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**Factors Inhibiting the Adoption of 3D Concrete Printing
in German Residential Construction**

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Abbreviations

3D concrete printing	<i>3DCP</i>
Additive Construction	<i>AC</i>
Additive manufacturing	<i>AM</i>
Additive Manufacturing for Construction	<i>AMC</i>
Arithmetic Mean	\bar{x}
Innovation Resistance Theory	<i>IRT</i>
Qualitative content analysis	<i>QCA</i>
Research and Development	<i>R&D</i>
<i>Research Question</i>	<i>RQ</i>
Return on investment	<i>ROI</i>
Standard deviation	σ
<i>Sub-Research Question</i>	<i>SRQ</i>
Thematic analysis.....	<i>TA</i>

Abstract

This study investigates the barriers to the adoption of 3D concrete printing (3DCP) in residential construction by combining insights from a systematic literature review (SLR) with primary qualitative research. The findings identify regulatory uncertainty, financial constraints, and technological skepticism as the most significant challenges, underscoring the gap between theoretical advancements and industry practices. Furthermore, the study highlights a notable absence of research addressing the German market, emphasizing the need for region-specific investigations to understand contextual adoption dynamics better.

The systematic literature review (SLR) adhered to PRISMA guidelines, screening 758 papers, selecting 89 for further evaluation, and conducting a full-text review of 77, ultimately identifying 48 relevant studies. The analysis categorized common themes and findings within the Innovation Resistance Theory (IRT) framework. A survey of industry professionals provided primary qualitative data to enhance these insights, enabling a comparative assessment of theoretical and practical barriers to 3DCP adoption.

Bureaucratic rigidity, industry inertia, and structural fragmentation significantly impede 3DCP adoption in Germany. Additionally, skepticism persists regarding its long-term economic viability and transformative potential. Overcoming these challenges requires greater regulatory transparency, targeted financial incentives, workforce development initiatives, and market-specific pilot projects. This study advances the discourse on technology diffusion and construction sector modernization.

Keywords: 3D concrete printing, Innovation Resistance Theory, Adoption barriers, Construction

1 Introduction

The construction sector plays a crucial role in shaping our built environment, yet it is slow to adopt more innovative methods, technologies, and tools. The construction sector in Germany is at a critical juncture, divided between traditional practices and the growing need for innovative solutions. Despite reports in real estate magazines and newspapers hailing 3D concrete printing (3DCP) as an innovative, resource-efficient, and potentially transformative technology, its adoption in the German residential construction market remains remarkably slow in comparison to the manufacturing sector. The construction sector, historically characterized by fragmented structures and low investment in research and development (Aouad et al., 2010; Ozorhon et al., 2010), shows a persistent reluctance towards innovative methods. Although some companies have begun to shift their practices in recent years by embracing digitalization and automation (Pezzei, 2023), the overarching adoption trend in the German construction sector remains hesitant, a reflection of a sector deeply rooted in conservative practices and heavily regulated by complex norms (Oesterreich & Teuteberg, 2016). Despite being a critical sector, it remains one of the least digitized industries, resulting in slow technological adoption that further impairs productivity, efficiency, and innovation (Turkyilmaz et al., 2024; Witthoeft et al., 2017) even though digital transformation could significantly improve the sector's quality, safety, sustainability, productivity, and competitiveness.

As construction methodologies and performance benchmarks stagnate (Oesterreich & Teuteberg, 2016), stakeholders face a multitude of challenges: the chronic shortage of skilled labor, increasing sustainability requirements, persistent cost pressures, and lengthy bureaucratic procedures (Lojanica et al., 2018; Olick, 2022). The urgency to innovate has rarely been more evident. In this context, 3DCP, in which concrete is extruded in layers to produce large-scale building elements, emerges as a promising method to industrialize construction processes. 3D printing enables the creation of customizable designs and complex geometries through the additive layering of materials based on digital models. By leveraging digital control and automation, 3DCP has the potential to streamline repetitive tasks, reduce reliance on manual labor, and turn construction sites into more controlled, factory-like environments (Gipperich, 2024; Lange, 2024). The utilization of the technology can reduce design errors and development cycles. Allowing for quick design changes and customer co-creation tailored to their specific requirements. However, despite these touted advantages, the technology has not gained the expected initial traction.

Understanding this paradox of why a seemingly transformative technology struggles to gain widespread adoption is the focus of this thesis. It will investigate the acceptance and diffusion

of 3DCP within the German residential market through technology acceptance theories, seeking to elucidate whether 3DCP is a promising solution for residential construction.

In doing so, the thesis not only questions the readiness of the German construction sector for a technology as revolutionary as 3DCP but also reflects on the broader inertia that hampers the acceptance of this technology in the sector. By illuminating the interplay of technical, regulatory, economic, and cultural factors, this research will help shape the narrative on how to forge a more dynamic, future-oriented approach to residential construction in Germany.

1.1 Problem Statement

Like its global counterparts, the German residential construction sector acknowledges the strategic importance of digitizing its operational processes (Aouad et al., 2010). Nevertheless, a gap remains between digital transformation discussions and implementation (Fraunhofer-Informationszentrum Raum und Bau IRB, 2024; PwC, 2024). Amplifying this discrepancy is the construction industry's fragmented, project-based structure, where temporary collaborations and short-term contracts diminish incentives for long-term research and development (Barbosa et al., 2017). Over the past few years, construction projects have grown increasingly complex, with rising budgets, tighter schedules, and higher quality standards (Shafei et al., 2022). However, despite a longstanding trend toward digitization, the sector remains in an early, scattered phase of digital adoption (Shafei et al., 2022). However, the number of publications on construction technologies is growing. Nevertheless, there is a lack of research on technology adoption and resistance that is highly relevant to academic research and management practices in the sector (Talke & Heidenreich, 2014).

Compounding this are the characteristics of the construction sector itself, including project complexity, uncertainty of external conditions, a fragmented supply chain, and entrenched short-term thinking that breed reluctance to embrace new technologies (Shafei et al., 2022). As a result, the industry-wide adoption of cutting-edge technologies such as Building Information Modeling (BIM), robotics, and 3DCP continues to lag behind that of other industries, contributing to persistently low labor productivity and slow innovation adoption (Osorio-Gómez et al., 2024; PwC, 2024; Witthoeft et al., 2017). 3DCP, in particular, has been touted as a tool capable of reshaping traditional design and construction processes by automating labor-intensive tasks and improving resource efficiency (Witthoeft et al., 2017). Despite its projected potential, mainstream adoption of 3DCP and market penetration in Germany remains limited (Gipperich, 2024; Oesterreich & Teuteberg, 2016). The reasons for this shortfall, whether technical, economic, regulatory, or cultural, are not comprehensively understood.

Although many studies have concentrated on enhancing 3DCP primarily through advances in material properties and manufacturing processes, the broader constraints and limitations integral to large-scale applications have been comparatively understudied. Similarly, despite implementing pilot projects in Germany, there remains a lack of comprehensive understanding regarding the unique challenges inherent to the German market. Moreover, the extant body of knowledge offers limited insight into the technology's potential challenges across the entire building lifecycle, signaling the need for a more holistic examination of 3DCP's feasibility within real-world construction contexts.

Identifying the factors that inhibit the mainstream uptake of 3DCP is thus essential to understanding how the sector can overcome longstanding barriers and move toward a more future-oriented mode of residential construction. In this future paradigm, additive manufacturing techniques will be regarded not as niche or experimental but as essential tools for keeping pace with technological advancements and enhancing both the construction process and the built environment.

Although the technology offers considerable potential for improving the construction process, numerous obstacles still need to be overcome, including technical feasibility, cost and time advantages, user training, and safety. Beyond compliance with contractual and normative requirements and departing from conventional practices (Despeisse et al., 2017). Necessitating further research into the primary reasons behind the limited adoption of this technology. Given the lack of compatibility, this thesis endeavors to identify and analyze the factors inhibiting market penetration, examining why a technology with such transformative potential struggles for traction, aiming to bridge the gap between the promise of 3DCP and the realities of a construction sector poised for, yet resistant to, digital transformation.

1.2 Research Question

The central objective of this thesis is to identify the factors that hinder the acceptance and diffusion of 3DCP in the residential construction sector. The market penetration of 3DCP remains limited despite its promotion as a disruptive and resource-efficient technology. The study aims to explain this gap and uncover the barriers to widespread adoption. Doing so will offer a deeper understanding of the underlying motives and relationships that shape the construction industry's readiness (or reluctance) to embrace 3DCP.

Research Question (RQ):

RQ: *Which factors impede the market penetration of 3D concrete printing in residential construction?*

Sub-Question (SRQ):

SRQ: *How do these factors contribute to resistance against 3D concrete printing adoption in the German residential construction sector?*

1.3 Structure of the Thesis

This thesis is divided into five main chapters, reflecting a logical progression from an overarching overview of 3DCP to an empirical investigation of the barriers identified in the literature. The second chapter contextualizes 3DCP by introducing its principal characteristics and underscoring its potential relevance for residential construction while highlighting the significance of studying obstacles to its wider adoption. The third chapter offers a systematic literature review conducted following the PRISMA framework, thereby identifying and classifying the barriers documented in existing research. Based on these findings, the fourth chapter empirically validates these barriers within the German residential construction sector, assessing the extent to which theoretical challenges align with practical industry conditions. The final chapters synthesize the insights gained from the literature review and the empirical investigation, discuss their broader implications, and propose avenues for future research. This structured progression lays a foundation for understanding the factors constraining the broader adoption of 3DCP in the German residential construction sector.

2 General Background and Context

This chapter provides a broad overview of 3DCP, laying the groundwork by discussing the technology's defining features, potential significance for residential construction, and adoption status. Subsequently, the chapter explores why it is crucial to examine the factors that hinder 3DCP adoption.

2.1 Technology Overview

Additive manufacturing (AM), which encompasses 3D printing as a subset, is defined by the international standard ISO/ASTM 52900. This standard, developed collaboratively by the American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO), characterizes AM as:

“[The] process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies” (ISO/ASTM 52900:2021-11).

This definition highlights the fundamental principles of AM: the layer-by-layer deposition of material, the reliance on digital models, and its distinction from traditional subtractive and formative manufacturing approaches (Gibson et al., 2015). AM processes are commonly categorized into seven groups: material extrusion, material jetting, binder jetting, powder bed fusion, directed energy deposition, vat photopolymerization, and sheet lamination (Ko, 2022; Paolini et al., 2019).

Within the broader context of AM, the terms Additive Construction (AC) or Additive Manufacturing for Construction (AMC) have emerged for the application of these principles and technologies to the construction sector (ISO/ASTM 52939:2023-12). The concept takes the conventional AM practice of producing parts layer by layer and adapts it to create buildings, structural and non-structural elements, or architectural components. Within this field, a significant subset is 3DCP, wherein cementitious mixtures serve as feedstock for printing structural or non-structural building elements (Bos et al., 2016). Although 3DCP is currently the most common form of additive manufacturing, it is only one technique within a broader array of AMC/AC methods. Therefore, this research will focus on the challenges of material extrusion.

Concrete is the most widely used construction material worldwide owing to its relatively low cost, global availability of raw materials, and advantageous properties such as high compressive strength, exceptional durability, and fire resistance (Bischof et al., 2022; Bos et al., 2016; Ko, 2022; Paul et al., 2018). It is also adaptable in its unhardened state, allowing casting or extrusion into complex shapes. Technically, “concrete” refers to a broad category of

composite mixtures that contain sand, gravel, or other aggregates bound by a mortar (e.g., ordinary Portland cement or cement-replacers) with water (Bos et al., 2016; Lyu et al., 2021). Depending on project requirements, specific admixtures (e.g., superplasticizers, accelerators) and alternative binders can be introduced to achieve properties like high strength, self-compaction, shape stability, or a low carbon footprint.

One of the earliest large-scale AMC/AC techniques for construction was proposed by Khoshnevis in the mid-1990s, known as “Contour Crafting.” This multi-material deposition technique combines an extrusion process for forming the outer surfaces and a filling process to create the internal core of the structure (Craveiro et al., 2019; Krimi et al., 2017; Bos et al., 2016). After forming the outer surfaces, the internal core gets filled with additional material and reinforcements to provide structural integrity. Beyond Contour Crafting, the construction sector has seen the emergence of various 3D printing techniques, including:

1. D-Shape: Uses powder deposition processes, where each layer is spread and compacted. A binder is then selectively deposited to solidify the layer precisely where the final part should form (Craveiro et al., 2019; Lim et al., 2012).
2. Shotcrete: Involves spraying concrete at high velocity using compressed air onto a surface, substrate, or rebar cage (Bischof et al., 2022; Graser et al., 2023).
3. Slip-forming: Involves pouring concrete into a continuously vertically or horizontally moving formwork, creating structures in an extrusion-like process. The resulting concrete element mirrors the formwork's geometry and motion, creating structures bigger than the formwork itself (Bischof et al., 2022; Graser et al., 2023).
4. Concrete Printing: Similar to Contour Crafting, it primarily relies on material extrusion to produce physical objects layer by layer (Bischof et al., 2022; Romdhane, 2020). This AM process represents what is typically referred to when discussing 3D printing.

In recent years, many new large-scale 3D printers have been introduced with expanded workspaces, enabling the fabrication of entire structures or large-building elements. Typically, these printing heads move via either a fixed gantry system or an arm-based robot with multiple degrees of freedom, as seen in Figure 1 (Paolini et al., 2019; Paul et al., 2018; Romdhane, 2020). Gantry systems generally support larger-scale projects and are more straightforward to operate, whereas robotic arms offer enhanced maneuverability and are more suitable for complex geometries and smaller structures. The choice of printing method depends on factors such as project size, desired geometry complexity, and mobility requirements. The size of the printer systems varies accordingly, ranging from small, laboratory-scale versions to large-format printers that can handle full-size building components.

