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KNOWLEDGE AND TECHNOLOGY TRANSFER IN CONSTRUCTION ENGINEERING: TWO CASE STUDIES INVOLVING SPECIAL CONCRETE

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Abstract. This research examines the dynamics of knowledge and technology transfer (KTT) within the construction industry while focusing on innovation in special concrete. The study aims to assess two representative cases in different European target regions, namely Germany and the Czech Republic. The aim is to evaluate the role of the KTT intermediaries employed, the significance of intellectual property during the transfer process, and the linearity of the transfer process. Methodologically, a qualitative case study approach was used, selecting two cases from prominent technical universities. The outcomes were complemented by additional research to unveil the prerequisites of the KTT structure within the selected institutions. Findings include the importance of KTT intermediaries in speeding up the transfer process.The presence of IP was not a determining factor in starting up a business. Lastly, a suggested linearity of the theoretical transfer process was not followed. These case studies serve as a call to action, aiming to explain and promote KTT processes within the construction sector and inspire further research to bridge the gap between theory and practical applications of transfer.

Keywords: Knowledge and technology transfer, ultra-high-performance concrete, textile reinforced concrete.

1. Introduction

Knowledge and technology transfer (KTT) remains a focal point within academic institutions. The strategic implementation of KTT within academia is geared towards fostering collaborations with industry partners, facilitating the transition of innovation to the market, and ultimately enhancing the socio-economic well-being of society. Academic institutions are increasingly expected to provide the foundation for transforming in-house inventions into marketable products or services. This undertaking is multifaceted and has numerous uncharted requirements and expectations, impacting researchers, institutions, funding organisations, and the industry.

A striking example of an ineffective transfer is observed in the construction sector, which has shown limited receptivity to technological innovations [1, 2]. Despite facing challenges like skilled labour shortages, global climate concerns, energy crises, demands for eco-friendly solutions, and discussions about Industry 4.0, the construction sector has been traditionally slow to embrace innovative technologies. Aspects such as digitalisation, disruptive technologies, mass production, high-performance materials, and streamlined construction processes are the future of construction.

In 2020, the construction industry employed an estimated 10 million people [3] in the EU member states, generating revenues of €1.7 trillion [4]. These figures highlight the importance of construction as a key economic sector and underline the need to involve research, development, and innovation (R&D&I).

Technical universities serve as hubs for innovation in construction-related fields, fostering advancements in sustainable infrastructure, advanced materials, and digitalisation. Researchers play a crucial role in translating their findings into industry applications by engaging in interdisciplinary projects, collaborating with knowledge and technology transfer offices (KTTOs), and navigating intellectual property (IP) frameworks. Key factors influencing a successful transfer include the technology readiness level (TRL), industry demand, regulatory standards, and the availability of funding and skilled labour.

In addition to innovation in construction technology and digitalisation, research into construction materials is an area that can lead to greater efficiency in this sector. For instance, special concrete has witnessed remarkable advancements over the past three decades, positioning it as one of the most promising construction materials available today [5]. With extensive global research efforts, ultra-high-performance concrete (UHPC) and textile-reinforced concrete (TRC) have found numerous applications in architecture and structural engineering [6, 7]. TRC, in particular, stands out for its capacity to replace steel with textiles, making it an ideal choice in situations where corrosion is a concern. A study reveals that over two hundred bridges have been completed, incorporating UHPC in one or more of their structural components [8], making UHPC another prominent material in this sector.

This paper explores two KTT cases involving these specialised concretes. UHPC, known for its strength, durability, and versatility is used in infrastructure works, such as roads, railways, and water barriers [5, 9]. TRC, which replaces steel reinforcements with carbon textiles, is suited for complex structures and rehabilitation projects. While both materials offer benefits, such as extended lifecycles and environmental sustainability, challenges such as high production costs, workforce skill gaps, and a lack of regulatory standards hinder their widespread adoption [10].

This study uses a qualitative research method in the form of two expert interviews to shed light on the intricacies of KTT in construction engineering and the associated transfer processes. Using a formal research design, we adopt a case study approach to gain in-depth insights into this complex process. These cases, representing common commercialisation practices, exemplify similar transfer endeavours in the construction sector.

2. Literature review

The construction sector has been slow to adopt innovation despite its potential for transformation through new technologies, materials and processes. Notably, the industry accounts for 38 % of global energy-related CO_2 emissions, including operational and building emissions [11]. Greater innovation is urgently needed to address its significant environmental impact.

A comprehensive literature review was conducted to gain a deeper understanding of the level of innovation in the construction engineering sector and the role of KTT, whether on an inter-organisational or intra-organisational level. Sexton & Barrett [12] conclude that the absorption of innovation is often a matter of capacity. Specifically, small construction companies tend to approach innovation cautiously, displaying a preference for calculated, risk-averse, and investment-conservative strategies. This inclination is not unique to small firms; it also extends to medium and larger construction companies.

Examining the innovation value chain in the construction sector revealed that the innovation patterns in the construction industry vary significantly from those observed in other sectors [13]. In the construction industry, innovation is primarily project-specific rather than firm-wide, tends to be incremental rather than radical, and mainly focuses on organisational enhancements rather than product innovations. It underscores that the level of innovation, particularly concerning products and the adoption of new technologies, needs to be higher. This aligns with the findings of Uusitalo and Lavikka [14], who highlighted that the focus of KTT in construction is predominantly on developing countries and the transfer of managerial knowledge and skills, with less emphasis on the technology itself.

Digital applications have been instrumental in automating the planning process, but substantial technological innovations have yet to find applications, although some do exist widely. Notable innovative domains include customisation in construction, automation, and high-performance materials.

For instance, the Industrialized House Building (IHB) sector is exploring innovative niche markets by automating construction in controlled environments through producing prefabricated or modular construction elements in factory settings. However, the market for prefabrication and modular construction remains relatively minor.

While 3D printing has revolutionised manufacturing, it holds similar transformative potential in construction. However, the adoption of 3D printing or contour crafting in construction is progressing at a slower pace, occupying a niche segment. As an embodiment of Industry 4.0, 3D printing in construction leverages robotics to reshape conventional construction methods, necessitating a different skill set, particularly IT skills, rather than traditional brick-and-mortar skills. This technology opens the industry to a more diverse labour force, including women or people with physical disabilities. Besides the technology itself, this field requires the need for extensive material R&D&I. Akhnouk [15] identifies civil construction projects that can benefit from this automated process, particularly those that are similar and repetitive, located in remote areas, facing a scarcity of skilled labour, or intended for military and space purposes.

While these technologies present compelling arguments, especially in times of high labour and resource costs and an imperative to reduce carbon emissions, they also face significant barriers. 3D printing technology is still in the experimental phase. According to El-Sayegh et al. [16], the challenges are multifaceted and encompass materials, 3D-printer software, architectural and design considerations, construction management, regulatory and liability issues, and stakeholder involvement. Given these diverse challenges, transitioning to disruptive innovation in the construction industry will require time before it becomes a mainstream technology.

