Contextualizing technology transfer: a review of university-industry transfer in the construction industry

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1. Introduction

The transfer of knowledge and technology from university to industry is a process fraught with difficulty (Shane, 2004). Over the past decades, the entrepreneurship, innovation, strategy, management and tech transfer (TT) literatures have extensively discussed barriers and facilitators to technology transfer, and have provided insights into the different channels through which TT takes place (such as spin-offs, patenting and licensing,…), the intermediaries that support TT (such as science parks, TT offices, incubators,…), and TT outcomes. The strong interest in TT has resulted in an abundance of studies on these topics, with a number of bibliometric analyses and review articles recently presenting an outline of the work published. Such recent reviews deal with university-industry collaborations (Skute et al., 2019), technology transfer in general (Bengoa et al., 2020), academic entrepreneurship ecosystems (Hayter et al., 2018), TT intermediaries (such as science parks (Lecluyse et al., 2019) and incubators and accelerators (Hausberg and Korreck, 2021), amongst others. While such reviews have provided interesting overviews of the state of the literature, they have often considered TT as a homogeneous phenomenon, hereby typically considering studies from any region, context or technology. This is somewhat in contrast to calls in the entrepreneurship and management literatures to take the context in which phenomena are studied into consideration. In management research, context (such as circumstances, conditions, situations or environments) is external to the phenomenon and may enable or constrain it. Contexts can be business-related, social, institutional or spatial, with the industry or market representing an important element of a business-related context (Welter, 2011). Important elements of industries and markets for instance include their industry life stage and the size and nature of the competition (Welter, 2011). In this chapter, we take a business-related contextual perspective into the technology transfer literature, and focus specifically on understanding what we know and what is still to be explored in terms of technology transfer in the construction industry.
The construction industry represents an interesting setting for a review with a contextual dimension. In Europe, the construction industry has often been considered a mature, traditional industry (Pries and Janszen, 1995), that is conservative and attached to familiar technologies (Beerepoot and Beerepoot, 2007). At the same time, the construction industry is challenged by increased global competition, urging firms in this industry to engage in innovation (Ahmad et al., 2005). Furthermore, research has identified inefficiencies in the construction process (Holley and Farrow, 2013), which has spurred the demand for innovation in the sector. Also, while the construction industry has traditionally to a larger extent engaged in incremental innovations and less in radical innovations, the emerging importance of environmental issues and informatics has affected firm R&D policies (Pries and Janszen, 1995; Uusitalo and Lavikka, 2020).

Specifically, while firms in this industry have predominantly focused on cost leadership, they have to a larger extent engage in a differentiation strategy (competition on quality instead of price), in which they more closely connect their offer to market demand (Pries and Janszen, 1995). As such, new construction technologies need to demonstrate not only cost reduction potential but also a potential increase in productivity and optimal resource usage (Ganesan and Kelsey, 2006). However, the extent to which firms are able to embrace and adopt new technologies is largely contingent on their dynamic capabilities, enabling them to adapt, integrate and reconfigure their organizational competences and resources in order to reach a fit with the changing business environment (Teece et al., 1997; Pinske and Dommiss, 2009). Furthermore, construction firms are challenged by the integration of new technologies into their project-based structure, which is typical for the construction industry (Pinske and Dommiss, 2009). Following these challenges, university-industry collaboration and technology transfer have become an essential part of innovation and growth in the construction industry, resulting in new product, service and process inventions, new patents and licenses (Al-Gasim et al., 2021). By consequence, in this chapter, we provide an overview of what we know on technology transfer in the construction industry based upon the literature, taking into consideration the specific nature of this industry. Furthermore, next to synthesizing current knowledge, and contrasting it to the tech transfer literature in general, we also present a research agenda for future research into this intriguing field. Specifically, in what follows, we first present our research method, followed by the results and our recommendations for future research.
2. Method

Our study aims at providing a review of the current literature on university-industry technology transfer in the construction sector. In order to reach our research aim, we conducted a systematic literature review following the recommendations of White and Schmidt (2005). In what follows, we present the different steps recommended by this review method, followed by an overview of the selected papers.

2.1. Article search and classification

We performed a six-stage search procedure including the following steps, which are also illustrated in Figure 1: (1) basic literature search, (2) title, keyword and abstract screening, (3) screening of the full text publications, (4) prior literature search: reviewing of the titles in the reference lists of the selected articles, (5) screening of the full texts of articles in the reference lists, and (6) analysis of the qualified articles for the review.

In the first step, we used the Web of Science database to search for articles and reviews. We included papers published until October 2020. Conference papers, books and book chapters were excluded from the analysis. Search terms include terms for technology transfer and channels, as shown in Table 1. The search was done by topic comprising title, abstract, and author keywords. We conducted our search in the following categories of the Web of Science: management, business, economics, engineering, materials and environmental sciences, and construction building technology. This first step resulted in 1649 articles.