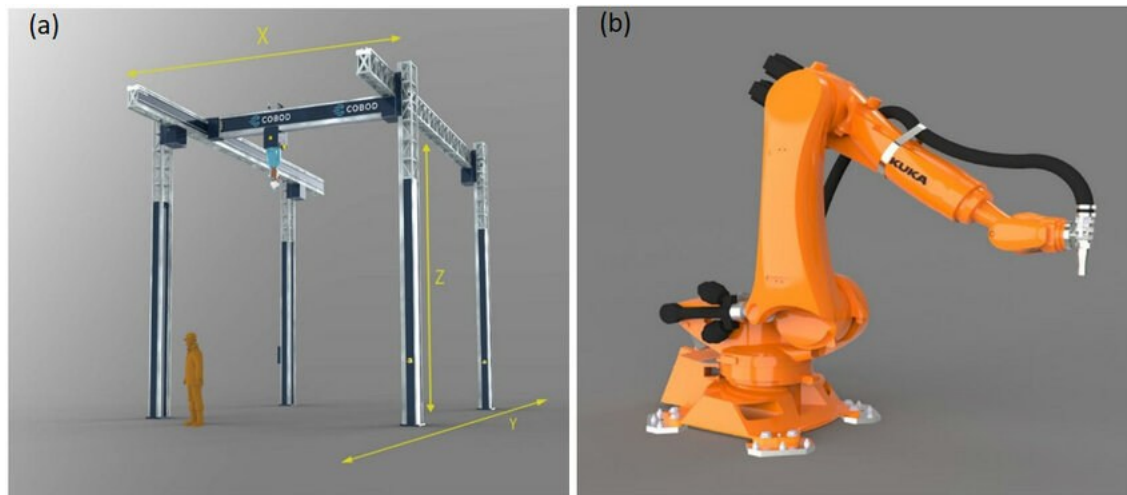


Figure 1. Types of Printers: (a) Gantry Printer; (b) Robotic Arm Printer (Aboelhassan, 2023)

The extrusion process generally begins with developing a digital model using a Computer-Aided Design (CAD) system. The digital model gets sliced into multiple cross-sectional layers and transmitted to the AM system for toolpath generation. The resulting toolpath directs the printer nozzle to deposit the cementitious mixture layer by layer (Craveiro et al., 2019). In construction settings, printing heads are commonly mounted on gantry or arm-based robotic systems that provide varying degrees of freedom (Paolini et al., 2019; Romdhane, 2020). A motion control system navigates the nozzle over the print surface according to coordinates supplied by the control unit. Nozzles can vary in size and shape and can be equipped with side trowels to enhance surface finishing (Paul et al., 2018). Regardless of the system chosen, suitable material mixtures are paramount. The pump transports the material from the mixing unit to the nozzle to extrude the concrete mix. High-performance concrete mixes are required to prevent nozzle clogging and impairing printing, as continuous control and supply of materials are necessary while printing.

Because 3DCP does not utilize supportive formwork, traditional concrete compositions cannot be used outright. The concrete composition must exhibit minimal settlement and maintain a low viscosity to minimize layer deformation (Paul et al., 2018). Setting time and material properties are controlled by adding superplasticizers, accelerators, and retarders to the mix. These additives ensure the material retains its structure before it hardens once deposited. A critical aspect of 3DCP is the rheological and mechanical behavior of the fresh mixture. The fresh mixture has to be pumpable, retain its shape, and support the subsequent layers with minimal deformation (Ma et al., 2022). Key material properties of the fresh mixture are pumpability, extrudability, buildability, and printability. Terms often used to describe the fresh-state material properties required for robust, reproducible printing (ISO/ASTM 52939:2023-12):

- **Pumpability:** The ease with which the material moves from the feed source through the conduits to the print head.
- **Extrudability:** The capacity of the mixture to flow smoothly through the nozzle without clogging or suffering quality degradation.
- **Buildability:** The ability to retain structural integrity under increasing loads from subsequent layers with minimal deformation over time.
- **Printability:** The measure of how effectively a mixture travels to the print head, extrudes smoothly, and preserves consistent layer geometry.

The current literature predominantly focuses on identifying the optimal material composition for 3DCP while concurrently refining processes that enable efficient and reliable large-scale construction through AM.

2.2 Challenges and Importance of Adoption

Despite rising costs, labor shortages, and growing sustainability requirements, the German residential construction sector continues to be hesitant to adopt 3DCP at scale. The interplay of multiple factors contributes to this technological inertia. Technical considerations for 3DCP include specialized hardware (i.e., gantry or robotic arm systems) and carefully engineered concrete mixtures that meet rigorous requirements for extrudability, buildability, and pumpability (Paolini et al., 2019). While this level of complexity reflects the relative infancy of 3DCP in terms of improving materials and scalability, it does not fully explain the broader resistance within the sector (Osorio-Gómez et al., 2024; Paul et al., 2018; Shafei et al., 2022) as it is considered a gateway towards digitalization (Ma et al., 2022).

Apart from technological considerations, the structural and economic realities of the German construction sector pose additional barriers. Strict regulations, varying building codes, and the fragmented, project-based nature of construction complicate the rapid integration, discouraging substantial investment in research and development (Lojanica et al., 2018; Oesterreich & Teuteberg, 2016). Rising material costs, labor shortages, and sustainability mandates amplify the need for solutions that optimize efficiency and minimize resource consumption. Although 3DCP promises to address these challenges and enable faster project completion, reduced waste, and greater design flexibility, uncertainties regarding hardware costs, build quality, and present-day restrictions on building height and material are hindering broader adoption (Bos et al., 2016; Ma et al., 2022). The layer-by-layer process can reduce formwork requirements and associated waste while facilitating complex geometries that traditional methods struggle to achieve. Throughout history, the construction sector has primarily relied on stacking layers of materials, including bricks, blocks, or prefabricated components, to construct the structural elements of buildings. This enduring practice, while

time-tested, presents numerous challenges in a contemporary context. It constrains productivity, necessitates a substantial workforce of skilled labor, and results in significant environmental and health impacts due to the production of waste, noise, and dust (Bos et al., 2016).

Nonetheless, isolated pilot projects in small-scale or demonstrational settings show that 3DCP can streamline workflows and optimize resource use (Dörfler et al., 2022; Ma et al., 2022; Naboni et al., 2020). The industry's mixed response, in which some stakeholders experiment with pilot projects while others remain skeptical, illustrates the interplay of hope and hesitancy in construction's path toward digitization. Such streamlined processes appear increasingly attractive for a sector grappling with multifaceted crises, from rising interest rates to supply chain disruptions (Forcael et al., 2025). To achieve a relevant significance, 3DCP must become competitive for applications in large-scale residential construction.

However, a more robust understanding of the barriers involved is indispensable for transitioning the technology from an experimental technique to a widespread practice. Academic and industry reports acknowledge the potential for lower costs and enhanced design freedom, yet, as this chapter suggests, such advantages alone do not suffice to overcome the entrenched hurdles of a sector wary of unproven methods.

2.3 Innovation Resistance Theory and its Relevance

Researchers have developed a wide range of theoretical frameworks to explain why some innovations gain rapid acceptance while others face considerable opposition (Davis, 1989; Davis et al., 1989; Rogers, 2003). However, most of these frameworks focus on the adoption drivers of innovation rather than the barriers that lead to rejection or resistance (Heidenreich & Spieth, 2013). In contrast, Innovation Resistance Theory (IRT) (Ram & Sheth, 1989) offers a systematic understanding of why individuals, organizations, or societies exhibit reluctance toward new products and services (see Figure 2), even when these innovations demonstrate considerable benefits. By emphasizing the negative factors hindering acceptance, the IRT provides a perspective through which scholars can investigate the unexpectedly slow diffusion of 3DCP in the construction sector.

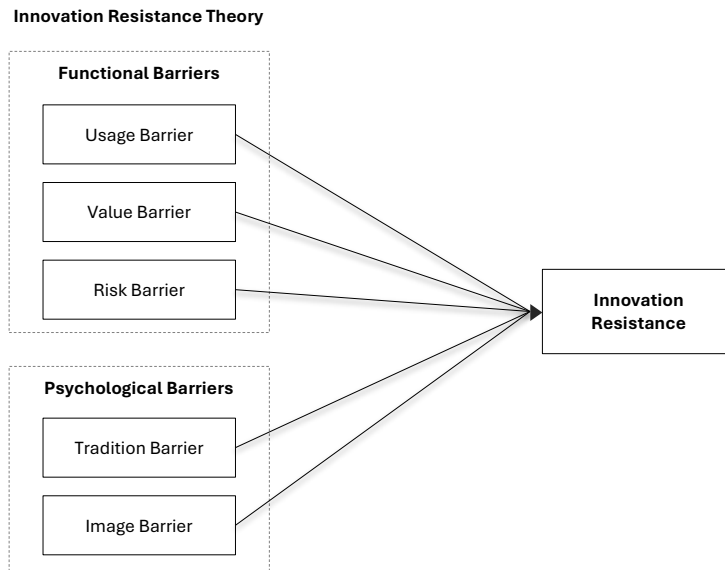


Figure 2. Research model

While acceptance models such as the Unified Theory of Acceptance and Use of Technology (UTAUT) and the Technology Acceptance Model (TAM) concentrate on enablers of adoption (Davis, 1989; Davis et al., 1989; Venkatesh et al., 2003), IRT shifts attention to the obstacles that prospective users or organizations face when encountering innovative solutions (Gupta & Arora, 2017; Talke & Heidenreich, 2014). IRT provides a framework for understanding resistance-oriented behaviors (Ram & Sheth, 1989; Talke & Heidenreich, 2014). Although IRT has been extensively examined in the context of various technologies such as advanced driver assistance systems, blockchain, green technologies, mobile banking and online services (Cheng et al., 2014; Chu, 2023; Dwivedi et al., 2023; Jisham et al., 2024; Sang et al., 2022; Van Offenbeek et al., 2013), it remains under-researched in the realm of 3DCP adoption. Investigating resistance to 3DCP can thus offer a deeper understanding of rejection in the construction sector, which continues to display considerable inertia in the face of emerging digital solutions. Inertia is commonly understood as the tendency of consumers to persist in certain practices even when superior alternatives exist (Jisham et al., 2024). At the sector level, this concept captures the inclination to uphold established routines despite the availability of other options, reflecting a persistent preference for traditional methods over the integration of innovations.

IRT describes the multifaceted nature of why individuals or organizations resist adopting new technologies, highlighting that many innovations fail not necessarily because of lacking benefits or technological sophistication but due to deeply entrenched habits, beliefs, and concerns (Ram & Sheth, 1989). By focusing on the obstacles to adoption, IRT shifts attention from simply promoting the merits of innovation to actively addressing the barriers that impede market penetration (Talke & Heidenreich, 2014).

Although the term “consumer resistance” frequently appears in IRT research (Ram & Sheth, 1989; Talke & Heidenreich, 2014), organizations can also function as customers (Freeman, 2010; North, 1990). Like individuals, organizations exhibit preferences, hold beliefs, consume products and services, and make decisions about adopting or rejecting emerging technologies (Gupta & Arora, 2017; Ram & Sheth, 1989). In the context of 3DCP, these decisions involve assessing whether and how the technology aligns with existing workflows, strategic goals, and industry standards. Thereby weighing the costs and benefits of adopting emerging technologies. Consequently, organizational resistance to 3DCP can result from similar fundamental barriers that deter individual consumers, including risk perception, values, and the incompatibility of innovation with prevailing habits (Hew et al., 2019; Jisham et al., 2024).

Resistance is conceptualized not as the exact opposite of acceptance but as a process of behavioral change that can lead to postponed, partial, or complete rejection of a novel technology (Sang et al., 2022). Grounded in the premise that consumers and organizations seek to maintain their psychological equilibrium or a satisfactory status quo, IRT posits that any significant disruption to this balance induces resistance (Heidenreich & Spieth, 2013; Ram & Sheth, 1989). This resistance can manifest either passively, without careful consideration of the innovation’s potential, or actively, through explicit opposition once the innovation is evaluated (Chu, 2023; Talke & Heidenreich, 2014). Resistance significantly impacts 3DCP, notably through organizational inertia and adherence to traditional construction methods, postponing or even preventing the adoption of emerging technologies. Researchers have noted a similar phenomenon in areas such as mobile banking (Cheng et al., 2014) and advanced driver assistance systems (Chu, 2023), where deeply entrenched habits and beliefs hinder the diffusion of innovations.

2.3.1 Dimensions of Innovation Resistance

IRT delineates innovation resistance into two main categories of barriers: functional and psychological (Ram & Sheth, 1989). Functional barriers encompass three sub-dimensions, whereas psychological barriers concern two sub-dimensions (see Figure 2). The functional barriers address usage, value, and risks of innovations, while psychological barriers result from traditions and perceived image. Scholars have further classified these barriers into active and passive forms of resistance (Heidenreich & Spieth, 2013; Sang et al., 2022; Talke & Heidenreich, 2014). Active resistance arises from concrete conflicts with innovation’s characteristics, while passive resistance emerges from an aversion to changing established practices or belief systems. Although 3DCP appears poised to address multiple challenges in the construction industry, particularly by streamlining operations and reducing material waste, it may still encounter functional and psychological barriers that deter its broader adoption in

residential projects. The existing literature has yet to explore these dynamics in depth, underscoring the importance of applying an IRT perspective to 3DCP.

Functional Barriers

Functional barriers occur when an innovation conflicts with established practices or its value proposition is unclear.

The first functional barrier is the most common reason for resistance to innovation. The **usage barrier** concerns how a new solution, such as 3DCP, fits existing routines and skill sets (Kaur et al., 2020; Ram & Sheth, 1989). Changes to routines require a relatively long development process before they are accepted. After all, each emerging product or service interacts with other products and activities and must fit into the existing system (Ram & Sheth, 1989). Usage barriers are an essential variable, as the usage-related complexity can significantly jeopardize the potential for market penetration (Kaur et al., 2020).

The **value barrier** is triggered when the perceived performance-to-price ratio of the innovation does not offer a compelling advantage over available substitutes (Ram & Sheth, 1989; Sang et al., 2022). If 3DCP is perceived as expensive, particularly when considering the trade-off between its costs of use and the associated learning effort relative to conventional construction methods, decision-makers will be reluctant to invest (Kaur et al., 2020). The cost of acquiring and implementing 3DCP can be significant, and without convincing evidence of cost savings or performance benefits, organizations postpone adoption. Addressing this barrier involves demonstrating superior product performance or reducing the overall cost burden for construction firms (Kaur et al., 2020; Ram & Sheth, 1989).