The construction industry's landscape differs significantly across countries. In the Czech Republic, large construction companies are predominantly foreign-owned, with most R&D activities taking place in their home countries, such as Germany and Austria. Conversely, Germany benefits from strong local construction companies, fostering a robust environment for R&D and University-Industry Collaboration (UIC) in the sector. As a result, KTT strategies in these regions must consider these distinct foundational differences.

The literature offers diverse reviews on KTT models, both general and industry-specific. Wahab et al. [17] provide a detailed exploration of the historical evolution of KTT, from prehistoric tacit knowledge transfer to modern explicit knowledge dissemination. Traditional KTT models are grouped into appropriability, dissemination, knowledge utilisation, and communication models. The first three follow linear paths, whereas the appropriability model assumes quality technologies naturally reach the market without formal structures; the dissemination model relies on technology experts driving innovation; and the knowledge utilisation model highlights the communication between providers and users, addressing organisational challenges. In contrast, the communication model adopts a dynamic, two-way interaction process.

Bogahawatte [18] further emphasizes that KTT can manifest vertically, progressing through stages from basic to applied research, and horizontally, moving from one place, organization, or context, to another. For this study, the authors focus on the horizontal transfer of knowledge and technology, which involves the evolution and transfer of knowledge across different contexts.

The conceptual KTT process encompasses eight key stages: knowledge creation or discovery, disclosure, assessment and evaluation, IP protection, marketing, commercialisation through licensing, start-ups or spin-outs, product development, and impact through public use and financial returns [19]. This process is typically represented circularly (see Figure 1).

Gann [20] examines the concept of absorptive capacity, which refers to an organisation's ability to identify, assimilate, and apply external knowledge. This capacity is highlighted as essential for translating academic research into practical advancements, but significant barriers to effective implementation are identified. These include organisational resistance to change, weak collaboration between the academia and industry, and insufficient investment in research and development.

Shapira & Rosenfeld [21] conclude that fostering strong partnerships between academic institutions and the construction industry is crucial for driving innovation. Aouad el al. [22] advocate for a more integrated approach, where academic institutions actively engage with industry stakeholders to facilitate the adoption of innovative practices and technologies in construction. Abbott et al. [23] identified the need for tailored approaches that consider the unique characteristics of the construction sector, emphasising the role of HEIs in supporting businesses to innovate and increase productivity and the introduction of an Innovation Platform.

Most start-ups in the construction industry, whether emerging from academia or the industry, tend to be centred around technological concepts related to artificial intelligence (AI), computerised planning, procurement, or sales, rather than innovations in materials or construction technology. Research has shown that the construction industry, particularly in construction site management, has benefited from integrating information and communication technology (ICT) applications from various industries [18]. This observation highlights a significant gap in research about KTT concepts and approaches in construction engineering as proposed in this paper.

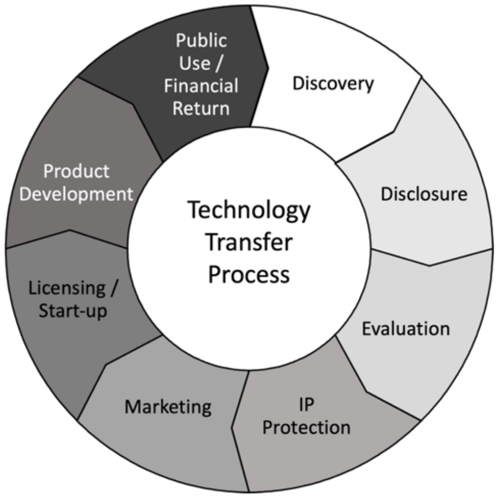

Figure 1. Technology transfer process [19].

3. The cases

The two cases examined in this study involve KTT of special concrete from renowned technical universities: the Czech Technical University in Prague (CTU) and the Technische Universität Dresden (TUD). The following sections provide an overview of the background of these two cases, concluding with research questions and corresponding hypotheses.

3.1. Czech Technical University in Prague

3.1.1. Transfer capacity, strategy, and environment at the CTU

Over the years, CTU has experienced a deviating approach to its KTT strategy and implementation. Various factors have influenced this transformation, including leadership changes, fluctuations in public funding schemes, shifts in available resources, and changes in higher education legislation.

Subsequently, multiple efforts were made to establish and sustain a functional and accepted KTT infrastructure on the campus. Public funding schemes, which provided financial support for developing a KTT structure within a specified timeframe, contributed to creating a KTT organisation. With the cessation of public funding, budget reductions led to the downsizing of newly trained staff, creating a repeated knowledge gap of KTT at the CTU.

As a result of staffing limitations, CTU's KTTO primarily functioned as an administrative point for transfer rather than an active transfer entity. KTT activities were divided among the transfer office, a separate IP department, and the university incubator INQBAY, supporting start-up initiatives, from the CTU as well as external. The university-wide trust in internal KTT activities dwindled, resulting in limited outcomes in terms of transfer activities.

Since 2021, renewed efforts have been made to establish a modern transfer infrastructure by creating ČVUT Tech s.r.o., a wholly owned limited liability company of the CTU. This entity is expected to streamline the transfer process, reduce bureaucratic hurdles, and make it more appealing for CTU researchers to use this transfer vehicle. In 2022, the new Department of Technology Transfer and Fundraising introduced promising strategies for CTU's transfer initiatives. The involvement of ČVUT Tech s.r.o. is pivotal in simplifying processes and bridging the gap between public funding and venture capital funds.

It is worth noting that the CTU has a unique organisational structure where, historically, faculties operated as autonomous entities. Today, these faculties are consolidated under a single entity led by the rectorate. However, the retained autonomy of faculties often results in IP rights remaining within the individual faculties unless otherwise specified. This decentralised approach to IP administration and commercialisation is limiting synergies within the university. The success of CTU's new transfer strategy, led by the rectorate, can overcome this barrier and foster confidence among the faculties in the new arrangement, potentially leading to more productive commercialisation outcomes.

Regarding entrepreneurial education, the CTU faces challenges as it is considered to have a relatively low level of emphasis. Compared to many universities, CTU does not include a dedicated faculty of business and economics within its technical framework. Historically, this faculty was separated from the CTU and founded as the University of Economics in Prague in 1953. While the Masaryk Institute of Advanced Studies was established to provide business education for CTU students, it remains distinct from technical studies. As a result, individual faculties try to incorporate some elements of business education into their curricula but with a limited impact on entrepreneurial education.

3.1.2. The technology

Lead scientists from the Faculty of Civil Engineering, including the interviewee Prof. R. Sovják, conducted a long-term research on UHPC. This research culminated in developing portable and ballistically-proven universal building blocks designed for mobile protection systems, featuring a rapid, manual assembly process. The concept emerged through collaboration with the Czech police and underwent testing with the Czech army [24]. Notably, the technology achieved a ballistic classification of FB4 by EN 1522, signifying its suitability for structures requiring resistance against extreme loads, such as explosions, gunfire, or impacts [25]. This innovative system caters to a diverse clientele, including police forces, armies, security units, operators of shooting ranges. The novelty of this research is twofold, stemming from the unique properties of the ballistic-proof UHPC material and the application of a manually stackable mobile system.