The second step of this process was the screening of articles by analysing the title, keywords and abstract. We subsequently considered the scope of the title, keywords and...
abstract and only selected papers that studied the transfer of technology from university to industry. We excluded papers on entrepreneurship education, the impact of cultural differences in technology transfer, gender bias and policy proposals for innovation because they are out of scope. Duplicate articles were also removed. This step yielded 73 relevant publications.

<table>
<thead>
<tr>
<th>Web of Science search terms</th>
<th>Number of articles – step 1</th>
<th>Selected articles – step 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(“technology transfer” OR &quot;TT&quot; OR commercialisation) AND (universit* OR academi*) AND (construction OR building OR engineering)</td>
<td>369</td>
<td>21</td>
</tr>
<tr>
<td>(“spin-off” OR “spin-out” OR spinoff OR spinout) AND (universit* OR academi*) AND (construction OR building OR engineering)</td>
<td>75</td>
<td>3</td>
</tr>
<tr>
<td>(“start-up” OR startup*) AND (universit* OR academi*) AND (construction OR building OR engineering)</td>
<td>197</td>
<td>2</td>
</tr>
<tr>
<td>patent* AND (universit* OR academi*) AND (construction OR building OR engineering)</td>
<td>218</td>
<td>7</td>
</tr>
<tr>
<td>licens* AND (universit* OR academi*) AND (construction OR building OR engineering)</td>
<td>117</td>
<td>0</td>
</tr>
<tr>
<td>(“contract research” OR “research and development project” OR “R&amp;D project” OR “R&amp;D” or “research and development”) AND (universit* OR academi*) AND (construction OR building OR engineering)</td>
<td>490</td>
<td>24</td>
</tr>
<tr>
<td>(consultan* OR “consultan* project”) AND (universit* OR academi*) AND (construction OR building OR engineering)</td>
<td>183</td>
<td>16</td>
</tr>
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</table>

**Table 1 - Web of Science search terms and their respective number of articles after step 1 and 2**

The third step was the screening of full texts using the screening strings ‘technology transfer’, ‘commercialisation’, ‘university’ and ‘construction’. Papers only focusing on the development of technologies, without any aspect of transferring these to industry or bringing them onto the marketplace were considered out of scope. In addition, studies investigating international technology transfer or simply not mentioning the involvement
of universities were also excluded. This resulted in 28 studies which were of relevance to our research aim.

The fourth step was the selection of relevant titles in the reference lists of the 28 articles, which yielded 18 articles, which were then screened in a similar way as explained above, resulting in 6 additional papers fitting the scope of our review. Consolidating the two lists led to a final list of 34 papers which are further analysed.

2.2. Coding frame and characteristics

In this section, we present the information transferred from the papers to the coding frame used in our analyses and provide deeper insights into the sample characteristics. The 34 papers were coded along the following dimensions: author, year, journal, title, author keywords, research questions/objectives, definitions, construction sector link, university-industry link, type of technology, methodology, units observed, country of study, key findings, and future research.

The total of 34 papers is published in 27 different journals. Table 2 gives an overview of the distribution of the final list of papers across the different journals. This overview shows that technology transfer in the construction industry has mainly been addressed in construction and engineering journals, with some interest in technology management and innovation journals.

<table>
<thead>
<tr>
<th>Journal</th>
<th>Number of articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D printing and additive manufacturing</td>
<td>1</td>
</tr>
<tr>
<td>Advanced engineering materials</td>
<td>1</td>
</tr>
<tr>
<td>Architectural engineering and design management</td>
<td>1</td>
</tr>
<tr>
<td>Climatic change</td>
<td>1</td>
</tr>
<tr>
<td>Composites engineering</td>
<td>1</td>
</tr>
<tr>
<td>Construction economics and building</td>
<td>2</td>
</tr>
<tr>
<td>Construction innovation</td>
<td>1</td>
</tr>
<tr>
<td>Construction Management and Economics</td>
<td>2</td>
</tr>
<tr>
<td>Environmental science and pollution research</td>
<td>1</td>
</tr>
<tr>
<td>Informes de la construccion</td>
<td>1</td>
</tr>
<tr>
<td>International journal of construction management</td>
<td>1</td>
</tr>
<tr>
<td>Journal of civil engineering and management</td>
<td>1</td>
</tr>
<tr>
<td>Journal of cleaner production</td>
<td>2</td>
</tr>
<tr>
<td>Journal of Construction Engineering and Management</td>
<td>2</td>
</tr>
<tr>
<td>Journal of engineering and technology management</td>
<td>1</td>
</tr>
<tr>
<td>Journal of hazardous materials</td>
<td>1</td>
</tr>
<tr>
<td>Journal of professional issues in engineering education and practice</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 2 - Number of papers per journal