Third, the **risk barrier** emerges from uncertainties inherent to any innovation (Sang et al., 2022). Raising concerns about **operational reliability (functional risk)**, **safety issues (physical risk)**, **social ostracism (social risks)**, or **potential financial losses (economic risk)** (Joachim et al., 2018; Ram & Sheth, 1989). Evidence of successful use cases, market exposure, expert endorsements, and trial opportunities can mitigate perceived risks (Kaur et al., 2020; Ram & Sheth, 1989). However, for 3DCP, concerns about structural integrity, reliability under various conditions, malfunction, and long-term maintenance costs can perpetuate perceived risks and thus hinder adoption. Economic risks can also be particularly salient for organizations considering 3DCP, as technology investments in heavy machinery and specialized materials often entail high upfront costs and uncertain returns.

Physical Barriers

Psychological barriers reflect underlying beliefs, traditions, and images associated with innovation. Implying that resistance does not arise solely from functional or rational factors.

Tradition barriers occur when the innovation challenges habitual practices, values, and organizational norms (Kaur et al., 2020; Ram & Sheth, 1989). Longstanding practices in the construction sector frequently become deeply entrenched, leading to reluctance to deviate from proven methods. Resistance increases with rising deviation from established practices, amplifying inertia (Ram & Sheth, 1989). Overcoming tradition barriers requires sustained educational efforts and the involvement of highly respected sector leaders who can endorse 3DCP (Chu, 2023; Ram & Sheth, 1989).

The **image barrier** involves negative perceptions about its origin, branding, or technological complexity that cause stakeholders to distrust efficacy or relevance (Kaur et al., 2020; Ram & Sheth, 1989; Sang et al., 2022). The image barrier is a perceptual problem rooted in stereotypical thinking. Overcoming these barriers requires market education, targeted endorsements from respected industry leaders, and policy support (Chu, 2023; Ram & Sheth, 1989). If decision-makers perceive 3DCP as overly complex or question its trustworthiness, these image concerns substantially hinder diffusion.

2.3.2 Advancing 3DCP Integration

Considering the ongoing digital transformation in related industries, the construction sector cannot afford to overlook the potential of advanced manufacturing methods. Systematic identification of adoption barriers is therefore indispensable for fostering the sustainable integration of 3DCP. On this basis, the following chapter will present a systematic literature review designed to map existing knowledge on barriers to 3DCP adoption with a transparent search strategy. Consolidating current empirical findings will identify specific factors hindering the market penetration of 3DCP in construction and lay the groundwork for empirical investigations in subsequent chapters. Ensuring that future studies and practical applications can address functional and psychological resistance to 3DCP more effectively.

Based on the theoretical perspective of IRT, functional and psychological barriers play pivotal roles in shaping technology adoption outcomes. Functional barriers such as usage complexity, high perceived risk, and psychological barriers involving tradition and negative perceptions can deter organizations from investing in new production methods. Since the construction sector tends to be conservative, understanding the interplay of these factors is vital for facilitating 3DCP adoption. Recognizing that organizations serve as customers who can resist disruptive innovations provides a powerful lens through which to analyze the slow diffusion of 3DCP.

3 Systematic Literature Review

This study investigates factors that hinder broader 3DCP adoption by employing a systematic literature review (SLR) guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. Developed in 2009, PRISMA is a widely accepted framework for conducting and documenting SLR, ensuring transparency, replicability, and rigor (Page et al., 2021). Its checklist facilitates transparent reporting of the review's purpose, procedure, and findings, thereby allowing readers to assess both the methodological robustness and the relevance of the outcomes. The PRISMA framework is structured around a systematic four-phase flow diagram, encompassing the following stages: phase 1: identification, phase 2: screening, phase 3: eligibility, and phase 4: inclusion (Moher et al., 2009).

A SLR allows to “evaluate theories about how or why phenomena occur” (Page et al., 2021), making it particularly suited for addressing the central RQ of this study, seeking to identify the specific obstacles impeding the technology's uptake. This review identifies and analyzes relevant literature in the construction sector to highlight the principal barriers constraining the broader adoption of 3DCP according to the IRT framework and synthesizes existing research to establish a theoretical foundation for subsequent empirical investigations. The structured approach of an SLR helps clarify these challenges and provides a basis for explaining why such barriers persist. This methodology ensures a transparent and replicable literature assessment, yielding credible insights into why 3DCP adoption remains limited.

Given the lack of results for the keywords “Germany” or “German,” this SLR examines adoption and barriers from a global perspective. The following chapter applies these findings to the German residential construction sector, allowing a context-specific assessment of whether the globally identified barriers match those in Germany. These insights establish a robust theoretical foundation for subsequent empirical investigations that evaluate whether the broader global barriers reflect the same concerns in the German residential construction context.

3.1 Identification

To perform the systematic literature review (SLR), Web of Science, a leading multidisciplinary database providing access to more than 20,000 peer-reviewed journals from various scientific fields, was used to identify research articles addressing adoption barriers to 3DCP in residential construction.

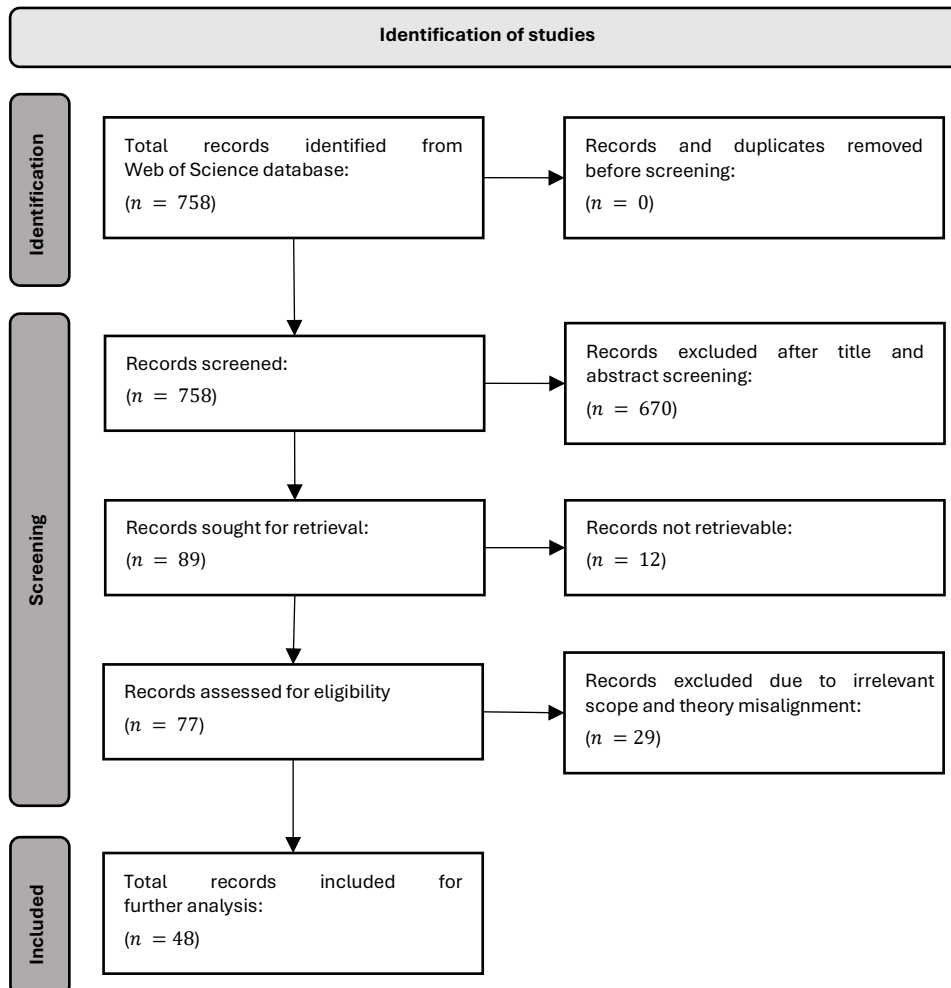


Figure 3. PRISMA flow diagram for systematic review

The search included publications from 2007 to 2025 to capture historical and emerging trends. The search terms had to appear in the title, abstract, or keywords to ensure thematic relevance. Restricting the search to English-language journal articles and review articles using the following search query:

(TITLE-ABS-KEY ("3D CONCRETE PRINTING" OR "DIGITAL FABRICATION" OR "ADDITIVE MANUFACTURING IN CONSTRUCTION" OR "3D PRINTED CONCRETE" OR "CONCRETE 3D PRINTING") AND (BARRIER OR CHALLENGE OR ISSUE OR PROBLEM OR LIMITATION OR DRIVERS OR READINESS OR ACCEPTANCE OR "TECHNOLOGY ADOPTION" OR ADOPTION))

This search resulted in 758 unique articles containing no duplicate entries. The analysis reveals an exponentially growing number of publications each year, increasing from just 0.13% in 2007 to 24.67% in 2024 (see Figure 4). This growth corresponds to an increase from a single publication in 2007 to 187 articles in 2024, demonstrating a substantial surge in research interest.

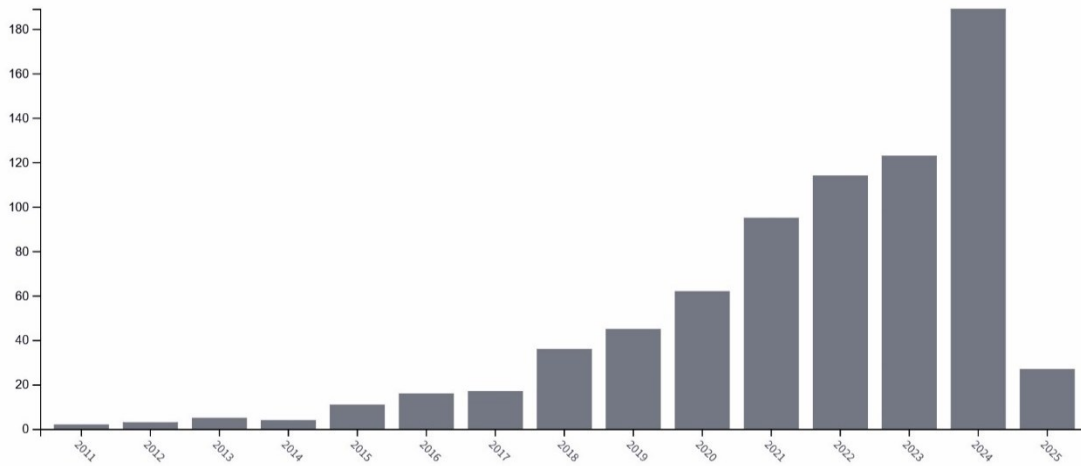


Figure 4 Number of selected articles per year

Notably, over 50% of these publications are concentrated in engineering, closely followed by construction building, technology, and materials science (see Figure 5). This distribution suggests that the primary challenges explored in the literature are more closely related to technical and materials science barriers rather than a general hesitancy toward innovation adoption.

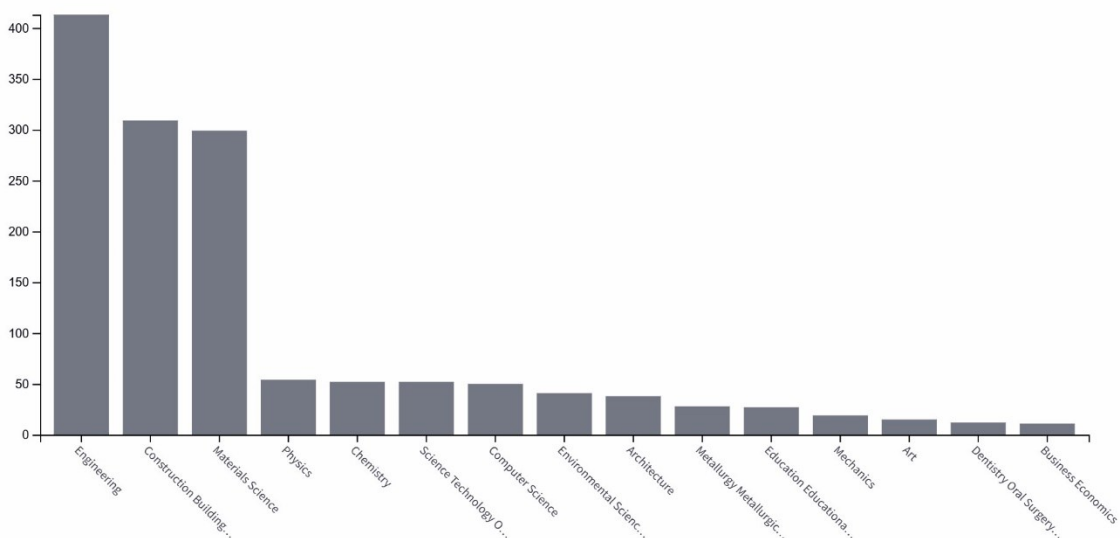


Figure 5 Research area of selected articles

For a visual representation of the article selection process, a PRISMA flow diagram details the number of records retrieved, screened, excluded, and ultimately included in the review. Figure 3 illustrates the SLR procedure, offering a concise overview of the number of records retained at each review stage.

3.2 Screening

A systematic screening evaluated the titles and abstracts of the retrieved articles to establish relevance to the research focus, including the article if:

- The article focuses on residential construction or construction specifics that apply to residential construction.
- The article discusses adoption, acceptance, barriers, resistance, or organizational perspectives regarding 3DCP.
- The article examines acceptance barriers, resistance, or limiting factors for 3DCP diffusion.

Excluding articles if:

- The article addresses construction specifics that do not apply to residential construction or focuses on applications beyond the construction sector.
- The article is limited to discussions on technical, engineering, or material science aspects of 3DCP without discussions on adoption, acceptance, or resistance factors.
- The article focuses on non-cementitious or non-extrusion-based 3D printing.