The Technology Agency of the Czech Republic (TAČR) was pivotal in supporting the initial research by providing financial assistance through a grant. This grant was awarded under the project titled "Starting of the Industrial Production Process of Protective Barriers Made of high-performance Concrete" [26]. The partner of the CTU project was the company KŠ PREFA s.r.o., a concrete manufacturer for construction elements. In 2019, the research team was honoured with the Willenberg Foundation medal in recognition of their contribution in supporting the defence of the Czech Republic through advancements in engineering or construction [27].

3.1.3. The transfer

A team of four researchers, who were instrumental in developing the innovative material solution and its application, joined forces with an external member to establish the start-up, MOB-Bars s.r.o. (MOB-Bars), in August 2016. This venture was set in motion by the patent filed by the CTU in February 2016, titled "A ballistic panel for special checkpoints, special fortified stands, mobile city barriers, and any other similar structures, specially made by using fiber-reinforced or rebar-reinforced cementitious composites for its production" [28]. The patent was filed for the region of the Czech Republic prior to the formation of MOB-Bars.

In November 2016, MOB-Bars entered a prepurchase agreement with CTU regarding the pending patent. Subsequently, in February 2017, patents were filed in the EU, USA, and Morocco. After extensive negotiations, the purchase of the pending patent was finalised in January 2018. These negotiations were conducted directly between the researchers and CTU. Notably, the patents for the Czech Republic, EU, USA, and Morocco were granted only following the transfer of the right to the pending patents.

The entrepreneurs financed the start-up costs, including the acquisition of the pending patents, through their own equity. MOB-Bars commenced its operations with the support of INQBAY, the university's incubator, which initially offered office space to entrepreneurs and provided startup advice during the company's early stages. The journey from the company's inception to the signing of the purchase agreement for the pending patent spanned approximately 14 months, during which extensive negotiations with the CTU took place. INQBAY's assistance was primarily centred on handling administrative matters in the start-up process and offering affordable office space.

The researchers have maintained their positions within the university while pursuing ongoing research on UHPC and other advanced materials. Over time, MOB-Bars has evolved into a stable enterprise, although its performance has remained modest. The company expanded its product portfolio beyond mobile systems to encompass solutions designed for the deceleration of vehicles and high-strength curb solutions. Furthermore, MOB-Bars offers tailored forms (i.e. high-resistant curbs, structures slowing down vehicles) of UHPC and extends consulting services to enhance the structural resilience of various constructions.

3.2. Technische Universität Dresden

3.2.1. Transfer capacity, strategy, and environment at TUD

KTT at TUD is well-established and followed concept known as the Dresden Model, which revolves around an independent private entity affiliated with the TUD, TUDAG AG (TUDAG), founded in 2000 [29–31]. TUDAG operates as a venture capitalist and is dedicated to advancing transfer, innovation, and education at the TUD, particularly by facilitating the transition of research from academia to the private sector. The exclusive shareholder of TUDAG is the Society of Friends and Sponsors of TU Dresden (Gesellschaft von Freunden und Förderern der TU Dresden e.V., or GFF). The GFF is a non-profit organisation separate from the TUD, and its statutes stipulate that the rector of the TUD is a member of the GFF's board. The supervisory board of TUDAG includes the chairman of GFF, the rector and chancellor of TUD, ensuring that TUDAG's interests align with those of TUD [29, 30]. Currently, TUDAG generates approximately €60 million in turnover and employs around 600 individuals, with 200 engaged in start-ups. Profits from TUDAG are allocated to the GFF and subsequently benefit the TUD through scholarships and other financial support for the public good.

TUDAG operates across three primary business segments: education, involving advanced academic and language training; transfer through R&D services, advisory, and project management; and entrepreneurship, focusing on start-up development and support. More than 30 entities associated with TUDAG are actively engaged in KTT for the university. The Society for Knowledge and Technology Transfer (Gesellschaft für Wissens- und Technologietransfer, or GWT), a part of TUDAG, stands as one of Germany's largest privately organised, university-related technology transfer service providers, primarily focusing on contract research.

A new approach to enhance and consolidate commercialisation efforts at the TUD started in 2023 with the establishment of TUD|excite, an excellence centre dedicated to innovation, transfer, and entrepreneurship within the university. This centre aligns with the mission of achieving excellence in these areas, consisting of six areas of competency, including units focused on innovation, patents, talents, facilitation, the Futurelab, and start-up advisory [31]. It is an effort to keep the transfer activities of the TUD under the control of the TUD. The centre aims to streamline the transfer process while boosting synergies and expanding its services.

Prof. Curbach [10] states that at the TUD, the rectorate is driving the topic of entrepreneurship; however, it is not perceived and practiced in the same way by all faculties and employees. Entrepreneurial education is, however, available at the TUD thanks to the Faculty of Business and Economics, where business skills, including entrepreneurship, are fostered.

3.2.2. The technology

Researching TRC is a deep-rooted tradition at the TUD. In 1994, pioneering efforts were initiated to incorporate alkali-resistant fiberglass into concrete, a composition that initially faced scepticism from experts. In 1999, the TUD, in collaboration with RWTH Aachen, launched the Collaborative Research Centre 528, focusing on textile reinforcements for structural reinforcement and repair. The aim was to develop alternatives to steel-reinforced concrete susceptible to corrosion. The project received funding from the German Research Foundation (DFG). TUD's specific focus was on repairing and reinforcing concrete structures using textile-reinforced concrete, a focus that continues to this day [10]. Carbon concrete emerged as a significant material as an outcome of this research partnership. Carbon concrete is defined as "a composite material made of concrete and non-metallic reinforcement composed of carbon or carbon fibres" [32].

A monumental milestone in this research journey occurred when TUD's scientists Offermann, Curbach, and Cherif were honoured with the prestigious German Future Prize in 2016 by the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, or BMBF) [33]. Subsequently, the BAMF funded the C3-Carbon Concrete Composite project consortium as part of the Zwanzig20-Partnership for Innovation program, with a budget of up to €45 million. This funding led to establishing the research group C3, which has since evolved into an association for carbon concrete professionals, boasting over 120 members. In 2021, the financial support of the consortium culminated in realising the world's first structure, the CUBE, built exclusively of concrete reinforced by non-metallic materials [34]. The CUBE is a distinctive architectural structure completed on the TUD campus as a demonstrative exhibit showcasing this innovative material's various facets, forms, and applications. Notably, the CUBE features a uniquely twisted roof seamlessly transitioning into a wall, exemplifying the expanded possibilities of architectural design offered by carbon concrete. Advocates of carbon concrete praise it as lighter, stronger, and environmentally friendlier, with research suggesting that it significantly outperforms traditional steel-reinforced concrete in terms of longevity and making it a more sustainable and climate-friendly alternative. Additional advantages include reduced maintenance costs, a remarkable reduction in resource usage by up to 80 %, and a notable reduction in CO_2 emissions by up to 50 % [32]. Three decades of dedicated research have yielded a ground breaking innovation with the potential to instigate the much-needed paradigm shift in the construction industry.