<table>
<thead>
<tr>
<th>Journal</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journal of technology transfer</td>
<td>1</td>
</tr>
<tr>
<td>Proceedings of the institution of civil engineers: civil engineering</td>
<td>1</td>
</tr>
<tr>
<td>Processes</td>
<td>1</td>
</tr>
<tr>
<td>Renewable and sustainable energy reviews</td>
<td>2</td>
</tr>
<tr>
<td>Smart and sustainable built environment</td>
<td>1</td>
</tr>
<tr>
<td>Sustainability</td>
<td>2</td>
</tr>
<tr>
<td>Sustainable cities and society</td>
<td>1</td>
</tr>
<tr>
<td>Technovation</td>
<td>1</td>
</tr>
<tr>
<td>Transportation management and public policy 2003: planning and administration</td>
<td>1</td>
</tr>
<tr>
<td>World journal of microbiology and biotechnology</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 2 provides an overview of the years in which these papers were published, showing an increase in interest over the past decade.

We observed that many papers address new technologies in the energy-efficiency field to reduce carbon emissions in construction. This is aligned with the concern about global warming and circular economy goals towards sustainability, which seems to spur innovation in the construction industry.

3. **Results of the literature review**

Our review points to three overarching themes which have been discussed in the literature. First, research has studied the technology transfer (TT) process. Second, it has looked into factors influencing this process or its implications, and finally, it has studied the outcomes of the TT process. We discuss the main take-aways from prior studies in what follows. We also summarize the current state of the literature in Figure 3.
3.1. The TT process

As to what the TT process is concerned, the literature has so far studied three main topics, namely stages, channels, and strategies, tools and frameworks.

3.1.1. Stages

A traditional university technology transfer process consists in several stages. It ranges from technology discovery by the university scientist, through the evaluation of intermediaries such as TT offices, to patent and technology licensing (Bradley et al., 2013). These stages are not specific to any industry and not linear in practice. In what follows, we discuss the TT stages that have been documented in the construction sector. While studies that looked into the stages (Bazan, 2019; Bossink 2020; Laborde and Sanvido, 1995; Shapira and Rosenfeld, 2011) show some overlap, they also present their own view on the TT process.

Bazan (2019) considers basic research, applied research, new product development, and commercialisation as the four consecutive stages of the TT process for engineering research. At the same time, the author also identifies three ‘efforts’ that need to be made simultaneously during the four stages, through a constant feedback mechanism, in order to successfully commercialise university research. These three efforts are related to the market (i.e., assuring and validating that the technology is aligned with the market needs), the product (i.e., designing the product’s attributes), and the science (i.e., technology development). Bossink (2020) indicates that successful commercialisation of new sustainable energy technologies takes place through a series of consecutive demonstration
projects. These projects typically start with the development and improvement of prototypes in labs, and are followed by the development of operational processes on production sites at which these prototypes are applied. The projects typically end with gaining knowledge regarding market demand. The case study of Shapira and Rosenfeld (2011) discusses the promotion and implementation of a construction technology that is developed through joint research by academia and industry. In doing so, they identify seven stages in the TT process: problem identification, formulation of a solution, prototype development, system test, initial implementation, commercialisation, and capitalization on success. For each stage, the authors describe how the university and the firm cooperate. This model of continuous cooperation at each stage of the process implies that, in order to be effective, a continuous combination of the transfer of tacit knowledge and explicit knowledge of the technology itself is needed. The work by Laborde and Sanvido (1995) then focuses on a particular type of technology transfer, namely one in which construction companies involve university students through a program to foster construction innovation. The technology transfer process they identify consists of technology identification and motivation for implementation, cost analysis and the development of a business plan as part of the technology evaluation, followed by the technology implementation and feedback.

We can conclude that there are different descriptions of the stages of the technology transfer process in the construction sector. However, while the building blocks of the TT processes described here are distinct, there are some communalities. First and foremost, the studies describe the stages of the TT process in construction from research to commercialisation, which does not differ from the traditional TT process described by (Bradley et al., 2013). In contrast, there are quite some differences between the studies and each study places a slightly different emphasis. While Bazan (2019) proposes a framework with feedback loops, the other studies (Bossink, 2020; Laborde & Sanvido, 1995; Shapira & Rosenfeld, 2011) mainly consider the TT process to be linear and consecutive, with technology implementation to test and eventually prove its efficiency to reach the market. Also, in comparison with the TT literature in general, the TT process in the construction sector seems to rely to a much larger involvement in demonstration projects and prototypes. Also, tech transfer in this sector seems to rely on a tight and continuous collaboration between industry and science, which already starts at the early stages of development, namely at the stage of technology discovery. This seems to be
somewhat different from the general TT literature, in which industry is often only considered later in the TT process (e.g. when the technology is already patent-protected).