The initial screening of titles and abstracts from the retrieved articles determined that only 89 studies met the inclusion criteria for full-text analysis. The predominant reasons for exclusion were as follows:

A total of 136 studies were omitted due to their emphasis on industry-specific or niche applications that extended beyond the defined research parameters (e.g., maritime or medical applications), rendering them inapplicable to the study's scope. An additional 92 papers were excluded because they focused on material-specific attributes without addressing critical factors related to adoption challenges or barriers (e.g., rheological properties, mechanical performance, and admixtures). Furthermore, 84 studies were eliminated as they primarily explored technical innovations without engaging with real-world implementation concerns. Fifty studies were deemed unsuitable based on their focus on educational programs in fabrication laboratories or schools emphasizing rapid prototyping. Lastly, 44 papers were excluded due to their focus on process-specific aspects without sufficiently discussing broader adoption-related challenges. The meticulous screening process refined the dataset, keeping the review focused on critical issues related to adoption challenges and barriers in the field.

3.3 Eligibility

After the screening phase, 77 of the 89 articles were retrieved for full-text analysis, while the remaining publications were excluded due to inaccessibility. Each article was reviewed for its alignment with the central research question, excluding the article if:

- The article did not explicitly address barriers to 3DCP adoption in residential construction or concentrated on entirely unrelated domains.
- The article is limited to discussions on technical, engineering, or material science aspects of 3DCP without discussions on adoption, acceptance, or resistance factors.
- The article provided insufficient empirical or theoretical grounding, making adequate mapping to the IRT dimensions or other resistance-oriented theoretical frameworks impossible.
- The article demonstrated methodological shortcomings, including unreliable data collection, inappropriate sample sizes, and non-robust analytical procedures.

This eligibility screening ensures that only studies with theoretical and methodological rigor relevant to 3DCP adoption barriers progress to the subsequent data extraction and synthesis phases. The eligibility assessment of the 77 articles revealed 48 articles relevant and eligible for further analysis.

The eligibility assessment reveals that the main reasons for article exclusion are their conformity mismatch against theoretical innovation frameworks, especially IRT, and their lack of focus on adoption barriers in a residential context. A significant proportion of the excluded articles primarily focus on the technical, engineering, or material science aspects of 3DCP, often discussing structural mechanics, defect control, or automation processes rather than the socio-economic or theoretical dimensions of adoption. Several studies also lack empirical rigor by failing to present original research, omitting explicit methodological frameworks, or limiting their scope to perspectives that do not engage with adoption challenges. Although some sources offer insights into related fields, such as AMC, digital fabrication, or parametric design, their contributions are often too broad or lack a direct focus on the specific barriers to adopting 3DCP in residential construction. Studies focusing solely on material performance aspects, such as fire resistance or thermal performance, were similarly excluded due to their insufficient emphasis on adoption dynamics. Metrics from this review indicate that the predominant reason for exclusion is a technical or material focus (over 50% of cases), followed by a lack of theoretical alignment with IRT or similar models (approximately 30%) and insufficient empirical depth or methodological transparency (around 20%). These findings highlight a gap in the literature where theoretical and adoption-oriented discussions of 3DCP in residential construction remain underexplored in contrast to its technical advancements.

3.4 Inclusion

Following a rigorous screening and eligibility assessment process, 48 studies met all inclusion criteria and were deemed relevant for further analysis. These studies focus reasonably, though not always substantially, on barriers to 3DCP adoption and align with the IRT framework. Discussing adoption, acceptance, barriers, resistance, or organizational challenges related to 3DCP and addressing key factors inhibiting diffusion. The 48 articles span various geographical regions, methodologies, and perspectives, ensuring a diverse and comprehensive understanding of the barriers to 3DCP adoption.

3.5 Data Analysis

This study employs a systematic qualitative analysis to examine the barriers hindering the adoption of 3DCP in residential construction. After identifying 49 high-quality, relevant studies through a rigorous selection process following the PRISMA framework, the next step involved extracting and analyzing data to uncover the key barriers to 3DCP adoption.

The study emphasizes conceptual and thematic insights and employs manual data extraction and qualitative synthesis instead of bibliometric analysis. This approach identifies specific barriers and aligns them with the IRT framework, a task that automated bibliometric tools such as VOSviewer (Visualization of Similarities Viewer) cannot accomplish. These tools visually analyze similar research using a co-occurrence matrix to create knowledge maps showing networks and keyword relations, indicating their influence and impact in the respective domain (Van Eck & Waltman, 2014).

Initially, the study explored bibliometric analysis as a potential method to identify recurring themes in the literature. Applying a text-based mapping approach with VOSviewer produced results that primarily formed broad and generic clusters such as "construction project," "cost," "process," and "sustainability," regardless of the minimum occurrence threshold. Although these terms provide insights into the broader discourse on 3DCP, they do not isolate specific adoption barriers or offer a meaningful connection to the IRT framework.

Furthermore, bibliometric analysis tends to be more effective in mapping research trends, collaboration networks, and citation relationships rather than extracting detailed thematic insights about technology adoption barriers (Soomro et al., 2022; Van Eck & Waltman, 2014). Given the relatively niche research area of 3DCP adoption, the automated clustering of keywords did not provide a meaningful classification of barriers or their relevance to the IRT framework. Consequently, the analysis shifted to manual qualitative extraction to capture the depth and specificity of the resistance factors discussed in the selected studies.

By systematically reviewing the abstracts, introduction, discussions, and conclusions of the identified 49 high-quality articles, specific barriers were identified and categorized within the IRT framework. Allowing for a deeper understanding of the factors inhibiting 3DCP adoption in construction, which bibliometric tools could not provide. A data extraction template standardized the coding process, capturing the following elements:

- Identified barrier category
- Detailed description of the barrier
- IRT framework mapping
- IRT mapping explanation
- Supportive quote if applicable

Each article underwent analysis for recurring themes, categorizing barriers according to the IRT framework. Allowing classification and interpretation of the findings based on the five dimensions of resistance in IRT: usage, value, risk, tradition, and image. This classification enables a comparative assessment across studies and establishes a theoretically grounded framework to understand the limited adoption of 3DCP in residential construction.

3.6 Results

The barriers identified in the literature have been according to the IRT framework to clarify their role in hindering market penetration. Figure 6 provides a visual summary of these barriers, ranked by their frequency of occurrence. The following section discusses each barrier in detail to illustrate its persistence and hindrance to widespread adoption.

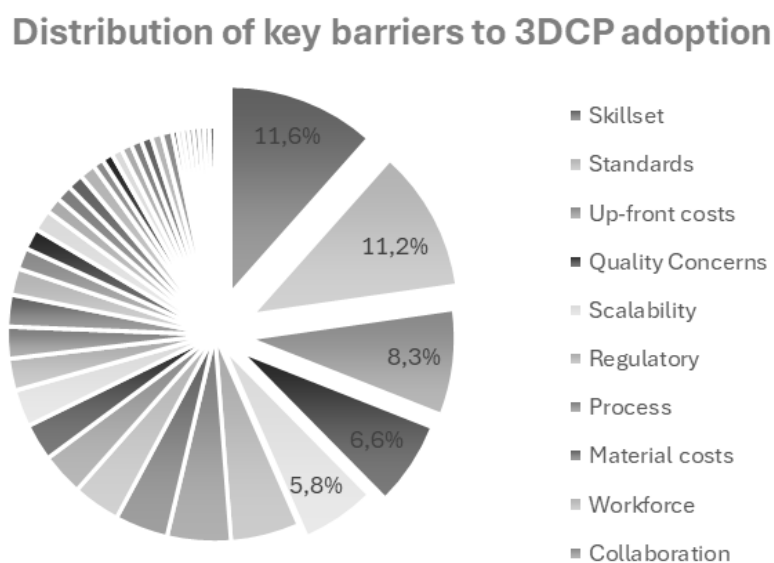


Figure 6. Distribution of key barriers based on occurrences

3.6.1 Key Barriers Mapped to IRT Dimensions

Skillset – Usage (18 occurrences) & Economic Risk (5 occurrences)

A significant constraint to 3DCP adoption is the lack of skilled labor capable of operating and maintaining digital fabrication processes. The requirement for new skills in operating and maintaining 3D printing equipment creates a significant barrier, as the existing construction workforce lacks expertise in digital fabrication and automation (Adaloudis & Roca, 2021; Al-Raqeb & Ghaffar, 2025; Ambily et al., 2024; Bazli et al., 2023; Gamage et al., 2024; Guaman-Rivera et al., 2022; S. Li et al., 2024; Potstada et al., 2016). The specialized training required to work with robotic systems, automated material deposition, and parametric design tools increases training costs, disrupts traditional labor practices, and slows adoption (Ambily et al., 2024; Gamage et al., 2024; Graser et al., 2021). Additionally, a lack of educational programs and curricula further delays skill development for 3DCP (Gamage et al., 2024). The transition from conventional to automated methods demands upskilling, often met with resistance due to unfamiliarity and the associated learning curve.

The demand for specialized training in 3D printing technologies significantly raises labor costs, presenting a significant economic barrier (Gamage et al., 2024; Hassan et al., 2024). The absence of standardized educational programs and industry-wide certification pathways further exacerbates the skills gap, making developing a workforce proficient in 3DCP demanding (Bazli et al., 2023). Additionally, the limited availability of institutional training initiatives restricts accessibility, slowing the industry's ability to integrate 3DCP on a larger scale (Gamage et al., 2024). Without structured workforce development, companies face increased labor costs and prolonged adoption timelines, reducing the overall feasibility (Adamtsevich et al., 2024; Al-Tamimi et al., 2023).

Standards – Functional Risk (18 occurrences)

The absence of standardized regulations and building codes tailored to 3DCP creates significant barriers to certification and project approvals, hindering widespread adoption (Ambily et al., 2024). Many regulatory bodies rely on analogies with conventional construction methods, which do not fully accommodate the unique material behaviors and structural properties of 3D-printed buildings (Adaloudis & Roca, 2021; Bazli et al., 2023; Khan & McNally, 2024). This regulatory misalignment fosters uncertainty regarding compliance, permitting, and liability, increasing the risk perception among stakeholders. The absence of universally accepted design and safety standards for 3DCP creates uncertainty for engineers, contractors, and regulators (Gamage et al., 2024; Nhieu & Dang, 2024). Consistent specifications across different regions slow standardization, impeding widespread implementation (Gamage et al., 2024).

Furthermore, the lack of accepted standardized quality control measures and performance benchmarks exacerbates these concerns, making establishing trust and credibility in 3DCP technology within the construction sector challenging (Nhieu & Dang, 2024). Higher porosity, rougher surface finishes, and inconsistent material properties contribute to skepticism about whether 3DCP structures can meet industry standards (Bazli et al., 2023; De Schutter et al., 2018; Gamage et al., 2024).

Up-Front Costs – Value (13 occurrences) & Economic Risk (5 occurrences)

Acquiring 3DCP technology requires substantial upfront investment in robotic printers, custom software, and infrastructure, which pose a significant financial barrier (Adaloudis & Roca, 2021; Al-Tamimi et al., 2023; Graser et al., 2021; Guaman-Rivera et al., 2022). Smaller firms, in particular, struggle to justify these expenditures, especially given the evolving nature of the technology and the uncertainty surrounding its long-term viability. If 3DCP fails to meet expectations, companies risk significant financial losses and sunk costs (Al-Tamimi et al., 2023; Bazli et al., 2023; Gamage et al., 2024; Josa & de la Fuente, 2024). Additionally, the lack of empirical data on the durability and maintenance costs of 3D-printed structures exacerbates economic risks (Bazli et al., 2023; Gamage et al., 2024). The uncertainty surrounding total project costs (including software, labor, materials, and maintenance) complicates financial planning and return on investment (ROI) evaluations (Al-Tamimi et al., 2023; Bazli et al., 2023; Gamage et al., 2024; Graser et al., 2021; Josa & de la Fuente, 2024). Unforeseen repairs or structural failures could impose substantial financial and legal burdens (Al-Tamimi et al., 2023; Potstada et al., 2016). Furthermore, the limited availability of material suppliers and the high cost of specialized materials erode 3DCP's economic competitiveness compared to traditional construction methods (Al-Tamimi et al., 2023; Josa & de la Fuente, 2024).

Up-front costs also present an economic risk due to uncertainties in operational efficiency, maintenance, and material availability (Al-Tamimi et al., 2023; Bazli et al., 2023; Gamage et al., 2024). Companies are hesitant to invest heavily in technologies lacking well-documented long-term cost benefits (Graser et al., 2021; Josa & de la Fuente, 2024; Ng et al., 2022).

Scalability – Usage (9 occurrences)

Scalability remains a critical challenge in the widespread adoption of 3DCP. Restricted volume and geometric constraints hinder the ability to print large or complex structures, making 3DCP impractical for specific construction projects (Bazli et al., 2023; Bos et al., 2022; Hassan et al., 2024). Current technology and workflows are not yet optimized for large-scale implementation, requiring further process standardization, workforce training, and technological advancements (Chen et al., 2024). The lack of automation in certain process aspects, such as reinforcement

placement and post-processing, further complicates scalability (Adamtsevich et al., 2024). Additionally, there is no clear evidence that 3DCP can achieve economies of scale, making it challenging to justify large-scale investment (Guaman-Rivera et al., 2022; Sovetova & Calautit, 2024). The uncertain ROI discourages decision-makers from allocating resources to technology with unclear long-term financial benefits (Placzek & Schwerdtner, 2024). Furthermore, the lack of practical experience and demonstrated success in large-scale projects limits user confidence in the technology's reliability and scalability (Ali et al., 2022). The absence of large-scale successful case studies demonstrating its economic advantages exacerbates adoption reluctance (Adaloudis & Roca, 2021).

Material Costs – Value (8 occurrences)

The high cost of specialized cementitious materials and proprietary printing mixes significantly impacts the cost-benefit ratio, making 3DCP financially unappealing compared to traditional construction methods (Bazli et al., 2023). The limited availability of 3D-printable concrete mixtures and proprietary formulations increases procurement costs, making the technology less competitive than conventional construction (Gamage et al., 2024). Smaller firms, in particular, struggle to absorb these expenses, further slowing adoption (Bazli et al., 2023).