3.2.3. The transfer

Leveraging their extensive expertise in TRC, which has been accumulated over decades, the Faculty of Civil Engineering at the TUD devised a strategy to transform their research into a profitable venture by establishing a spin-out. In 2014, the engineering firm CARBOCON GmbH (CARBOCON) was founded by three primary stakeholders: two TUD professors and TUDAG. TUDAG, functioning as a transfer intermediary, played an active role in supporting the venture from its inception and through its growth phases to the present day. The transition, encompassing company formation and formulating relevant contracts, transpired over approximately six months. During this period, TUDAG applied, through DIBt (German Institute for Building Technology), to approve a carbon concrete process. This process was officially registered under the registration number Z-31.10-182, and it was marketed as CARBOrefit®.

In response to the increasing interest in carbon concrete and the company's expansion, the executive board of CARBOCON was enlarged in 2017 with two new members [10]. Today, CARBOCON has evolved into a well-established and leading service provider in carbon concrete. The company serves as both an advisory entity and a distributor of licenses for in-house developed and accredited carbon concrete products. CARBOCON collaborates with the TUD in the research and development of new product lines related to carbon concrete. The company maintains close connections with the TUD; most of its employees originate from the TUD Faculty of Civil Engineering. Due to the extensive research and ongoing dissemination of research findings over the years, securing IP in the form of patents was not possible.

This study explores the mechanisms and challenges of KTT in construction, focusing on how researchers navigate these factors to bridge the gap between the academic innovation and industrial application. Specifically, three research questions underline the study. Firstly, the study aimed to investigate what role institutional KTT infrastructures involving intermediaries, such as KTTOs, play in the process of transfer. Secondly, the study intended to explore how IP rights are typically managed during the transfer. Lastly, the study should shed light on how the practical implementation of KTT aligns with the theoretical linear KTT process. From these questions, the authors developed three hypotheses:

- **Hypothesis 1:** The involvement of KTT intermediaries significantly improves the efficiency and speed of the KTT process.
- **Hypothesis 2:** The role of IP rights is not a critical determinant of successful KTT outcomes.
- **Hypothesis 3:** The application of a linear KTT model is infrequent and largely context-dependent, reflecting variations across different fields and organisational environments.

These hypotheses present the focus of this qualitative work.

4. Methodology

The research design used in this study adheres to the principles of a qualitative approach. More specifically, this work aligns with the guidelines of a case study, which, as defined by Crowe et al. [35], is a research methodology designed to provide a comprehensive and multidimensional insight into a complex issue within its real-world context. They further distinguish between three types of case studies: the intrinsic, the instrumental, and the collective approach. During this case study, the following steps, as recommended by Crowe et al. [35], were undertaken.

The first step was to define the case selection criteria. To align with the study's objective of examining the KTT process of an academic invention, the selected cases had to meet specific parameters. Each case had to have undergone the full KTT process, from initial research to commercialisation, ensuring a comprehensive analysis. The invention needed to represent novel research applicable to the construction sector, with a focus on hardware rather than software solutions. To maintain relevance, the KTT process must have taken place within the last ten years, reflecting contemporary industry practices.

Furthermore, key researchers had to demonstrate active involvement in the KTT process, outlining the steps taken to bring their innovation to the market. If an intermediary played a role, its function in facilitating the transfer had to be documented. The sequence of the KTT process, as well as considerations regarding IP rights, was also examined. Through the systematic analysis of these processes within leading academic institutions, this study provides valuable insights into how research-driven innovations transition from theory to practical application in the construction industry.

In the second step, the cases were selected. Focusing on a collaborative case study approach, multiple cases were chosen with the aim to examine more comprehensive insight into a particular topic [35]. The selected institutions with the case include the CTU, where the authors are pursuing their Ph.D., and the TUD, specialising in concrete research, and in collaboration with the CTU. At the CTU, a robust ongoing research effort focused on UHPC has yielded several practical applications. Having undergone a comprehensive transfer process, MOB-Bars is an innovative start-up sprung from the CTU, specialising in developing mobile safety barriers made from concrete composites. At the TUD, another prestigious case revolves around extensive research in the field of TRC, leading to the establishment of a spin-out entity known as CARBOCON. It has emerged as a prominent player in the planning and execution of construction projects involving TRC, particularly with a focus on carbon concrete.

Both cases under examination represent pioneering research efforts to address contemporary global challenges and indicate their respective institutions' activities.

In the third step, the data were collected. The research process unfolded in several distinct steps. First and foremost, a comprehensive literature review was conducted, focusing on KTT within the construction industry. Innovative in construction concepts, such as materials, prefabrication, modular construction, and 3D printing. KTT concepts in the construction industry were further reviewed. Simultaneously, the examination extended to scrutinise the existing transfer structures and capacities within the respective academic institutions, with the findings thoroughly documented.

In the next step, interviewees were carefully selected, focusing on key scientists directly involved in the research and KTT. After the initial contact and presentation of the study, interview appointments were scheduled to facilitate in-depth discussions.

A questionnaire was designed to collect relevant data, primarily through open-ended questions aimed at eliciting insightful responses. To ensure effective communication, the questionnaire was prepared in both English and German.

The interviews were conducted face-to-face in a semi-structured format, typically lasting between one and two hours. During these sessions, the authors took detailed written notes, occasionally following up with additional questions to validate and refine the collected data.

The final step involved analysing, interpreting, and reporting the case studies. Given the limited dataset and the nature of the two cases, the analysis began with separate documentation before proceeding to a comparative evaluation. To provide context, background information was gathered on the universities' transfer capacity, strategies, and institutional environments.

A detailed description of the technology was included, emphasising its novelty and distinctive characteristics. The transfer process was then examined, focusing on key parameters, such as the mode of transfer, formation process, support mechanisms provided by the KTT intermediary, and transfer duration.

Further assessment identified any anomalies or deviations from typical transfer processes, highlighting exceptional cases or significant findings. This comprehensive analysis ultimately led to the adoption of a theoretical framework to identify patterns and test the initial hypotheses of the study.

5. Results

The technology transfer process referred to earlier and depicted in Figure 1 defines the foundation of the KTT process analysis of the cases. In theory, it begins with research-driven innovation, followed by securing IP rights. The technology is then assessed for feasibility and market potential, leading to a commercialisation strategy through licensing or spin-offs. Industry collaboration and negotiations facilitate its transfer, after which the innovation is refined and adapted for practical use. Finally, the technology enters the market, where it is implemented and further optimised, ensuring a successful transition from the academia to industry.