3.1.2. Channels

There are different channels through which technology from university can be transferred to industry. Wright et al. (2008)’s study in a general, non-construction specific context identifies the following channels: spin-off creation, patenting and licensing, contract research, consulting, and graduate and researcher mobility. Our review on channels of technology transfer in the construction sector, points to a more limited number of channels used in this industry, namely university spin-off creation, joint R&D, and patenting and licensing.

First, university spin-off creation is one of the commercialisation routes through which researchers bring their ideas to market. Several studies have highlighted the suitability of establishing university spin-offs to successfully commercialise university-developed construction technologies, such as geosynthetic technology (Jones et al., 2017), nanotechnology (Ozin et al., 2013), and technology for water quality monitoring (Bazan, 2019). Moreover, spin-off creation seems to be particularly relevant for the commercialisation of sustainable solutions because this approach allows to extensively conduct experiments, test the value proposition and the market potential in the university context before making a significant investment (Bazan, 2019). Indeed, the work of Nejabat and Geenhuizen (2019) analyses 107 spin-offs in Northwest Europe, including Denmark, Finland, Norway, Sweden, and the Netherlands, and indicates that 60% of sustainable energy spin-offs are able to reach the market and most of them do so within the first five years of their existence. On the downside, however, they do find that the entrepreneurs in these spin-offs face difficulties in scaling their ventures due to insufficient capital and constraints from regulations, and are sometimes forced by market forces to select strategies that are cost-focused instead of sustainability-focused. In contrast, some authors are less convinced that establishing university spin-offs is the best commercialisation route for construction innovation. For instance, Bröchner and Lagerqvist (2016) investigate the most important university-industry types of interaction through a questionnaire with industry and university respondents. They find that academic spin-offs are not considered the mainstream type of interaction. Instead, they point to the importance of informal contacts, joint research projects and staff mobility.
Second, the literature on technology transfer in the construction sector has discussed joint R&D as a commercialisation channel. Watson et al. (2015) for instance document that, in the sector of low carbon technologies such as energy efficient cement production, Chinese firms largely benefit from engaging in joint R&D projects with local universities. This is because the jointly developed technologies are cheaper than foreign-made equipment, the after-sales service is more convenient, further improvements are easier to implement, and there is a desire to support the local industry. Along the same lines, Lee and Win (2004) consider joint research to be efficient as it ensures high commitment of the industry to increase the transferability and, as such, enhances the facilities and expertise of both university and industry. The work by Hall (2003) and Shapira and Rosenfeld (2011) also studies joint R&D projects and points to the importance of organizing professional conferences and seminars for both academics and practitioners, to boost the transfer of technology developed in joint R&D projects. Alwan et al. (2017) consider the involvement of academia important as it provides research and design expertise, as well as technical innovation and skills training. In their case study, joint research is adopted to develop a model that can facilitate strategies to reduce environmental impacts in construction. The authors state that the interaction between academia and industry already exists in the construction sector, but that it is often informal and uncoordinated. With the aim of fostering industry innovation, Laborde and Sanvido (1995) propose a program to establish partnerships between the university and industry to achieve excellence in construction. Apart from educating students as future leaders and improving their skills, the program has the objective to study and develop new construction methods and processes, as well as to provide a forum to share the knowledge among industry, students, and faculty. In addition, Bröchner and Lagerqvist (2016) suggest that industry and university consider joint research as the preferred TT route, while pointing to the importance of combining transfer of tacit knowledge with acquiring intellectual property rights.

Third, patenting and licensing is another way in which technology can be transferred from the university to industry. The study by Zhong et al. (2009) analyses almost 40,000 Chinese patents in the construction field from 2000 to 2015 and indicates that the majority of patents deal with the preparation, handling, or processing of building materials or building components on the construction site. They find that universities have increasingly engaged in patent applications since 2007. The important role of universities
in patenting activity is also highlighted in the study by Dapurkar and Telang (2017) in which they investigate 228 patents on the application of micro-organisms used in the construction industry as cement and concrete additives. The authors find that universities or research institutes are the second largest major player in the field (holding 28% of all patents), while patents stemming from university-industry collaborations only account for 4% of the patents. Interestingly, there seem to be important regional differences in terms of patenting. For instance, Bröchner (2013) indicates that in the Nordic region (Denmark, Finland, Norway, and Sweden), industry-science collaborations seldomly results in patents, while in the US, many patents stem from university-industry collaborations. The case study conducted by Holley and Farrow (2013) presents a collaborative interdisciplinary product development program at a university in the US to improve productivity and safety in the construction sector. As a result of the program and the partnership with a manufacturer, the developed products were submitted for patenting and licensing. However, there is little unanimity in the literature on the use of patents in construction as a measure to indicate the success of university-industry collaboration (Bröchner, 2013).