Additionally, uncertainty regarding long-term material performance and maintenance costs adds to the financial risk, discouraging investment (Adaloudis & Roca, 2021). The need for specialized concrete formulations that are extrudable, self-supporting, and fast-setting, combined with the absence of well-established supply chains and economies of scale, not only adds further complexity but also exacerbates cost disparities, thereby limiting broader market penetration (S. Li et al., 2024). Without clear cost-reduction strategies or demonstrated long-term financial benefits, stakeholders remain hesitant to invest (Gamage et al., 2024).

3.6.2 Further Takeaways

Beyond the primary barriers, the research also identifies additional yet highly relevant factors that influence the resistance to 3DCP adoption. While not the most frequently cited, these secondary challenges play a critical role in shaping the perception and practical feasibility of 3DCP.

Collaboration – Usage (7 occurrences)

The success of 3DCP adoption relies on effective collaboration among architects, engineers, and contractors (Ng et al., 2023). However, industry fragmentation, lack of interdisciplinary knowledge, and resistance to process integration hinder widespread implementation. Traditional construction professionals often lack familiarity with digital workflows, creating challenges in aligning 3DCP with conventional project management and supply chains (C. Li

et al., 2022). Addressing these issues requires better coordination, knowledge sharing, compatible communication, and interdisciplinary collaboration between stakeholders. Effective stakeholder communication ensures sustainable cooperation (Graser et al., 2021; C. Li et al., 2022).

Conventional Construction – Tradition (7 occurrences)

The construction industry's reliance on traditional methodologies fosters inertia against emerging technologies like 3DCP (Gamage et al., 2024; Guaman-Rivera et al., 2022). This resistance extends beyond habitual reliance on conventional building techniques, including preferences for well-established supply chains, regulatory compliance pathways, and workforce structures (Al-Raqeb & Ghaffar, 2025). Many stakeholders remain skeptical of 3DCP's ability to meet existing industry norms, leading to reluctance to transition from traditional craftsmanship to automated fabrication (Ma et al., 2022). Overcoming this inertia requires evidence of 3DCP's long-term reliability, regulatory adaptability, and integration within established supply chain frameworks (Gamage et al., 2024).

Quality Concerns – Functional Risk (7 occurrences) & Value (6 occurrences)

Concerns regarding layer bonding, porosity, and structural performance raise questions about the long-term durability of 3D-printed structures (Ali et al., 2022; Bazli et al., 2023). The absence of standardized testing methodologies for material performance under various environmental conditions contributes to skepticism about its functional reliability (Hasani & Dorafshan, 2024; Khan & McNally, 2024). Aesthetic inconsistencies and rough surface finishes necessitate additional post-processing, which increases costs, reduces time efficiency, impairs usability, and diminishes practicality (Ali et al., 2022; Al-Raqeb & Ghaffar, 2025; Bazli et al., 2023; Khan & McNally, 2024). The skepticism surrounding the quality and durability of 3D-printed structures relative to conventionally manufactured structures jeopardizes investor confidence and customer appeal (Ahmed, 2023).

Process – Usage (6 occurrences)

The intricate operational workflows of 3DCP, including printer set-up and calibration, material handling, and reinforcement integration, present significant challenges to workflow efficiency (Ali et al., 2022; Geneidy et al., 2019; Khajavi et al., 2021). The absence of standardized operational guidelines creates uncertainty regarding best practices, further hindering seamless integration into conventional construction methods (Geneidy et al., 2019; Graser et al., 2021). The conventional separation of design and manufacturing in 3DCP creates operational risks, including responsibilities and complete digital modeling of designs that cause potential errors (Buswell et al., 2008). The lack of automated error correction mechanisms also exacerbates

these challenges, increasing the risk of material extrusion and structural performance inconsistencies (Bazli et al., 2023).

Regulatory – Usage (5 occurrences) & Tradition (4 occurrences)

Regulatory approval processes for 3DCP remain inconsistent, mainly due to building authorities' lack of technical expertise (Graser et al., 2021). The absence of standardized review frameworks results in varied compliance interpretations, prolonging approval timelines and creating uncertainty for developers and contractors (Adamtsevich et al., 2024; Ko, 2022). Moreover, ambiguities in permitting procedures and compliance requirements add bureaucratic complexity, increasing project risks and discouraging firms from adopting 3DCP (Graser et al., 2023).

Beyond procedural inconsistencies, regulatory inertia presents a fundamental challenge to 3DCP adoption. Existing construction codes and legal frameworks were established to govern conventional materials and methods, making it difficult for emerging technologies like 3DCP to achieve seamless integration (Nhieu & Dang, 2024). Policymakers and regulatory bodies often default to traditional safety and quality benchmarks, which fail to accommodate the distinct properties of additively manufactured structures (Hasani & Dorafshan, 2024). As a result, the process of adapting regulations to support 3DCP remains slow, further reinforcing the dominance of conventional building methods and discouraging large-scale investment in 3D-printed construction (Al-Tamimi et al., 2023).

Inertia – Tradition (5 occurrences)

Construction sector stakeholders often adhere to established workflows, resisting adopting unproven methods (De Schutter et al., 2018; Ter Haar et al., 2023). Traditional brick-and-mortar construction methods have been refined over centuries, reinforcing confidence in their efficiency and reliability (Akman & Sadhu, 2024). Consequently, stakeholders favor well-established supply chains, regulatory pathways, and workforce structures, further impeding the transition to 3DCP (Chen et al., 2024). Overcoming this resistance requires compelling evidence of 3DCP's superiority in cost-effectiveness, structural integrity, and long-term viability.

Investment Reluctance – Value (5 occurrences)

Despite advancements in 3DCP technology, investors remain hesitant to allocate financial resources due to the absence of long-term financial case studies demonstrating apparent profitability (Adaloudis & Roca, 2021; Singh et al., 2023). This reluctance applies particularly to regions with low-risk tolerance for construction innovation (Potstada et al., 2016). The lack of comprehensive market validation and historical performance data further delays large-scale

investment as decision-makers struggle to justify significant capital commitments to technology with uncertain long-term returns (Adaloudis & Roca, 2021; Singh et al., 2023).

3.6.3 Under-Considered Inhibiting Factors

While the most frequently cited barriers provide a broad understanding of the resistance to 3DCP adoption, additional under-considered factors present nuanced challenges that can significantly impact its wider implementation. Though mentioned less frequently, these barriers highlight critical economic, legal, and operational obstacles that require further investigation and strategic resolution.

The underdeveloped supply chain for 3DCP creates economic and operational challenges, as the limited availability of specialized raw materials and proprietary printing equipment increases costs and restricts accessibility (Gamage et al., 2024; Graser et al., 2023). Inefficiencies in logistics and distribution networks further hinder large-scale adoption, preventing seamless integration into existing construction processes (Khan & McNally, 2024; Ng et al., 2022). Legal uncertainties exacerbate these issues, as ambiguity regarding liability, intellectual property rights, and contract enforcement raises significant risks (Ko, 2022; Ramadany & Bajjou, 2021). The absence of legal precedents and standardized regulatory frameworks complicates compliance, insurance, and contractual obligations, deterring widespread adoption (De Schutter et al., 2018; Ter Haar et al., 2023).

Economic uncertainty further compounds investment reluctance, as fluctuating costs related to materials, workforce adaptation, and capital expenditure make financial projections difficult (Josa & de la Fuente, 2024; Ma et al., 2022). The lack of long-term financial case studies prevents firms from accurately assessing potential returns, leading to hesitation in allocating resources (Ahmed, 2023; Momeni et al., 2025). This hesitancy is particularly evident in leadership resistance, where decision-makers embedded in traditional construction practices may perceive 3DCP as disruptive rather than viable (Al-Tamimi et al., 2023; Khajavi et al., 2021). The unwillingness of top management to allocate funding for experimentation and technological integration significantly slows industry-wide adoption (Bazli et al., 2023; Bos et al., 2022).

Furthermore, maintenance costs represent an overlooked factor in assessing the long-term viability of 3DCP. Although the technology offers construction cost efficiencies, concerns persist regarding the durability of printed structures, repair methodologies, and lifecycle costs (Hasani & Dorafshan, 2024; Xiao et al., 2021). The absence of empirical data on long-term maintenance expenditures adds to investor skepticism, reinforcing uncertainty about its financial feasibility (Ali et al., 2022; Robayo-Salazar et al., 2023).

Though less frequently discussed in academic discourse, these under-considered factors present substantive challenges that warrant greater attention. Addressing these barriers through targeted research, policy development, and industry collaboration will be crucial in fostering a smoother transition toward the broader adoption of 3DCP.

3.6.4 Moving from Theory to Practice

The SLR has provided a structured framework for understanding the barriers inhibiting 3DCP adoption in residential construction. This research has identified high-impact inhibitors, further takeaways, and under-explored factors that shape market resistance by mapping these challenges within the IRT framework. However, while the literature offers valuable insights, practical validation through industry engagement and market-specific research is necessary to refine these findings.

Future research should focus on empirical validation, industry collaboration, and policy interventions to bridge the gap between theoretical analysis and real-world adoption. Conducting a qualitative survey within the German construction market will offer contextualized insights and assess whether the identified barriers persist in practice. Integrating expert feedback, regulatory perspectives, and technological advancements will provide a more comprehensive understanding of 3DCP's market readiness and pave the way for actionable strategies to enhance its adoption.

Furthermore, the complex interplay of economic, technological, and institutional factors suggests that overcoming these barriers requires a multi-stakeholder approach. Industry associations, policymakers, and research institutions must work collaboratively to establish clear regulatory frameworks, workforce training initiatives, and incentives for technological investment. The role of public-private partnerships should also be explored, as they can provide financial support and risk-sharing mechanisms to facilitate adoption.

Additionally, academics should prioritize longitudinal studies and pilot projects to evaluate the long-term viability, cost-effectiveness, and scalability of 3DCP. By evaluating real-world implementations, future research can determine whether 3DCP meets sustainability targets, economic expectations, and structural performance benchmarks in various housing segments. Addressing these questions will be instrumental in transitioning from theoretical exploration to tangible industry transformation, ensuring that 3DCP becomes a viable solution in residential construction.

4 Empirical Validation of Barriers in the Research Field

This study employs an online survey targeting industry professionals to empirically validate the barriers identified in the systematic literature review. This empirical investigation aims to capture expert insights and assess the significance of the identified barriers within the German residential market, thereby contributing to a more comprehensive understanding of the peculiarities of this underexplored context.

4.1 Methodological Approach

This research is grounded in an epistemological framework that embraces qualitative inquiry, utilizing qualitative content analysis (QCA) and thematic analysis (TA) to systematically identify, categorize, and interpret resistance factors to 3DCP adoption. By contextualizing how resistance to 3DCP manifests across different stakeholder groups, the study categorizes these factors into the IRT framework to identify real-world variables that influence resistance in the German residential construction sector. This approach identifies recurring themes of industry resistance, facilitating a systematic and structured assessment of how these factors shape market dynamics. Qualitative research aims to describe, explore, understand, and explain social phenomena by eliciting non-numerical data, making it particularly well-suited for capturing industry professionals' nuanced experiences, interpretations, and decision-making processes.

The findings of the SLR were categorized using the IRT, which will also serve as an analytical framework for the empirical data obtained. This approach allows for a direct comparison between theoretical assumptions and real-world industry observations, ensuring the identification of country-specific characteristics that may diverge from established literature. The study bridges the gap between theoretical barriers and practical challenges by validating the SLR findings through industry engagement and empirical validation within the German residential construction sector. The QCA method enables a structured classification of survey responses, ensuring that resistance patterns are systematically mapped to IRT categories, while TA allows for emerging insights beyond predefined theoretical dimensions.

The following SRQ will emphasize the focus of this empirical validation:

How do these factors contribute to resistance against 3D concrete printing adoption in the German residential construction sector?

The SRQ refines the investigation by examining how these barriers translate into resistance to adoption and stakeholder perceptions of market feasibility. Given the study's focus on

resistance within the framework of IRT, it ensures a contextualized understanding of industry hesitancy and adoption challenges specific to Germany.

An online survey was selected as the research instrument to ensure a robust and comprehensive data collection process. This method enables broad participation across diverse industry professionals, overcoming geographical constraints and ensuring a representative sample of stakeholders in the German construction sector. Since the survey builds directly upon the findings of the SLR, the identified resistance factors were validated through a structured Likert-scale evaluation, ensuring alignment between theoretical insights and empirical data. The online format allows respondents to articulate their perspectives in detail, making it particularly effective in investigating barriers to innovation adoption in 3DCP. Alternative methodologies, such as purely quantitative surveys or experimental research, were deemed less appropriate due to their inability to capture the complex, subjective, and context-dependent nature of resistance to technological change. The literature supports the use of qualitative research in examining technology adoption barriers within the architecture, engineering, and construction sector (Algassim et al., 2023; Saka & Chan, 2020; Wang et al., 2019). This qualitative approach acknowledges that reality is socially constructed, complex, and multifaceted, emphasizing the importance of understanding the viewpoints of industry stakeholders (Algassim et al., 2023; Marjan, 2017).

4.2 Survey Design and Data Collection

The survey is structured to capture quantitative validation and qualitative exploration of the resistance factors identified in the SLR. Given the need to explore inhibiting factors affecting 3DCP adoption qualitatively, the survey consists of open-ended questions that retrieve expert insights and provide an in-depth understanding of the barriers in the German residential market. As qualitative methods allow for the emergence of unforeseen resistance factors, the open-ended responses will be analyzed utilizing TA, ensuring that new resistance themes get incorporated beyond the predefined IRT categories.

An English and German bilingual questionnaire seemed appropriate to reflect the study's focus on the German residential construction market. This bilingual approach enhances the validity and reliability of the collected data by ensuring accessibility to a broader respondent base while minimizing potential language-related biases. The survey ensures greater accuracy and contextual relevance in stakeholder insights by allowing participants to respond in their preferred language.

The target audience encompasses industry experts, stakeholders, and decision-makers within the construction and real estate sector, comprising professionals across various domains such

as architecture, general construction, real estate development, public entities, machinery and equipment suppliers, and research and development. By engaging a diverse set of industry participants, the study ensures a comprehensive and well-rounded understanding of both perceived and actual barriers to 3DCP adoption.