The following section outlines the actual transfer process of both cases, accompanied by a graphic illustration of the actual steps taken. It becomes evident that neither of the cases has followed the linear path as proposed in the theoretical model.

5.1. CTU

The transfer process is characterised by the university selling the pending patent to the researchers, which occurred relatively early in the process. The university opted for a straightforward transaction involving the researchers purchasing the IP rights for a predetermined, fixed amount. This approach excluded the university's future income potential, such as licensing revenues or a minority stake in the start-up entity. The researchers chose this transfer model for its advantages, which included lower fees for acquiring the pending IP rights and the freedom to steer the start-up without external shareholder interference. The university's KTT incubator, INQBAY, played a central role by providing initial administrative support and office space, facilitating the transition into operating under the new entity. INQBAY's contribution is evident in its role in reducing the start-up's initial burden and expediting the process for new entrepreneurs.

One weakness associated with this transfer approach lies in the researchers' exposure to the financial risk of using their own capital. Opting for a licensing agreement with the CTU was not their preferred structure, and involving the CTU as a shareholder in the new entity was formally unfeasible at the time. Prior experiences with another spin-out (2006), where the CTU became a shareholder after a two-year formation process, proved an inefficient solution. Overcoming bureaucratic hurdles, such as forming agreements with the academic senate and rectorate, proved highly inefficient, in particular for the fast-moving sectors. A transfer model involving the CTU as a shareholder was deemed unfeasible at the time and in the context of increasingly shorter innovation cycles. However, with the establishment of CTU's transfer vehicle, ČVUT Tech s.r.o., a streamlined transfer process now allows the university to retain rights to university-generated IP.

At the time of the MOB-Bars formation, the transfer process could be considered the best choice for both the university and the entrepreneurial researchers. The university met its objectives to divest IP and promote university start-ups, while the researchers were free to make decisions that best suited their company. Prof. Sovják states that they chose not to take a li-

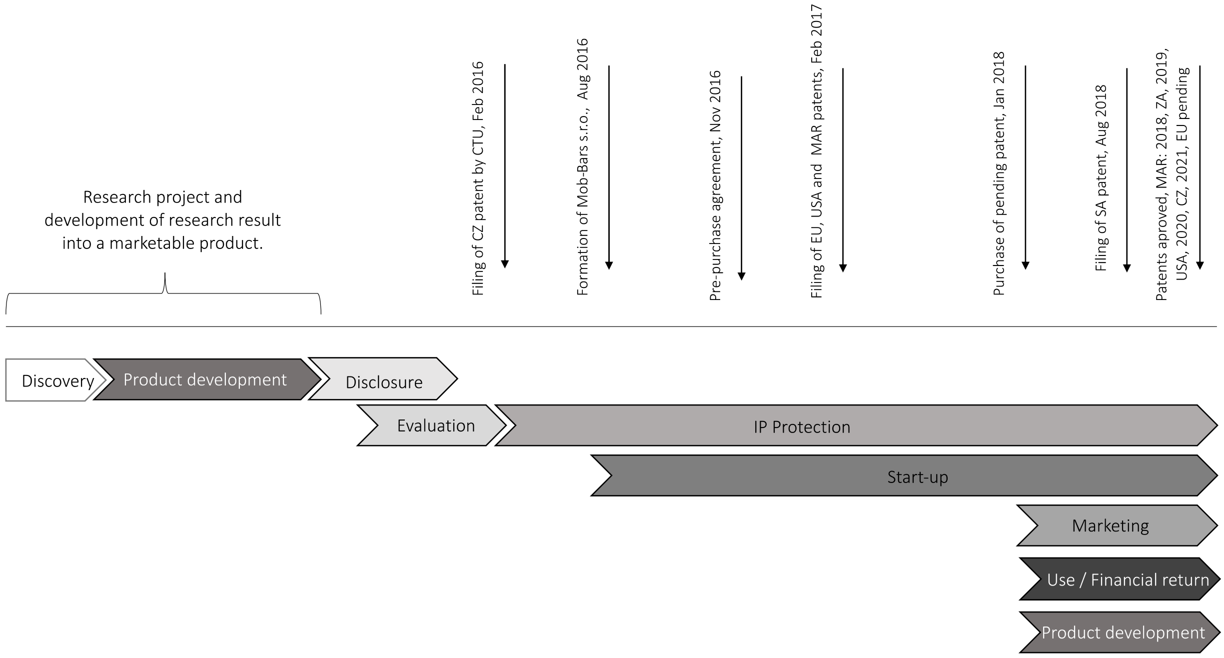

Figure 2. Technology transfer process of MOB-Bars.

cense because they wanted to have control over their invention. Given today's more comprehensive array of options, a different transfer model might have been considered. The extended negotiation period between the CTU and the start-up was due to non-standardised transfer procedures and uncertainties.

The researchers' long-term motivation involved retaining their positions within the university research team while participating in the start-up. At present, two founding members are primarily focused on managing the company while maintaining their roles within the university. The start-up chose to outsource manufacturing to an external party, the same entity with which the initial research was conducted.

When comparing the actual transfer process with the theoretical linear model (Figure 1), it becomes evident that the MOB-Bars' transfer model does not strictly adhere to the linear model's phases. In reality, these phases follow different timelines, occur partially in parallel, and even take place in different orders. For instance, the discovery of the novel material represented the initial step. However, the product development, and consequently the development of the mobile bar application, occurred before the disclosure and evaluation phase. The IP protection process, from filing patents to obtaining granted patents, extended over a significant period. This process involved filing patents at different times, with the initial patent application filed for the Czech Republic. While the university still held these pending IP rights, applications for the EU, USA, and Morocco took place one year later. A subsequent transfer of the pending patents occurred when another patent was filed for South Africa. The granting of patents occurred at varying times or is still pending. Simultaneously with the IP phase, the start-up phase began, encompassing company formation, the waiting period until the acquisition of the pending patent rights, and initial marketing and sales efforts. Further product development under the patented technology also continued. Figure 2 illustrates the MOB-Bars transfer process.

5.2. TUD

In the personal interview with Prof. Curbach, the Director of the Institute of Concrete Structures at the TUD's Faculty of Civil Engineering [10], it became evident that researchers at the TUD have a solid motivation to use the transfer vehicle provided by TUDAG when seeking to commercialise their inventions. In the case of the spin-out CARBOCON, TUDAG initially supplied all the essential administrative and management support and continued to offer long-term assistance. The decision to grant shares to TUDAG in the new entity was not considered a drawback for the researchers, but rather an intelligent business decision.

While there may appear to be a conflict of interest when leading researchers create spin-outs, in the case of CARBOCON, this approach is viewed as a beneficial and effective means of transfer, actively encouraged by the TUD. Prof. Curbach states that most professors in civil engineering have their own engineering offices. This is a concept requested by the university to help bring research to the market. This arrangement offers several advantages, such as providing the market access to new technologies developed within the institutes and professionals already trained in specialised fields. It also facilitates internships and job opportunities for students. According to Prof. Dr. Curbach, involving researchers and professors in commercial entities supports the ecosystem, particularly for TRC.

