactions of the Digital Games Research Association*, *3*(2), 175-211. https://doi.org/10.26503/todigra.v3i2.73
50. World Economic Forum. (2016). Shaping the future of construction: A breakthrough in mindset and technology.https://www.weforum.org/reports/shaping-the-future-of-construction-a-breakthrough-in-mindset-and-technology/
51. World Economic Forum. (2018). Shaping the future of construction: An action plan to accelerate building information modeling (BIM) adoption. https://www.globalbim.org/node/1231