The survey comprises five key sections, structured around eight questions, systematically gathering relevant insights.

1. The first section captures respondents' professional roles, industry affiliations, and prior exposure to 3DCP. This information contextualizes the responses by allowing for analysis based on the level of expertise and industry segment representation.
2. The second section employs a five-point Likert scale to validate the relevance and significance of various resistance factors in the German market, with 1 indicating a low level of agreement and 5 representing a high level of agreement. The Likert scale, widely utilized in social sciences research, is a well-established measurement tool in qualitative research, providing acceptable reliability in assessing stakeholder opinions. Each item assesses a unique aspect of market resistance, allowing respondents to rate barriers regarding their perceived impact on 3DCP feasibility. This evaluation validates the SLR findings by determining whether the barriers identified in previous research align with industry realities or whether the German market exhibits unique resistance patterns that require further exploration.
3. The third section integrates open-ended questions to assess stakeholder perceptions of 3DCP resistance and the conditions necessary for broader adoption. The goal is to retrieve nuanced insights regarding deal-breakers versus manageable concerns. This section also identifies factors that may be inadequately represented in existing research, particularly those that are distinctive to the German market or absent from previous studies. Responses were analyzed using TA to capture emerging themes beyond the predefined IRT framework. The TA of the responses facilitates a more holistic examination of country-specific industry characteristics, enabling the identification of potential deviations from the established literature.
4. The fourth section provides space for additional comments and suggestions, allowing respondents to propose strategies for overcoming resistance. This section also includes a question assessing the industry's willingness to invest in 3DCP technology within the next five years. Understanding investment intent provides valuable insights into whether market hesitancy stems from practical concerns or whether structural barriers such as regulation and financing dominate resistance.

5. The final section collects demographic data, including age and education. The study intentionally omits gender-related questions as they are deemed irrelevant to its core objectives.

4.3 Data Analysis Approach

The qualitative data will be analyzed using QCA and TA, methods widely recognized for identifying recurring themes and linking them to real-world industry challenges. The analysis classified responses into IRT dimensions using a structured coding process and incorporated emerging themes through inductive coding.

The quantitative Likert-scale data will be analyzed using descriptive statistics, including mean scores, standard deviations, and response distributions, to identify the most significant barriers. The analysis ranks resistance factors according to stakeholder perceptions, identifying the most pressing challenges for 3DCP adoption. The Likert-scale evaluation was cross-analyzed with industry background data to determine whether specific professional groups or sectors perceive barriers differently.

For qualitative responses, QCA systematically categorized stakeholder comments into IRT dimensions. This structured coding process ensured that responses were mapped directly into pre-existing theoretical categories, maintaining consistency with the SLR framework. Additionally, TA was applied to detect emerging themes beyond predefined IRT dimensions. This inductive approach ensured that IRT did not explicitly cover stakeholder perspectives.

5 Research Findings

This section presents the findings of the study based on the descriptive statistical analysis of Likert-scale responses, complemented by QCA and TA of open-ended survey responses. The results are structured according to the IRT framework, categorizing resistance factors into functional barriers (usage, value, and risk barriers, including functional, physical, social, and economic risks) and physical barriers (tradition and image barriers). Additionally, emergent themes beyond the IRT framework get captured to address broader stakeholder concerns.

Google Forms supported the survey, incorporating skip-logic questions to enhance data reliability and integrity. A preliminary filter question excluded respondents with little interest in the research, reducing response bias and the risk of distorted results. Consequently, the final dataset comprises 40 responses, whereof 38 were fully completed, drawn from a broader pool of stakeholders in the construction industry. Personal distribution targeted 150 individuals, and social media channels extended the survey's reach. Analytical tools on these platforms indicated that the post reached an estimated 1,092 individuals, although precise engagement

metrics remain unavailable. These findings imply that attempts to maximize visibility did not yield widespread attention for the study's topic.

Before conducting descriptive analysis, researchers thoroughly reviewed the dataset to understand respondent demographics and experience levels. Respondents were predominantly 25 to 44 and exhibited a trimmed mean of 7.6 years of professional experience after excluding the lowest and highest 15% of observations. Most participants were from construction, project management, and real estate development (Figure 7). A significant portion of respondents, nearly half, had no prior experience with 3DCP but demonstrated interest in the technology. Likewise, 45% of participants reported moderate to extensive degrees of experience, highlighting a diverse mix of familiarity within the sample. The study excluded 5% of participants who expressed insufficient interest in the investigation.

In welchem Berufsfeld sind Sie tätig?

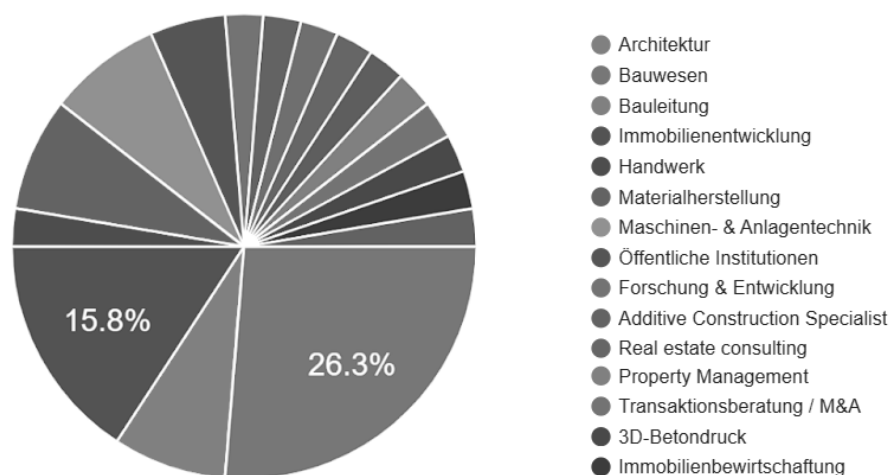


Figure 7. Occupational Distribution

A Likert-scale survey collected respondents' ratings from 1 (not influential at all) to 5 (extremely influential) to assess decision-making factors in the construction sector. The survey provided a structured approach to evaluating perceived influences and identified the factors that exert the most significant impact and display the highest stability through rigorous statistical analysis. Descriptive statistics, including arithmetic mean, median, range, variance, and standard deviation, were computed to analyze central tendency, variability, and distribution characteristics (Table 1). For enhanced interpretability, the analysis categorizes results into three variance levels: low ($\sigma < 1.05$), moderate ($1.05 < \sigma < 1.10$), and high ($\sigma > 1.10$), providing insights into the relative consistency and significance of different factors.

5.1 Most Influential Factors in the German Residential Market

Descriptive analysis of Likert-scale data identifies “*regulatory uncertainty*” as the most significant and stable barrier to 3DCP adoption in the German residential construction sector ($\bar{x} = 4.000$; $\sigma = 0.986$). Respondents consistently regard regulatory ambiguity as the primary challenge. This finding highlights concerns over unclear policies, compliance burdens, and legal ambiguities hindering wider adoption. Regulatory and approval barriers emerged as the most influential constraint. The lack of standardized building codes and approval pathways generates significant uncertainty, posing substantial compliance challenges for stakeholders. This regulatory ambiguity fosters reluctance to invest in 3DCP, as companies face unclear legal obligations and potential liability risks.

Other significant and stable barriers are “*high up-front costs*,” “*risk aversion*,” and “*lack of collaboration among stakeholders*” (Table 1). The high relevance combined with a low σ -value of the mentioned barriers suggests a strong economic reluctance and a lack of collaboration among stakeholders, leading to significant entry barriers for this technology.

Table 1. Descriptive Analysis of Research Findings

Inhibiting Factor	Arithmetic Mean (\bar{x})	Sample Variance (σ^2)	Sample Standard Deviation (σ)	Median
Regulatory uncertainty	4,000	0,973	0,986	4
Risk aversion/risk avoidance	3,842	1,110	1,053	4
Traditional construction practices and established methods	3,842	1,380	1,175	4
Unclear or missing building regulations and approval procedures	3,737	1,280	1,131	4
Unclear long-term cost-benefit ratio	3,711	1,292	1,137	4
Lack of industrial standards	3,684	1,249	1,118	4
Poor investment readiness	3,632	1,536	1,239	4
High up-front costs	3,632	1,050	1,025	3,5
High material costs	3,447	1,389	1,179	3,5
Economic uncertainty and unclear ROI	3,395	1,543	1,242	4
Process complexity	3,342	1,312	1,146	3,5
Customer acceptance	3,263	1,172	1,083	3,5
High industry fragmentation	3,211	1,198	1,094	3
Lack of collaboration among stakeholders	3,132	1,090	1,044	3
Perceived quality concerns	3,079	1,210	1,100	3
Lack of qualifications/skills	2,895	1,286	1,134	3
Public image and perception	2,553	1,173	1,083	3
Skillset gaps	2,447	1,173	1,083	2
Supply chain inefficiencies	2,395	1,326	1,152	2

Conversely, factors such as “*traditional construction practices and established methods*,” “*unclear long-term cost-benefit ratio*,” “*poor investment readiness*,” as well as “*unclear or missing building regulations and approval procedures*” in combination with a “*lack of industrial standards*” were perceived as significant but show a fair amount of disagreement among the respondents ($\sigma > 1.25$). Reflecting a more divided opinion among respondents. Divergent opinions indicate that industry stakeholders regard these barriers as less significant than regulatory uncertainty, which exhibits lower variance and more substantial consensus.

The opinions on “*economic uncertainties and unclear ROI*,” “*high material costs*,” “*process complexities*,” and “*high industry fragmentation*” are equally diverging, indicating a wide variation in perceived impact among respondents. While these factors were considered moderately significant for 3DCP adoption, their relevance is highly context-dependent. The successful integration of 3DCP into existing construction processes demands specialized expertise and a strong willingness to adapt, leading to a knowledge gap that acts as a barrier to adoption.

Furthermore, economic uncertainty exacerbates resistance, as the long-term cost-effectiveness and material expenses of 3DCP remain ambiguous, making investment decisions riskier. Moreover, “*customer acceptance*” also plays a crucial role in shaping market dynamics. The perception of 3DCP as a viable and reliable construction method influences demand, affecting the supply-side willingness to invest. Developers and suppliers may be reluctant to commit resources without sufficient consumer interest, reinforcing economic hesitation and further delaying widespread adoption.

In contrast, “*supply chain limitations*,” “*skillset gaps*,” and “*public image and perception*” issues were identified as the least significant barriers in the study. These inhibiting factors reflect a high convergence of perception among participants, suggesting a shared consensus that these factors are of relatively lower concern than other more pressing barriers ($\sigma < 1.10$). Industry stakeholders consider regulatory and financial concerns more significant obstacles than the logistical challenges associated with supplier networks. Public perception and end-user resistance do not decisively influence the industry's adoption of 3D concrete printing. The findings suggest that while these factors may contribute to the overall complexity of implementing 3DCP, they do not carry the same weight as regulatory ambiguity, economic uncertainty, and high investment costs. Consequently, addressing these primary constraints is more effective in accelerating the adoption of 3DCP than focusing on issues related to supply chains and public perception.

5.2 Country-specific Peculiarities

The survey results offer a structured perspective on the barriers to innovation adoption, categorized through the IRT framework. Among the most frequently mentioned obstacles is cost, which falls under the value dimension of IRT. Concerns about cost extend beyond the initial investment to encompass long-term financial burdens such as maintenance and integration expenditures. Many respondents also highlighted the uncertainty surrounding the cost-benefit ratio, as the lack of clarity regarding long-term financial returns further reinforces hesitancy. Additionally, regulatory uncertainty exacerbates cost concerns, as businesses remain reluctant to commit to investments due to unclear compliance costs and legal requirements.

Another critical factor is the need for government intervention in cost management, as respondents suggest that regulatory support or subsidies could alleviate financial concerns. Given the German market's stringent policies, compliance costs add another layer of hesitation, reinforcing firms' reluctance to invest in new technologies. This need for intervention is particularly relevant given the German market's regulatory landscape, where stringent policies often increase compliance costs and deter firms from investing in new technologies. Furthermore, while automation is often associated with cost reduction, many respondents pointed out that the persistence of manual labor in critical tasks (such as scaffolding, wiring, and plumbing) prevents significant cost savings, challenging initial expectations of economic efficiency. This resistance is rooted in economic factors and a preference for familiar, proven methods over untested innovations.

These concerns strongly align with the findings from the descriptive analysis, where cost-related barriers, including up-front investments and unclear financial returns, were consistently ranked among the top concerns. The alignment between these data points highlights the ongoing financial skepticism surrounding the innovation, emphasizing the need for more evident economic justifications and potential regulatory incentives to encourage adoption.

Regulatory and economic risks were also mentioned, particularly regarding the rigidity of legal frameworks and dependency on external entities. Classified under the functional risk dimension of IRT, these concerns reflect skepticism about the adaptability of regulatory environments to accommodate new technological solutions. Many respondents cited unclear or restrictive policies, such as a lack of standardized guidelines and legal uncertainties, which hinder investment and slow down the adoption of innovative practices. Additionally, some noted that political factors influence regulatory frameworks, further complicating the integration of new technologies. A significant concern is the lack of established standards, which makes builders reluctant to experiment with 3DCP due to uncertainties about compliance and best

practices. As regulatory challenges persist, respondents emphasize the need for clear, standardized guidelines to facilitate smoother adoption.

Descriptive analysis findings underscore regulatory uncertainty as the dominant challenge and highlight the necessity for industry-wide regulatory clarity and support mechanisms to facilitate smoother adoption. Qualitative and quantitative responses consistently identify the absence of cohesive legal frameworks and inconsistent policy enforcement as significant barriers. This alignment underscores the need for industry-wide efforts to create clear regulations and support mechanisms that enable smoother adoption. The reliance on existing processes, supply chains, and workforce specialization further raises concerns about the feasibility of seamless integration.

Resistance to change emerges as another significant barrier, closely associated with traditional practices and categorized under the tradition dimension of IRT. Respondents highlight a reluctance within the construction sector to deviate from established methods, particularly in cases where traditional craftsmanship is deeply valued. Emotional resistance, though not explicitly emphasized, is inferred through references to cultural attachment, suggesting that legacy practices may present a hidden yet powerful impediment to technological adoption. The industry's overall conservatism and risk aversion further reinforce this hesitancy. Many respondents indicated that the construction sector's traditional mindset makes it particularly resistant to disruptive innovations like 3DCP, as companies tend to favor familiar, proven methods over untested technological advancements. This cultural resistance creates a significant hurdle, making it difficult for new solutions to gain traction in the industry.