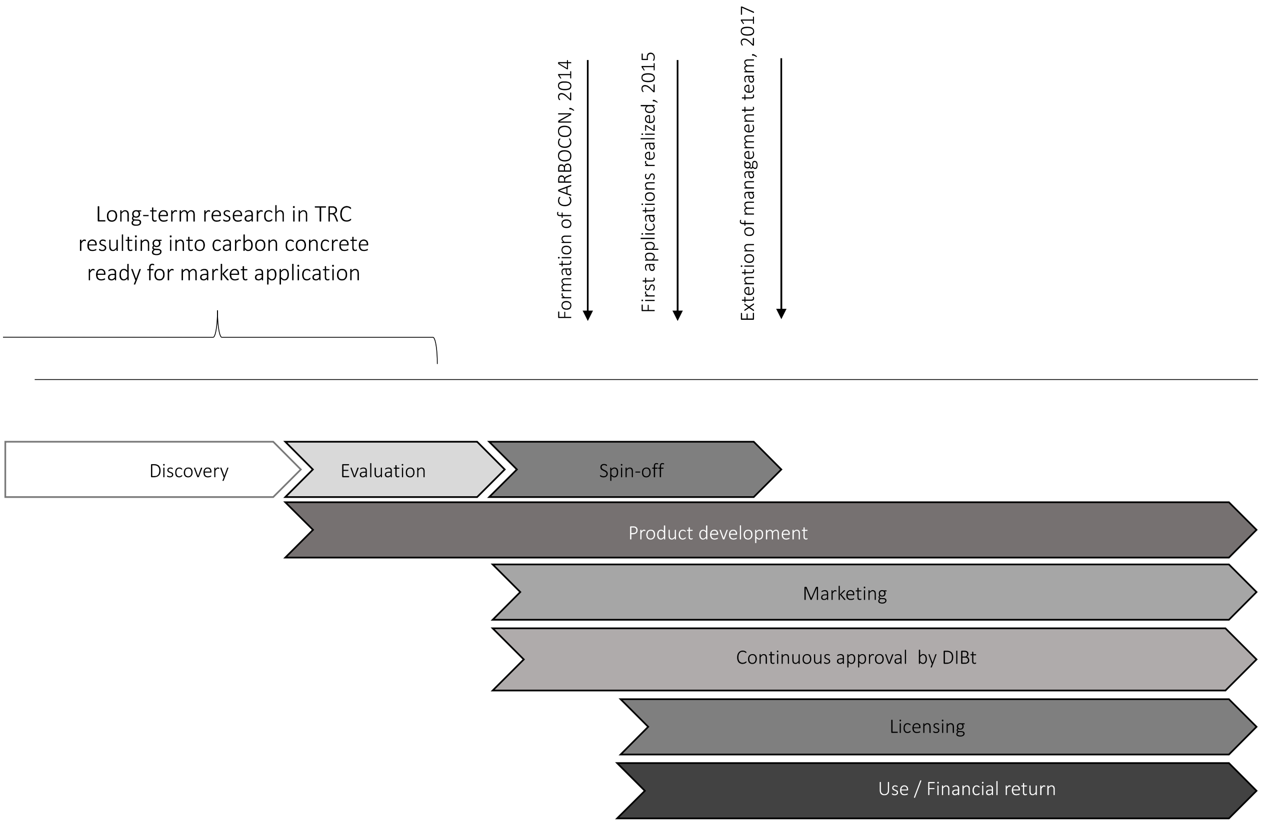

Figure 3. Technology transfer process of CARBOCON.

The transfer approach benefits both the researchers and the TUD. Researchers can continue to focus on the subject matter they are well-versed in while leaving administrative and management responsibilities to competent bodies like TUDAG. However, TUD retains an indirect stake in the spin-out, reaping the benefits of commercial income and the ability to transfer expertise in the form of graduates to the industry while also providing internship opportunities for its students.

The CARBOCON transfer model also deviates from the theoretical model presented in Figure 1. It offers a model similar to MOB-Bars, where the order of phases is altered and phases occur in parallel rather than sequentially.

This model stands out as it does not rely on traditional IP protection through patents. Instead, an alternative form of protection was established via the DIBt-registered approval process for CARBOrefit®. This certification enables CARBOCON to license its technology based on a square-meter area where the procedure is applied. This is providing a scalable revenue model. Unlike patents, this approval must be periodically renewed, ensuring compliance with evolving industry standards.

Notably, a distinct disclosure phase was absent in the CARBOCON's transfer process, as research findings were continuously published and no trade secrets were formally registered. Despite the lack of patent protection, the company successfully monetised its expertise through licensing agreements, demonstrating that regulatory certification can serve as a viable alternative to conventional IP strategies.

Product development remains an ongoing process, with new solutions continuously being introduced for DIBt certification and licensing expansion. Additionally, tacit knowledge transfer plays a significant role in the CARBOCON's business model, with consulting services providing an additional channel for disseminating expertise and supporting industry adoption. Figure 3 illustrates the transfer process.

The overview in Table 1 provides a concise summary of the compared cases, highlighting their distinctions and commonalities. While several similarities are present, such as transfer through company formation, type of company, researchers self-funding the transfer, and researchers maintaining their position within the university, the differences are primarily observed in the standardisation of support functions and contractual regulations provided by the institutions for fostering the start-up or spin-out.

Both cases exhibit both similarities and disparities in their approaches to KTT. The disparities primarily stem from the institutional structure during the transfer process. CTU's INQBAY is acting as a KTT intermediary, offering advisory support for administrative start-up assistance on a short-term basis. At the same time, the TUD case embraced a strategic venture capitalist role and maintained a shareholding position in the spin-out long-term. TUD's more pronounced