In summary, the literature has discussed three technology transfer channels, namely spin-off creation, joint R&D, and patenting and licensing. Our review indicates that joint research is the most studied TT channel in the construction industry, which is in line with our observation that industry-science collaboration is rather common in all stages of the TT process in the construction industry. The advantages of joint research are addressed in several studies (Laborde and Sanvido, 1995; Lee and Win, 2004; Shapira and Rosenfeld, 2011; Watson et al., 2015). Joint research seems to facilitate the introduction of innovation in the market. Despite the contributions that the discussed studies have brought to the TT field, the current state of the literature is largely descriptive and provides few insights into the contingencies under which specific channels are more or less effective. Neither do these present the decision factors that are taken into account when choosing the channel, nor do they present the advantages and disadvantages of the selected channel. In addition, the transfer channels in the selected articles are restricted to spin-offs, joint R&D and patenting and licensing, with few insights presented into the (potential) role of other TT channels, such as consulting or contract research.

### 3.1.3. TT strategies, tools and frameworks
Effective strategies are required to overcome challenges in the TT process and ensure its success. For instance, according to Owusu-Manu et al. (2015), there is a need to synthesize sustainable methodologies to improve organizational efficiency of construction consulting firms and innovations into a business framework which enables monitoring TT developments (Gann, 2001). In this regard, the literature has explored strategies, business management tools and frameworks that have the purpose of achieving a sustainable planning process and reaching the market. Specifically, studies have been undertaken to evaluate and identify optimal management practices in TT in the construction industry (Alwan et al., 2017; Muslemani et al., 2020; Shakeel et al., 2017; Suprun et al., 2019; Yin and Li, 2018a, 2018b).

For instance, to improve the energy efficiency for cleaner production in the construction industry, Yin and Li (2018a) propose and implement a decision-making model to match supply and demand of Green Building Technologies (GBT) to promote TT from academic research institutes to construction enterprises. Along the same lines, Yin and Li (2018b) study the TT process based on a dynamic framework through a stochastic differential game approach to investigate strategies that work better in the transfer of GBT. These strategies are related to incentive mechanisms and revenue distribution of GBT. The findings show that the effort level in terms of time of academic research institutes and construction enterprises is proportional to the government subsidy of GBT innovation, pointing to government subsidies as potential long-term incentives to promote TT for these technologies. Alwan et al. (2017) apply a framework for strategic sustainable development in the UK construction industry to assist with the transfer and implementation of new technologies that aim to reduce negative environmental impacts of construction. The framework is tested by use of a case study to evaluate its potential, in which the academic institution provided research and design expertise, as well as technical innovation and skills training. Through this case study, ineffective strategies, policies and leadership were highlighted, which have prevented the full exploitation towards sustainable production. Next, by exploring the theoretical underpinnings of low-carbon technology business models and through semi-structured interviews with industry experts and academics, Muslemani et al. (2020) point to revenue as the central element in creating value for these business models. However, despite the promising potential of low-carbon technologies for energy efficiency in the construction sector, the lack of a viable business model has deterred the commercialisation of these technologies.
developed within universities (Muslemani et al., 2020). Shakeel et al. (2017) present a comprehensive framework for effective commercialisation of renewable energy technologies in Finland, highlighting the importance of university-industry collaboration. The framework comprises barriers related to commercialisation and measures to overcome these barriers, such as encouraging university-industry collaboration to reduce costs. Uusitalo and Lavikka (2020) develop a platform strategy as a technology in which they aim to standardise construction materials and processes used in the TT process. The platform strategy entails identifying predictable supply chains to provide technological solutions and it helps companies to overcome uncertainties associated with the TT process.

In sum, the studies presented strategies and frameworks for effective technology commercialisation of specific technologies in the construction industry. These studies present a rather fragmented view as they are often focused on a single technology. Also, they have typically focused on a particular strategy or methodology, as such providing few insights into the extent to which these strategies or methodologies could be applicable to other technologies or markets. While the current state of the literature provides some insights into strategies and methodologies currently used in specific cases, it does not present specific solutions regarding the most suitable strategy for a certain purpose. Furthermore, neither contingencies at technology or contextual level affecting the effectiveness of strategies and frameworks have been studied so far.

3.2. Impediments and facilitators to TT

Several studies have elucidated and examined factors that influence the TT process in the construction sector. These factors can either spur or constrain the TT process, its efficiency, and outcomes. In what follows, we identify these factors and discuss how they can affect the TT process and its outcomes.