The descriptive analysis strongly supports this finding, where "traditional construction practices" ranked among the top three barriers to adoption. The alignment between qualitative responses and quantitative data highlights how deeply rooted this resistance is within the sector, further emphasizing the need for strategies that address cultural and structural inertia.

Industry professionals demonstrate insufficient awareness of the tool. Some respondents explicitly mention a lack of knowledge, while others do not respond. Their silence may indicate unfamiliarity, disinterest, or the belief that previously identified obstacles encompass all potential barriers. The finding reveals a hidden adoption barrier omitted from the IRT framework, as many professionals experience limited exposure to practical implementations of the technology. The issue is further compounded by the lack of integration into industry training programs and real-world demonstration projects, leaving many unsure about how to engage with 3DCP effectively. Without sufficient awareness, professionals struggle to recognize the potential advantages and limitations of 3DCP, further hindering informed decision-making.

Moreover, beyond general unfamiliarity, many professionals do not fully understand how to implement 3DCP effectively, slowing its adoption. Industry professionals require local adoption stories to establish trust in new technologies. The absence of widely recognized examples, particularly in Germany, intensifies skepticism, revealing a gap not only in available knowledge but also in the demonstrated feasibility within relevant market contexts.

Education remains a crucial component in bridging this knowledge gap. Respondents suggest that incorporating 3DCP into university curriculums and professional training programs could foster industry-wide adoption by ensuring that future professionals can effectively integrate the technology. Without such structured learning pathways, the industry may struggle with hesitancy and fragmented knowledge dissemination, reinforcing existing barriers to adoption.

Even among those familiar with the technology, some respondents argue that 3DCP does not seamlessly integrate into real-world construction workflows, raising concerns about its compatibility with established industry processes. This disconnect suggests that disengagement is not solely a result of resistance to change but rather stems from the tool's perceived incompatibility with industry needs. The fragmented nature of the construction sector further compounds this issue. Given its division into multiple trades with distinct priorities, integrating a tool designed for cross-functional utility proves challenging due to a lack of centralized coordination. This structural complexity reinforces barriers to adoption beyond traditional resistance factors.

Some respondents question the broader viability of the tool beyond its specific use case. They perceive the tool as a complementary construction method instead of a disruptive innovation. This observation echoes concerns regarding scalability and practical feasibility. Doubts remain about whether 3DCP applies effectively to large-scale projects and if its advantages extend beyond specialized applications. Respondents argue that hybrid approaches offer a more viable solution, including integrating 3DCP within modular construction frameworks. This method employs automation in contexts that benefit from it while retaining traditional techniques when necessary.

Industry professionals regard the market perception of 3DCP as viewing it as an additional tool in the construction ecosystem rather than a revolutionary shift. This skepticism influences consumer demand, a decisive factor in determining the technology's long-term success. End-users such as developers and clients may not recognize the substantial value in 3DCP beyond cost efficiency and design flexibility, which may limit its widespread adoption. Scalability, perception, and market acceptance collectively shape the potential trajectory of 3DCP adoption.

Overall, the findings illustrate a multifaceted resistance to innovation within the construction sector, shaped by economic concerns, entrenched traditions, regulatory constraints, skepticism about automation, and an overall conservative industry mindset. These interwoven barriers suggest that overcoming resistance will require coordinated efforts across policy, education, and industry collaboration. While some barriers are explicit, others manifest in more implicit ways, reinforcing the complexity of technology adoption in this industry.

The German market exemplifies these challenges, where a combination of stringent regulations, sector fragmentation, and cultural attachment to traditional craftsmanship significantly hinders the adoption of new technologies. The industry's established reliance on proven methodologies creates additional inertia, making it difficult for disruptive innovations like 3DCP to gain traction. Moreover, risk-averse investment tendencies in Germany exacerbate economic concerns, as firms hesitate to allocate resources to technologies perceived as unproven or outside existing regulatory frameworks. These market-specific peculiarities further highlight the structural resistance to change and the need for targeted strategies to facilitate adoption.

5.3 Investment Willingness and Market Polarization

An additional aspect explored in the survey is the investment willingness of participants regarding 3DCP, revealing an intense polarization in opinions. While some respondents express enthusiasm and are already planning investments, others remain undecided or reject the idea entirely. The right-skewed distribution indicates that non-investors predominate, though a smaller, highly engaged segment sees strong potential in 3DCP and is eager to invest (Figure 8).

A substantial standard deviation in responses indicates divergence among actors. Some actors consider 3DCP a transformative innovation that warrants early adoption, while others hesitate because unclear regulatory frameworks, cost structures, and scalability issues deter them. Broader survey findings consistently identify economic uncertainty, industry conservatism, and regulatory barriers as key obstacles. Investment risks appear closely linked to concerns about 3DCP's scalability, feasibility for large-scale applications, and market demand. Consumer demand remains a decisive factor, with some respondents emphasizing that end-user interest will ultimately determine whether 3DCP achieves widespread adoption. Additionally, the market perception of 3DCP as a supplementary tool rather than an industry-wide game-changer contributes to investment reluctance among traditional industry players. This right-skewed distribution of investment willingness suggests that while early adopters see strong potential, the majority remains hesitant, reinforcing broader concerns about scalability and regulatory uncertainty.

Inwieweit zieht Ihr Unternehmen oder Ihre Organisation eine Investition in 3DCP innerhalb der nächsten fünf Jahre in Betracht?

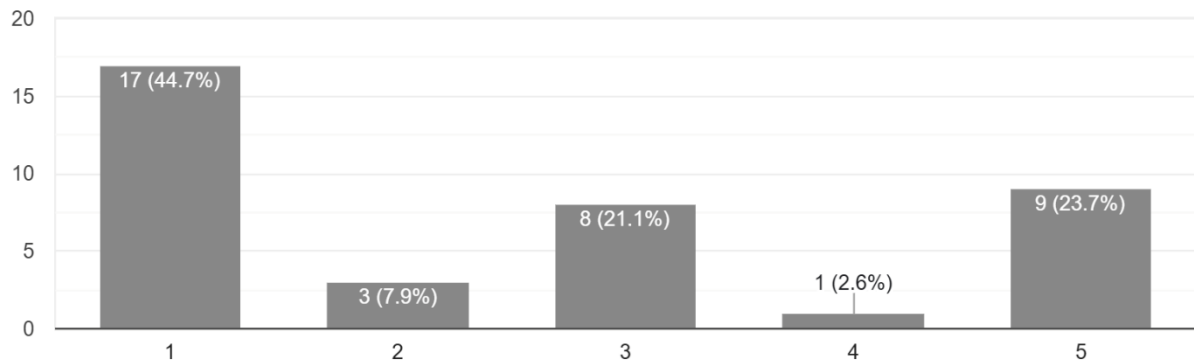


Figure 8. Investment confidence among respondents

The pronounced divide in investment willingness underscores that the future adoption of 3DCP depends on resolving key structural barriers, particularly those tied to regulatory uncertainty and cost feasibility while ensuring more transparent financial frameworks. While a subset of respondents expresses strong enthusiasm, their confidence alone may not be sufficient to drive widespread adoption, especially when investment risks remain closely tied to scalability concerns and the lack of a clear regulatory framework. Targeted support mechanisms, such as subsidies or more precise policy guidelines, were identified by some respondents as potential factors that could encourage undecided participants to invest. Ultimately, narrowing the gap between early adopters and cautious investors will be essential for fostering broader market acceptance. Some respondents indicate that hybrid construction methods, combining traditional and additive manufacturing techniques, may offer a transition approach for hesitant investors not ready for full commitment to 3DCP.

6 Discussion

The findings from the survey reveal several critical barriers that hinder the adoption of 3DCP. Respondents identified concerns regarding cost, regulatory uncertainty, market perception, and technological scalability, aligning with the IRT categories. These factors create a landscape where investment hesitation predominates, as indicated by the right-skewed distribution of investment willingness.

6.1 Barriers Hindering 3DCP Adoption

Economic risks dominate discussions surrounding 3D concrete printing. Significant initial investments in hardware, software, and workforce training increase financial resistance, particularly among smaller firms with limited fiscal flexibility. Survey participants identify high material and production costs as limiting factors. The systematic literature review supports these findings by pinpointing initial research and development investments and uncertain returns on investment as major deterrents (Adaloudis & Roca, 2021; Gamage et al., 2024). The lack of financial predictability appears to be a critical reason why non-investors outweigh early adopters, as echoed in previous research emphasizing the financial instability associated with emerging construction methods (Bazli et al., 2023; De Schutter et al., 2018; Ramadany & Bajjou, 2021). The high initial investment costs, including expenses for 3D printing hardware, software, and workforce training, impose a significant financial burden, especially on smaller firms. Survey participants highlighted high material and production costs as limiting factors, aligning with findings from the SLR, which identify initial R&D investments and uncertain return on investment (ROI) as major deterrents (Adaloudis & Roca, 2021; Bazli et al., 2023; Gamage et al., 2024). The lack of financial predictability remains a decisive factor in industry hesitation, reinforcing non-investors dominance over early adopters.

Regulatory uncertainty remains a central barrier, as it significantly influences industry decision-making. Addressing this challenge through more explicit regulatory frameworks and consistent policies could reduce investment hesitation and facilitate wider adoption. Many respondents described unclear legal frameworks and certification requirements as obstacles to investment. The literature consistently reveals that no standardized regulations for 3DCP materials and construction processes undermine industry confidence (Adaloudis & Roca, 2021; Graser et al., 2023). Respondents further noted that existing policies favor traditional construction, making it difficult for 3DCP to gain institutional legitimacy, a challenge similarly highlighted in global market analyses (Josa & de la Fuente, 2024; Potstada et al., 2016; Sovetova & Calautit, 2024). Regulatory uncertainty remains the most stable and influential factor in industry decision-making. Addressing this challenge through more explicit regulatory frameworks and policy consistency could significantly reduce barriers and encourage investment. Many

respondents described unclear legal frameworks and certification requirements as obstacles to investment. The literature echoes these concerns, highlighting that the lack of standardized regulations for 3DCP materials and construction processes hampers industry confidence (Adaloudis & Roca, 2021; Ahmed, 2023; Buswell et al., 2008). Respondents further noted that existing policies favor traditional construction, making it difficult for 3DCP to gain institutional legitimacy.

Beyond financial and regulatory constraints, technological scalability, market perception, and entrenched traditional construction practices emerged as influential barriers. The sector's reliance on conventional materials, supply chains, and workflows presents a significant obstacle to adopting innovative techniques, reinforcing hesitation toward disruptive methods such as 3DCP. Survey participants expressed divergent opinions regarding whether 3DCP constitutes a transformative innovation or a complementary tool. The systematic literature review indicates that limited real-world applications contribute to doubts about the feasibility of 3DCP for large-scale projects (Adaloudis & Roca, 2021). A significant share of respondents also expressed concerns about supply chain reliability and skill shortages, further complicating adoption.

6.2 Industry Strategies to Overcome Resistance

The study revealed valuable insights on remedial actions to overcome common challenges. One of the most frequently proposed solutions was cost reduction through optimized production processes and government subsidies. Participants recommended reducing material costs and increasing manufacturing efficiency to boost 3DCP competitiveness. Scholarly literature supports policy interventions to facilitate emerging technologies (Adaloudis & Roca, 2021).

Respondents cited the need for regulatory clarity, simplified certification processes, and standardized building codes. The systematic literature review reveals that ambiguous certification requirements create uncertainty and deter investment (Gamage et al., 2024). Harmonized regulations similar to those developed for other emerging construction methods may significantly increase the adoption of 3DCP.

Market analysis identifies increased awareness and educational initiatives as critical interventions. Beyond individual training programs, trust-building initiatives must extend to industry stakeholders. Collaboration among manufacturers, policymakers, and early adopters demonstrates real-world applications and successful projects while reinforcing credibility. Many respondents recommended university programs and industry workshops to bridge the knowledge gap. The literature supports this approach, indicating that lack of specialized training is one of the most significant barriers to widespread 3DCP adoption (Bos et al., 2022;

Geneidy et al., 2019). Establishing formal educational pathways could facilitate greater industry acceptance and skill development.

6.3 Bridging the Gap Between Industry and Research

One of the most striking findings in the discussion is the divergence between industry perception and academic insights regarding 3DCP's potential. A key concern among respondents is customer acceptance, with skepticism surrounding the reliability, durability, and aesthetic appeal of 3D-printed structures. The perception that 3DCP may lack the quality standards of traditional methods remains a significant hurdle. While survey respondents generally view 3DCP skeptically, literature findings suggest that technological advancements in material science and automation could mitigate many existing concerns. The hesitation among non-investors may stem from a lack of exposure to cutting-edge developments rather than inherent flaws in the technology.

The literature suggests that hybrid construction approaches, integrating 3DCP with traditional techniques, may provide a more practical transition for the industry (Ambily et al., 2024; Ma et al., 2022; Placzek & Schwerdtner, 2024). Ensuring market viability without government subsidies poses a significant challenge. Developing sustainable business models enables 3DCP to compete against conventional construction methods and demonstrate long-term economic feasibility (Bazli et al., 2023).

Survey data indicate that many participants view 3DCP as a technology that requires full-scale implementation rather than gradual integration into existing construction processes. This perspective contrasts with the literature, which endorses incremental adoption strategies using hybrid methods to mitigate risk and foster acceptance. Bridging this gap through pilot projects and real-world demonstrations could recalibrate industry expectations and align them with academic findings on 3DCP's potential benefits (Gamage et al., 2024; Josa & de la Fuente, 2024; Singh et al., 2023). Establishing financial sustainability will require efficiency improvements, cost reductions, and scalable applications, addressing concerns about the technology's long-term viability (Adaloudis & Roca, 2021).