Institution	**CTU**	**TUD**
Location	Prague, Czech Republic	Dresden, Germany
Name of entity	MOB-Bars s.r.o.	Carbocon GmbH
Form of Transfer	Start-up	Spin-out
Invention and application	• Ballistic proven lightweight UHPC protection wall for manual manipulation under ballistic classification FB4 according to EN 1522 • UHPC consultancy services	• Project management, planning, and consultancy for construction projects involving carbon concrete • CARBOrefit®, a reinforcement solution • DistTEX, spacers for textile concrete and carbon concrete or textile structures and reinforcements
KTT support used	INQBAY: incubator and start-up advisor of the CTU; supported the foundation and initial office space in the form of non-financial contributions	TUDAG: a private company indirectly linked to TUD and venture capitalist; shareholders in the spin-out, taking care of administrative aspects of the formation and management of the entity.
Co-developed with	Czech Police, Czech Army, and a partner from the industry of construction materials	Various industrial partners from the construction industry and other research partners
Timing	14 months (from company formation to obtaining (pending) patent application)	6 months (company formation process to start of operation)
Founded	2016	2014
Start of operations	2018 (Delay due to negotiations with the university and further application of patents)	2014
Shareholders	Researchers and one external person	Researchers and TUDAG (2 staff joint later)
Research funded by	TAČR	Long-term research funded by several programmes incl. DFG, BMBF (programme Zwanzig20)
IP rights	Start-up purchased the rights from the CTU to patent applications for different markets. CTU is no longer involved, however, initial researchers and entrepreneurs remain within CTU research teams.	No patent possible due to previous publications. Approval was given by the German Institute for Building Technology (DIBt) for specific products or procedures to be licensed
Revenue generation	• Sale of modules and newly developed products manufactured by an external partner. • Consultancy services	• Advisory service through the engineering and planning office • Licensing in the form of approved/licensed products (CARBOrefit® and DistTEX)
Target market	Police, army, security forces and operators of shooting ranges, operators of roads and parking grounds	A non-clearly defined and wide array of customers ranging from engineering offices to architects, building companies, state institutes
Milestones and awards	Recipient of the Willenberg Foundation Medal (2019)	CUBE: carbon concrete structure without steel reinforcement CARBOCON: Top Innovator 2021 CARBOrefit®: German Raw Material Efficiency Award 2022 CARBOCON: wins audience award of the DGNB Sustainability Challenge 2023

Table 1. Summary of transfer highlights.

KTT structure led to enduring benefits for the university and the company's success, underlining the importance of a robust university KTT environment in promoting entrepreneurial initiatives.

Commonalities are also evident in several aspects. Firstly, both cases adopted the same legal entity structure, opting for a limited liability company managed by one of the founders. Additionally, there was an apparent inclination among the scientists to stay within their university positions, indicating a reluctance to depart from their established research environments in part because of the uncertainties of the start-up environment but also due to the continued interest in a research career. Launching a business outside the university was considered a supplementary endeavour rather than a primary profession. Third-party financing was not favoured in either case, leaving limited resources for business expansion. Both parties perceived involving external financing as risky and, in their specific circumstances, unnecessary. Further research could shed light on this reluctance to external funding and its impact on the management team and business success.

MOB-Bars was a self-funded start-up with limited financial resources for substantial advancements. Third-party financing remains undesired to date. The promising target market, which initially included the Czech police force and Czech Army, with whom the invention was developed and tested, needed to be revised for the company's growth. The anticipated interest in protective barriers was limited. Thus, a significant challenge for the start-up was diversifying its product portfolio. This hurdle has been overcome by the introduction of alternative systems, such as solutions for decelerating and stopping vehicles. Overall, MOB-Bars' primary challenge has been and continues to be the marketing and sales of its innovative products. Licensing the technology to established companies, especially in foreign markets with significant shipping costs, is a suitable approach. Regarding industry standards, the product met the necessary ballistic norms based on material tests and encountered only minor challenges.

CARBOCON faces the challenge of the absence of industry standards for textile-reinforced concrete in construction. Germany maintains strict safety requirements for construction, and approval for using carbon concrete material remains necessary on a case-by-case basis unless DIBt-certified components are used. Lacking IP rights, CARBOCON had to tackle the challenge of certifying construction components with DIBt, where components or processes must receive an approval. Certifying the first carbon concrete construction element took five years, an extended duration for ambitious and innovative construction entrepreneurs. Currently, 20 accreditations for carbon concrete elements are registered in the German market, including Carborefit® by CARBOCON, with more components in development.

Establishing the spin-out with TUDAG's involvement was not seen as an obstacle but rather a benefit. Like MOB-Bars, CARBOCON was also self-financed by its founders, as third-party financing was not sought. TUDAG's involvement reduced the initial start-up costs and time. The CUBE project, a publicly funded initiative showcasing the possibilities of carbon concrete, played a pivotal role in marketing the technology. This involved producing marketing materials such as brochures and a book detailing the history and development of the CUBE, along with various commercial and scientific articles, to bring CARBOCON's work to an international audience.

6. Discussion

6.1. The role of KTT intermediaries

The analysis of the two cases reveals important insights into the KTT process at the institutions involved. The following discussion seeks to address the research questions and hypotheses raised at the beginning of the paper.

The study demonstrates that a more developed and structured institutional approach to KTT positively impacts the willingness for collaborative KTT between the researcher and the institution. The TUD followed a well-established, structured, and strategic KTT model through the TUDAG, acting as a venture capitalist and administrator for spin-outs like CARBOCON. This structured framework facilitated a smoother transition from research to commercialisation, ensuring access to managerial expertise, funding mechanisms, and a streamlined transfer process. The collaboration with TUDAG was structured as a long-term partnership. This encourages researchers to participate in the transfer intentions of their research.

In contrast, the CTU lacked a similarly established framework at the time of the MOB-Bars start-up and experienced a lack of trust in the KTT framework. Researchers navigated the KTT process largely on their own, preferring a company formation without the future involvement of the institution. They relied on INQBAY for some administrative support and office space on a short-term basis. The lack of standardised KTT processes at the CTU led to extended negotiations over patent rights and IP ownership, delaying the commercialisation. It is assumed that the absence of clear guidelines or regulations for researchers simultaneously acting as both entrepreneurs and academics may have created potential conflicts of interest among peers, resulting in little participation in transfer activities of researchers in general.

This comparison suggests that a well-developed and trusted KTT infrastructure involving intermediaries plays a crucial role in accelerating technology commercialisation not just for individual cases but also to drive the interest and realisation of transfer among the research community overall. Sexton and Barrett [12] emphasise that the absorptive capacity of smaller construction firms can be improved significantly when supported by institutional frameworks that facilitate the transfer of technology and knowledge. Universities that proactively establish robust transfer mechanisms, provide intermediary support, and offer clear pathways for success in transfer are more likely to foster innovation. The case of CTU's recent establishment of ČVUT Tech s.r.o. as a formal transfer vehicle in connection with the newly aligned KTT strategy may mark a shift toward a more structured approach, which could be beneficial for future start-ups emerging from the CTU.

Hypothesis 1: The involvement of KTT intermediaries significantly improves the efficiency and the speed of the KTT process, can be confirmed. This hypothesis is supported by evidence showing that intermediaries not only streamline and accelerate the transfer but also allow founding teams to focus on their core competencies. Cases where KTT intermediaries played pivotal roles highlight their value in facilitating smoother transfers. Furthermore, the more sophisticated the transfer models employed by institutions and their intermediaries (e.g. TUDAG), the more efficient and effective the overall transfer process becomes.

6.2. The role of IP strategies in the KTT process

IP strategies are often considered crucial in the KTT process. However, this study demonstrates that patenting is not always a prerequisite for a successful commercialisation. For instance, MOB-Bars' startup business model was based on acquiring pending patent rights without the guarantee of securing the final patent. In contrast, CARBOCON's spin-out did not rely on patent protection at all. Instead, it focused on know-how consultation, securing certification from the German Institute for Construction Technology (DIBt), and generating revenue through licensing its carbon concrete solutions under the CARBOrefit® brand.