As the TT process is embedded in the regional context, many studies discuss government regulations and the political situation that positively or negatively affect TT and its outcomes. Indeed, it is often argued that the government can impose restrictive regulations and barriers, for instance related to safety, which may impede TT and innovation in the construction sector (Laborde and Sanvido, 1995; Suprun et al., 2019). Nejabat and Geenhuizen (2019) even found that many university spin-offs had to close down partly as a result of the severe policy restrictions they were confronted with.
However, the government can also adapt policy and provide incentives in support of TT and innovation in the construction sector (Suprun et al., 2019; Jones et al., 2017). These government incentives can for instance include providing loans, fiscal concessions, subsidies or funding. By doing so, the government can promote collaboration between academia and the construction industry (Suprun et al., 2019; Bazan, 2019) which has shown to enhance innovative activity in the construction sector (Suprun et al., 2019). Related, the government can provide incentives to increase the demand for products and services that may be developed and commercialised through TT (Tassicker et al., 2016; Suprun et al., 2019). Finally, the political situation may affect TT. Suprun et al. (2019) indicate that the political situation in some countries, such as Russia, may limit international TT, requiring increased national R&D efforts with efficient collaboration between university and industry (Suprun et al., 2019).

Some studies have also considered the impact of larger societal trends and the economic climate when studying TT in the construction sector. The larger trends in society, such as the transition to sustainability and concerns regarding climate change, represent pressing issues in society and can affect the TT process and its outcomes. Specifically, the construction sector is required to reduce its environmental footprint (Richner et al., 2017), which represents opportunities to develop new energy efficient materials, use renewable energy, and so on. Yet, these trends require much additional research and environmental considerations will likely impact the TT and innovation process (Jones et al., 2017). Furthermore, the broader (economic) climate and situation may also influence the TT process and its outcomes (Suprun et al., 2019). For instance, Shapira and Rosenfeld (2011) refer to the impact of the Israeli recession on a successful university-industry collaboration in the construction sector, and argue that, in general, an industry is driven to innovation in the face of a crisis.

Another critical element that affects TT in the construction sector and its success is the internal resources of the parties involved in the process. Specifically, engaging the right people, having sufficient internal R&D capabilities and money to invest appear to be crucial for firms and universities to successfully go through the TT process. First, firms aiming to adopt and commercialise university research require internal R&D capabilities, suitable infrastructure, and skilled staff members to be able to absorb and utilize these new ideas (Gann, 2001). However, calculations of Gann (2001) show that only 1% of the construction firms in the U.K. have sufficient internal R&D capabilities to successfully
absorb and act upon academic research results. Moreover, the author argues that, even when construction firms have the technical competencies to absorb academic research, they often do not have the internal structure nor the culture to internalize these results, learn from them in the long run, and capitalize on them. Along the same lines, for university spin-offs to be successful, it is recommended that experienced business managers join the founding team (Nejabat and Geenhuizen, 2019). Second, having access to investment capital (with acceptable refunding periods) is also essential to successful TT (Nejabat and Geenhuizen, 2019). This is especially important for firms in hardware, machinery, and new materials, which face large investment needs, quick depreciation, and require testing at large scale. Particularly, innovations in the construction sector often require a large upfront investment, with effects taking a longer time span to mature. As such, the development cost is often considered the main barrier for the implementation of new technologies (Addy et al., 2020; Dapurkar and Telang, 2017; Peña et al., 2014; Sorrell and Hoffman, 1994). However, the costs can be compensated by savings on maintenance and the subsequent favourable life cycle (Tassicker et al., 2016). The literature indicates that it is often difficult to get innovations accepted into civil engineering practice (Jones et al., 2017), and a variety of restrictive codes and regulations contribute to this (Laborde and Sanvido, 1995). Furthermore, prior research in the construction sector suggests that university spin-offs are often not sufficiently attractive for investors (Nejabat and Geenhuizen, 2019).

Another factor that undeniably affects the TT and its outcomes, especially since the prior section shows that firms and universities often do not have sufficient internal resources to bring TT to a successful conclusion, is the mutual understanding and collaboration between the university and the industry. Good collaboration can facilitate the TT process and lead to positive outcomes. Shapira and Rosenfeld (2011) studied a case of a highly successful academic-practitioner cooperation which led to a successful innovation, and summarize several important lessons learned. The lessons include that construction academics should visit construction sites and meet regularly with practitioners and laborers to fully understand the issues and needs of the industry. Also, in the testing and implementation phases, close cooperation between practitioners and academics with daily feedback loops appears to be decisive. The lack of a mutual understanding and collaboration often originates from the differences between university and industry. A first issue relates to the differences in the ways in which they generate and manage
knowledge (Gann, 2001). For instance, while university knowledge production encompasses a wide range of disciplines and typically takes a long time, industrial knowledge production generally entails combining limited specialized and generalist knowledge and is developed more rapidly. Related, academic researchers and practitioners may not speak the same language because of different training and experience (Bazan, 2019). These distinctions, along with differences in research objectives, may not only impede collaborations between the two parties, but may already discourage them from considering to collaborate in the first place. Additionally, universities typically value openness and produce knowledge as a public good. Yet, while some construction engineering and design firms also value that their employees publish in prestigious journals, the industry typically aims at protecting its knowledge and intellectual property as much as possible to secure private profits (Gann, 2001; Hairstans and Smith, 2018). These tensions between the university and industry are again difficult to reconcile and may hinder TT. However, it is important to note that many universities also started to realize the benefits related to commercialising university research. Therefore, many have introduced general TT policies encouraging academics to engage in TT and research commercialisation (Bazan, 2019). Such policies can for instance state that academics will be rewarded for the contributions they make to R&D projects with commercial purposes. Also, many universities have set up TTOs (Technology Transfer Offices) that provide a range of integrated services, from managing IP to helping with funding applications, all to support TT.