An evaluation of these two approaches suggests that alternative IP strategies – such as regulatory certifications, know-how licensing, and trade secrets – can be equally effective in bringing new technologies to market. This is particularly relevant in cases where patenting is not feasible due to prior publications, as seen with CARBOCON.

These findings align with the broader understanding of technology transfer models. Wahab [17] and Bogahawatte [18] argue that traditional IP-centric approaches may not always be the most effective, especially in industries like construction where practical applications, certifications, and know-how can be more valuable than the patents. The knowledge utilisation model emphasises the communication between technology providers and users, which aligns with CARBOCON's reliance on certification and consultancy.

Hypothesis 2: The role of IP rights is not a critical determinant of successful KTT outcomes.

This hypothesis is supported by the findings of this study. While IP rights, whether in the form of patents or certified products, were essential in shaping the business models of these new companies, their presence was not a strict prerequisite during the initial company formation phase. The success of both MOB-Bars and CARBOCON illustrates that flexible and diversified IP strategies can lead to an effective commercialisation.

Future KTT research should explore how universities and spin-outs can optimise non-traditional IP protection strategies. Approaches such as branding, standardisation, and exclusive licensing agreements may serve as viable alternatives to patent-centric models, offering new pathways for commercialisation of technology in varying regulatory and market contexts.

6.3. Linearity of transfer model

At the CTU, the KTT process was managed on a case-by-case basis, whereas at the TUD, a standardised process was implemented, resulting in a shorter overall transfer duration. However, in both cases, the traditional linear transfer model was not strictly followed. Instead, processes often overlapped and occurred in parallel, with certain phases taking longer than others. The sequence of steps deviated from the theoretical model, and some phases were either omitted or merged, reflecting the flexible nature of real-world transfers.

Contextual factors played a pivotal role in shaping these processes. The nature of the invention, industry standards, and certification requirements were significant determinants. Additionally, the level of institutional KTT support influenced the process. For example, when an institution actively participates in a spin-out and assumes responsibility for the commercialisation, the process differs markedly from cases where the institution simply sells the invention, leaving entrepreneurial researchers to navigate the commercialisation independently.

The duration and complexity of IP protection also affected the transfer timeline. Prolonged IP approval processes can delay commercialisation, necessitating a parallel progress in other stages or the early completion of certain phases. Furthermore, securing commercial partnerships early in the process can accelerate market introduction, highlighting the interplay of various factors in the transfer timeline.

Ozorhon et al. [13] emphasise that construction innovation often occurs at the project level, where dynamic interactions between stakeholders shape the transfer process. Uusitalo and Lavikka [14] further argue that the construction industry's unique characteristics, such as project specificity and regulatory constraints, need non-linear, flexible KTT models. This aligns with the findings of this study, where both the MOB-Bars and CARBOCON deviated from the linear KTT model.

Moreover, emerging technologies like 3D printing and contour crafting add another layer of complexity to KTT in construction. Akhnoukh [15] highlights the transformative potential of contour crafting, while El-Sayegh [16] focuses on the challenges and risks associated with 3D printing in construction. These technologies require adaptable transfer models that can accommodate rapid technological advancements and changing industry standards.

In conclusion, while the linear transfer model provides a useful framework for understanding the steps involved in KTT, it does not accurately reflect the dynamic, nonlinear, and adaptable nature of the process in practice. Each transfer is influenced by a unique combination of contextual, institutional, and technological factors, resulting in varied pathways to commercialisation.

Hypothesis 3: The application of a linear KTT model is infrequent and largely context-dependent, reflecting variations across different fields and organisational environments.

This hypothesis is supported by the evidence from the case studies, which illustrate the flexible, iterative nature of KTT processes in diverse institutional and industrial contexts.

6.4. Implications for future research and practice

The findings of this study highlight several implications for future research and practice in KTT within the construction industry. While there is extensive research on drivers and barriers to KTT, there is a need to further investigate how different institutional environments influence the willingness of researchers to engage in commercialisation activities, specifically in the construction sector, where investments in non-ICT-related technology are high. Understanding the motivations and barriers faced by researchers can help institutions design more effective KTT frameworks.

Second, future research should explore the role of alternative IP strategies in other sectors, beyond construction, to assess their broader applicability. Comparative studies across industries could provide valuable insights into the effectiveness of non-traditional IP protection mechanisms.

Finally, there is a need for more in-depth studies on the impact of emerging technologies on KTT processes. Technologies like 3D printing represent significant shifts in construction practices, and understanding how these innovations affect the knowledge transfer can inform the development of more adaptive and resilient KTT models.

In practice, universities and policymakers should prioritise the creation of flexible, supportive environments that encourage innovation and KTT. By recognising the diverse pathways through which knowledge and technology can be commercialised, institutions can better support researchers and entrepreneurs in bringing their innovations to market.

7. Conclusion

In today's industrial age, the need to innovate the construction industry not only from a building process point of view, but also from a materials and technology point of view, needs to see more practical examples of innovation. This study explored the dynamics of KTT in the construction sector through two case studies involving technologies of specialised concrete, namely UHPC at the CTU and TRC at the TUD. The comparative analysis of these cases offers valuable insights into the roles of KTT intermediaries, IP strategies, and the practical application of linear transfer models in the construction sector.

First, the study confirms that the involvement of KTT intermediaries significantly improves the efficiency and speed of the transfer process. A structured and strategic support provided by the institution facilitates a smooth and expedited transition from research to commercialisation, allowing researchers to focus on their core competencies. In contrast, the more fragmented KTT support can lead to extended negotiations between researchers and the institution in commercialisation and IP matters and delays, highlighting the importance of robust institutional frameworks for effective technology transfer.

Second, the findings demonstrate that IP rights are not always critical determinants of successful KTT outcomes. While MOB-Bars relied on acquiring pending patent rights, CARBOCON successfully commercialised its technology without patent protection, instead leveraging regulatory certification (DIBt) and know-how licensing. These cases illustrate that alternative IP strategies, such as certifications, trade secrets, and licensing, can be equally effective, particularly in contexts where patenting is infeasible.

Third, the study reveals that the traditional linear KTT model does not accurately reflect real-world transfer processes. Both case studies showed that phases of the transfer process often overlapped, occurred in parallel, or were omitted altogether, depending on contextual factors, such as the nature of the invention, regulatory requirements, and the level of institutional support. This underscores the need for flexible, adaptable transfer models that account for the complexities of different technological, organisational, and industrial environments.

In conclusion, this research highlights the multifaceted nature of KTT in construction engineering and calls for a more nuanced understanding of how institutional structures, IP strategies, and process models interact in practice. The findings suggest that universities and spin-outs can benefit from embracing diverse, non-linear approaches to KTT, moving beyond patent-centric models, and leveraging a broader array of commercialisation strategies. Future research should continue to explore how these alternative pathways can be optimised to bridge the gap between the academic innovation and industrial application, particularly in sectors like construction that have traditionally been slow to adopt new technologies.

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