In summary, the literature has pointed to a number of factors which can impede or stimulate TT in the construction industry. Specifically, it has pointed to the role of government regulations, societal trends and the economic climate, internal resources at the firm level and a mutual understanding and collaboration between industry and university. Overall, these factors seem to coincide to a large extent with the factors that have been considered relevant for tech transfer in general (see, for instance, Bruneel et al., 2010).

3.3. Outcomes of the TT process

A number of studies has considered the outcomes of TT. In what follows, we provide an overview of studies that have discussed the impact of university-industry TT for firm performance, the firm’s business and business models and knowledge development. First, a new technology may affect performance and efficiency (Jones et al., 2001; Jones
et al., 2017). In addition to the optimization of construction processes, the interaction between university and industry can reduce costs, provide support for companies to globalize their operations and offer infrastructural support (Shakeel et al., 2017). In general, increasing the efficiency of the process implies cost savings, but the outcome of TT includes furthering efforts for technology’s consistency and standardization (Peña et al., 2014). Construction companies expect to increase profitability and productivity with the TT process (Suprun et al., 2019). At the same time, the involvement of researchers provides better solutions to industry (Gambatese and Hallowell, 2011; Jones et al., 2017; Rynska et al., 2019), either through new technologies or decision support models. The current studies have mainly made such claims, often supported by theory. However, we did not find any studies that empirically studied the relationship between TT and firm performance or other firm outcomes in the construction industry.

Second, construction innovation has an impact for a firm’s business and business models. By transferring new technology to the market and promoting it, construction enterprises can improve their competitiveness (Yin and Li, 2018b), whereby technological innovation acts as an important marketing element for the company (Shapira and Rosenfeld, 2011). Innovation is likely to attract new customers. This is particularly the case when more sustainable technologies are being developed, not only because of demands following climate change, but also due to the growing awareness of people, pushing policies towards sustainability. Consequently, these technologies can shape the industry as it has been a pressing issue to reduce carbon dioxide emissions. New construction materials, processes and designs have been developed to improve energy efficiency and meet the building sector requirements to reduce its environmental footprint (Richner et al., 2017). TT is an essential part of business models, as well as a way to gain competitive advantage through market disruption (Uusitalo and Lavikka, 2020). Specifically, it is argued that TT can be an effective way for construction companies to move away from the current economic model towards a more resource-efficient one, in line with increased demand for sustainability. Next to these efficiency gains, CEOs of construction companies are also interested in TT as it could benefit their employees and the community (Uusitalo and Lavikka, 2020). Bridging the gap between academic research and university through TT helps firms in bringing new construction products and services to the market, driving the development of the sector (Richner et al., 2017). The
industry then benefits from the opportunities that a new technology brings by providing value to clients (Owusu-Manu et al., 2015).

Third, the literature has discussed benefits of TT in terms of knowledge development. Specifically, by engaging in academia-industry cooperation, the construction industry benefits from the synergic outcome (Shapira et al., 2008), improving its absorptive capacity by developing better feedback and life-long learning mechanisms, education and training (Gann, 2001). Rynska et al. (2019) consider the fact that TT provides better knowledge to industry as one of the main implications. The interaction between educational institutions and industries provides vital resources to the companies, in the form of human capital and knowledge that can be useful in improving the technical aspects of technology (Shakeel et al., 2017). At the same time, TT brings research opportunities for the university, allows for expanding relationships with industry partners, and provides research validation (Holley and Farrow, 2013).

In summary, studies into the outcomes of the TT process in the construction industry have focused on firm performance, the firm’s business and business models and knowledge development. Despite the insights that these studies have generated, a number of important gaps remain in the literature. First, the focus of studies into the implications of technology transfer have mainly been case-based. While cases provide important insights, they often do not allow for generalization. Second, the literature has remained vague on how TT effectiveness can be measured and assessed. Third, the predominant focus on the outcomes for firms and the industry, has led to scant insights into the outcomes and implications of TT for the involved universities and research institutions.

4. A future research agenda for TT studies in the construction industry

In what follows, we propose a future research agenda, guided by our analysis on the current state of the literature on TT in the construction industry. Specifically, we highlight opportunities for qualitative and quantitative research to further contribute to the advancement of knowledge regarding the TT process, its influencing factors, and outcomes in the construction industry.

4.1. TT process

First, our study indicated that prototyping and demonstration projects are rather common in TT in the construction industry. Interestingly, the general TT literature has not considered these as typical elements of the TT process or as part of TT channels (Wright
et al., 2008). Therefore, we are convinced that both the general and the construction-specific TT literature could benefit from more in-depth studies into prototyping and demonstration projects. This is because prototypes are not only common in construction, but may also be particularly relevant in other industries, such as software development and car manufacturing (Elverum et al., 2016). Prototypes and demonstration projects are relevant to verify and validate assumptions and calculations, and are particularly relevant in contexts in which large upfront investments are required. They can also help in gaining institutional support for new technologies and to convince stakeholders such as investors and customers (Elverum et al., 2016). Furthermore, the case studies of prototypes and demonstration projects addressed in this review are mainly focused on incremental innovations. Thus, further studies could discuss radically new technologies and shed light on the role of prototypes and demonstration projects in reaching the market.

Second, our review also indicates that some TT channels, such as spin-offs, joint R&D, and patenting and licensing have been frequently studied. Future research could purposefully focus on less frequently studied channels, such as consulting, contract research, and graduate mobility, and shed light on whether or not they are used in the construction sector. Furthermore, future studies could investigate the advantages and disadvantages of the chosen channel for this specific industry. More insights into these channels could also provide important indications on which is the most suitable channel and TT strategy for a certain purpose, and it could help in understanding the factors that affect the effectiveness of specific channels. As such, future research could develop a framework that could guide the choice for specific channels. Finally, we also urge future research to investigate the later stages of the TT process, in which new technologies are brought to market, in contrast to many studies which have considered the earlier stages of the process, namely that of technology development.

Finally, although our review indicates that the literature has discussed the stages, channels, and strategies, frameworks and tools of the TT process in the construction industry, we still have scant insights how TT in the construction has emerged, and what the main best practices during the evolution were. While the general TT literature refers to the Bayh-Dole act as a major milestone for TT in general (Shane, 2004), the literature on TT in the construction industry provides few insights into when and how TT in the construction industry emerged, and what the major achievements of TT in this industry
Future research could provide deeper insights into the history of TT in the construction industry, and would allow to learn from best practices in this field.

4.2. Impediments and facilitators

First, studies into TT in the construction industry have either used a case based approach, or have considered the construction industry as a whole (e.g. studies into patents). However, the construction industry likely consists of subindustries, with diverse market dynamics. For instance, while the construction industry is typically considered conservative (Beerepoot and Beerepoot, 2007), some subindustries such as environmental engineering may be less conservative, and more open to radical innovations and TT collaborations. Future research could assess the extent to which the subindustry a firm belongs to affects its engagement in TT. In order to do so, a research design that unites firms or TT collaborations in different subindustries should be developed. Taking such a perspective would allow for a stronger contextualisation of TT, within and beyond, the construction industry.

Second, our review indicates that there are regional differences in the use of specific TT channels. However, the literature provides few insights into the factors that affect the choice of specific TT channels. Future research could assess these factors, which could be situated at the regional or national (e.g. regulations, market dynamics, political and economic situation) or firm level (management experience, available absorptive capacity,…).

4.3. Outcomes

First, following the largely case-based nature of studies into the TT process in the construction industry, future research could use quantitative, large-scale studies to provide insights which are more generalizable. In order to do so, the identification or development of performance indicators which are of relevance to this industry or subindustry would help to provide such generalizable and quantifiable insights. As the construction industry is a conservative one and is resistant to the entry of new technologies and innovation (Shapira et al., 2011), such generalizability and quantification may have important practical implications, as it may encourage the transfer of technology.

Second, future research could also identify business models of TT that work and conditions under which they do. For instance, does the seminal model on
commercialisation strategies for new technologies developed by Gans and Stern (2003), based upon Teece’s work (1986) also hold for the construction industry? Does it allow for differentiating between construction technologies that should be brought to the market for ideas or the market for products? Are there factors that the model does not incorporate, but that are of particular relevance to this industry?

Finally, as much of the research into outcomes of the TT process has taken the perspective of the firm or industry, future studies can evaluate how and when TT in the construction sector may, or may not, be beneficial to universities and research institutions, and may identify barriers and stimuli to such transfer from the academic perspective. Here again, the identification or development of performance indicators, would be an important step forward.

5. Conclusion

This study analysed 34 papers on TT in the construction industry, which is considered a rather conservative industry, however experiencing a number of pressures towards the implementation of new technologies and innovation. We found that the literature has mainly studied the TT process, impediments and facilitators and outcomes. We summarised these insights from the literature, and provided a research agenda for future research.

Acknowledgement

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 860006.
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