6.4 Policy and Market Adjustments for Sustainable Adoption

Regulatory uncertainty has consistently emerged as a central barrier to 3DCP adoption, with respondents highlighting the need for more transparent certification standards and streamlined approval processes. The literature reinforces these concerns, emphasizing that the absence of standardized regulatory frameworks creates significant hesitation among investors and industry stakeholders (Adaloudis & Roca, 2021; Graser et al., 2023). Addressing these legal ambiguities could enhance confidence in the technology, encouraging greater participation from both public and private sectors. The German market, in particular, presents unique regulatory challenges due to its stringent building codes and highly structured approval procedures, making policy reforms a decisive factor in facilitating adoption (Josa & de la Fuente, 2024).

Economic considerations play an equally critical role in shaping market adoption, as high initial investment costs and unclear return on investment remain significant concerns. The survey data suggests that financial incentives, such as subsidies, tax breaks, and low-interest loans, could ease the burden on smaller firms, which often struggle to allocate resources for experimental technologies (Bazli et al., 2023; De Schutter et al., 2018). Literature findings similarly argue that reducing economic risk through policy-driven incentives is a key strategy in supporting emerging construction technologies, particularly in highly cost-sensitive sectors (Ramadany & Bajjou, 2021). Ensuring that financial support mechanisms are effectively structured and targeted could improve accessibility, bridging the gap between early adopters and hesitant firms.

Education and workforce development enable the long-term viability of 3DCP. Respondents emphasize integrating specialized training programs into existing vocational and university curricula to equip professionals with the technical skills required for 3DCP applications. The SLR findings confirm that skill shortages hinder implementation, as transitioning from conventional to digital construction methods demands an expertise shift that institutions have not yet fully embraced (Ambily et al., 2024; Ma et al., 2022). Establishing structured training initiatives and certification programs would address this gap and increase trust in the technology, reinforcing its credibility within the broader construction sector.

A critical aspect of policy and market adjustments is the perception of 3DCP within the construction sector. The survey findings indicate that many industry professionals regard 3DCP as a standalone innovation rather than an integrated component of existing construction workflows, which limits its perceived applicability. However, the literature highlights hybrid construction models in which 3DCP complements rather than replaces traditional methods as a more practical approach to adoption (Placzek & Schwerdtner, 2024; Potstada et al., 2016).

Demonstrating the compatibility of 3DCP with conventional processes through successful case studies could foster trust and acceptance, particularly in conservative markets such as Germany, where traditional craftsmanship remains highly valued.

Transparency and real-world validation efforts also play a decisive role in shaping industry acceptance. The lack of large-scale demonstrative projects has contributed to skepticism regarding the scalability and reliability of 3DCP, with both primary and secondary data highlighting the necessity of pilot programs to validate performance claims. Studies emphasize that providing precise, evidence-based data on material durability, construction speed, and long-term cost benefits is essential in overcoming market hesitancy (Gamage et al., 2024; Josa & de la Fuente, 2024). Implementing targeted demonstration projects supported by regulatory bodies and industry leaders could catalyze wider adoption by addressing technical and psychological barriers.

These policy and market adjustments are not standalone solutions but interconnected mechanisms that must work together to facilitate sustainable adoption. Regulatory clarity, financial incentives, workforce development, hybrid construction models, and increased transparency collectively contribute to an ecosystem where 3DCP can transition from an emerging innovation to a mainstream construction method. By aligning policy frameworks with industry needs and addressing region-specific barriers, particularly in structured markets such as Germany, a more strategic and coordinated approach to adoption can be realized.

6.5 Rethinking Adoption Challenges

Another limitation is the small sample size, which is not fully representative of the entire construction population but still provides valuable insights into emerging trends. A larger sample size could help improve the reliability of the findings, reducing the risk of downwardly biased variance and increasing the likelihood that the sample mean resembles the broader industry perspective.

The primary data analysis (research findings) compared with secondary data (SLR findings) reveals key differences in how industry professionals and researchers perceive barriers to 3DCP adoption. While both sources recognize regulatory uncertainty and financial constraints as central challenges, survey respondents focus more on practical adoption issues such as labor shortages, supply chain dependencies, and reluctance from established stakeholders. These factors receive less emphasis in academic literature, which instead highlights advancements in material science, automation, and hybrid construction methods as promising solutions. Divergent perspectives indicate that operational constraints shape real-world adoption, while academic research fails to address these constraints fully. This contrast underscores the need for a practice-oriented approach to assessing innovation.

While academic literature presents 3DCP as a scalable and efficient alternative, discrepancies arise regarding technological feasibility and market readiness, with industry respondents questioning its durability, large-scale applicability, and economic viability. While researchers highlight its potential, survey respondents remain skeptical about long-term durability, aesthetic appeal, and large-scale applicability (Bazli et al., 2023; Josa & de la Fuente, 2024). Additionally, investment willingness follows a polarized pattern in primary data, with many respondents dismissing 3DCP, whereas secondary sources suggest a more optimistic outlook (Ambily et al., 2024). This suggests that perceived financial risks shape industry hesitancy and the absence of proven large-scale case studies rather than an outright rejection of the technology, a trend similarly noted in international adoption patterns (Gamage et al., 2024).

These findings highlight a fundamental contrast between theoretical advancements and practical constraints. While researchers continue to refine materials, automation, and efficiency improvements, industry professionals remain concerned with market feasibility, workforce integration, and real-world application challenges. Addressing these concerns through pilot projects, transparent data on long-term performance, and regulatory standardization could help bridge the gap between innovation and industry-wide acceptance. By integrating practice-oriented research with technological advancements, the construction sector may develop a more balanced and evidence-based approach to 3DCP adoption.

6.6 Comparing Global and German Market Barriers

A notable distinction exists between global perspectives from the SLR and the regional context of Germany, where strict regulations, a fragmented industry structure, and deep-rooted traditional craftsmanship create adoption barriers that are not as pronounced in other markets. While global literature acknowledges regulatory hurdles, German respondents frequently cite stringent building codes, prolonged approval processes, and industry-wide reluctance to embrace new technologies as significant obstacles. The conservative nature of the construction sector impedes change, requiring more than just technical progress but a fundamental shift in industry culture. This reluctance extends beyond firms to regulatory bodies, where the absence of clear guidelines raises contractor liability risks, complicates compliance with safety and quality regulations, and ultimately slows innovation.

Germany's cautious investment culture further reinforces skepticism, making financial incentives crucial for broader adoption (Adaloudis & Roca, 2021; Graser et al., 2023). Resistance to change does not arise solely from economic or technological concerns. A societal preference for stability over experimentation further contributes to resistance. Germany's bureaucratic structures and reliance on established, thoroughly tested processes generate inertia that delays the diffusion of three-dimensional concrete printing, contrasting

with trends observed in more innovation-driven markets (Josa & de la Fuente, 2024; Potstada et al., 2016). Structural challenges such as slow adaptation to new methods, fragmented market coordination, and dependence on conventional construction techniques further hinder innovation. The German construction industry, characterized by strict regulatory compliance and a strong tradition of craftsmanship, requires more than technical advancements to facilitate change (Ahmed, 2023; Sovetova & Calautit, 2024). A fundamental mindset shift toward digital construction technologies is necessary to align Germany with the faster-moving global market.

The role of government intervention in driving technological integration, promoting industry-wide education, and facilitating a broader cultural shift toward innovation is particularly vital in Germany, where private sector investment alone is insufficient to drive transformation. The entrenched adherence to conventional workflows and reliance on established construction methods present barriers beyond regulatory challenges. Without explicit governmental efforts to reframe innovation as an economic opportunity rather than a disruption, resistance within the sector may continue to delay widespread adoption (Buswell et al., 2008; De Schutter et al., 2018). A fundamental shift in regulatory frameworks targeted financial incentives and empirical validation of 3DCP's benefits will be essential to move beyond experimental applications toward mainstream adoption in Germany (Bazli et al., 2023; Ramadany & Bajjou, 2021).

Beyond regulatory and financial constraints, a significant challenge shaping Germany's hesitancy toward 3DCP originates in the practical feasibility of automating construction. Advocates promote 3DCP as an automated solution to labor shortages and inefficiencies; however, manual labor remains essential for completing construction projects. This reliance on manual processes raises concerns about the economic benefits of 3DCP relative to the substantial investment required for its adoption, particularly given that conventional methods already offer well-understood cost structures and workflows. Therefore, automation's economic viability must be critically assessed, particularly given the ongoing reliance on manual labor, to determine whether 3DCP presents a sufficiently compelling advantage over traditional methods (Wolfs, 2024).

Further skepticism exists regarding 3DCP's legitimacy as a transformative construction method. Some respondents argue that 3DCP is a solution in search of a problem rather than a response to a clearly defined industry need. Rather than emerging as a response to a critical industry challenge, 3DCP is often promoted as a solution for broader societal concerns post hoc, leading to skepticism about its fundamental necessity (Wolfs, 2024). Skepticism reinforces the perception that 3DCP functions as a tool tailored to specific construction needs rather than representing a transformative breakthrough. Many industry professionals suggest that its success depends not on disruptive potential but on its ability to provide tangible, practical advantages over existing construction techniques (Buswell et al., 2008; Gamage et

al., 2024). These insights highlight the need for 3DCP to demonstrate concrete economic and operational benefits rather than being positioned as an all-encompassing solution.

Regulatory uncertainty, economic hesitation, cultural resistance, and skepticism regarding technological necessity hinder the adoption of 3DCP in Germany. Addressing these challenges requires more explicit policies, economic incentives, and evidence of long-term viability to facilitate the transition of 3DCP from an experimental technology to an accepted construction method.

7 Conclusion and Implications

The findings of this study provide a comprehensive understanding of the barriers to 3DCP adoption by integrating insights from academic literature and industry professionals. This research identifies key constraints preventing widespread implementation through a systematic literature review and an empirical survey, highlighting gaps between theoretical advancements and practical challenges. The following sections summarize the main findings and discuss future research and industry development implications.

7.1 Summary of Findings

This study successfully addresses the research questions by identifying the primary factors impeding the market penetration of 3DCP in residential construction and examining how these barriers contribute to resistance within the German construction sector. The findings confirm that regulatory uncertainty, financial constraints, and technological skepticism are the most significant obstacles, aligning with insights from both academic literature and industry professionals (Adaloudis & Roca, 2021; Ambily et al., 2024; Bazli et al., 2023; Gamage et al., 2024). As revealed through the Web of Science database, the absence of prior research explicitly focused on the German market underscores the need for region-specific investigations to understand localized adoption challenges better.

This study employs a two-step approach to investigate obstacles hindering 3DCP adoption. First, a systematic literature review using the Web of Science database applies PRISMA inclusion and exclusion criteria. Researchers code the extracted data according to IRT to categorize key obstacles. The study then validates the theoretical foundation by contrasting these findings with primary survey data collected from industry professionals. The comparative approach reveals converging and diverging perspectives between academic insights and real-world industry experiences.

While academic literature emphasizes advancements in materials, automation, and efficiency, industry stakeholders remain hesitant due to concerns regarding cost, long-term reliability, and

regulatory uncertainty. The conservative nature of the German construction industry further amplifies these challenges, as strong adherence to traditional methods and bureaucratic rigidity slows the diffusion of innovative technologies (Josa & de la Fuente, 2024; Potstada et al., 2016). Additionally, findings indicate that 3DCP is often positioned as a solution in search of a problem, contributing to skepticism regarding its legitimacy and economic feasibility (Wolfs, 2024).

Despite these concerns, the study identifies regulatory clarity, targeted financial incentives, workforce development, and real-world pilot projects as potential pathways to overcome resistance. Addressing these barriers requires enhanced collaboration between policymakers, industry leaders, and researchers to align technological advancements with market needs.

7.2 Limitations and Further Research Needs

Research on 3DCP has expanded, yet the literature neglects the German market. A systematic literature review using the Web of Science database found no studies that explicitly analyze 3DCP adoption in Germany. This gap suggests that region-specific challenges such as bureaucratic rigidity, fragmented industry structures, and stringent regulatory constraints remain underexplored. Future research should localize investigations to examine the unique conditions of the German construction sector.

The primary survey suffers from a small sample size, limiting the study's scope. Although the survey captures relevant industry insights, high response variance indicates significant differences in stakeholders' perceptions of 3DCP adoption. Future research should incorporate larger, more representative samples across multiple industry segments to enhance statistical reliability and reduce response deviations. Longitudinal studies should track how industry attitudes toward 3DCP evolve in response to changes in regulations, financial incentives, and technological advancements. Research may determine whether resistance diminishes as 3DCP matures or whether fundamental barriers persist.

The study focuses primarily on industry and regulatory challenges, leaving consumer perceptions of 3D concrete printing largely unexplored. Future research must investigate public trust, aesthetic preferences, and investment willingness in 3D-printed structures, especially following pilot projects demonstrating real-world applications. The study further reveals uncertainty about 3D concrete printing's role within the construction ecosystem. Some respondents view the technology as a tool rather than a transformative innovation, which prompts examination of whether hybrid construction models that integrate 3D concrete printing with conventional techniques offer a practical adoption pathway. Additional research must assess the feasibility of these models.

Regulatory standardization remains a key area for further research. Without clear building codes and internationally accepted safety benchmarks, there is uncertainty among engineers, contractors, and regulatory authorities (Adaloudis & Roca, 2021; Ambily et al., 2024). Investigating how different regulatory environments influence the adoption and development of standardized quality control measures will be essential for broader implementation (Adaloudis & Roca, 2021; Ambily et al., 2024; Khan & McNally, 2024; Nhieu & Dang, 2024).

Finally, economic feasibility and cost-benefit analyses require further exploration. High upfront investment costs, uncertain long-term maintenance expenses, and material availability challenges remain significant deterrents to industry adoption (Al-Tamimi et al., 2023; Bazli et al., 2023). Future research should quantify the financial viability of 3DCP through comparative analyses with traditional construction methods, factoring in total project costs, labor savings, and long-term durability (Al-Tamimi et al., 2023; Bazli et al., 2023; Gamage et al., 2024; Josa & de la Fuente, 2024).

Addressing these research gaps will provide deeper insights into the practical, regulatory, and economic factors shaping 3DCP adoption. A comprehensive, evidence-based approach is crucial to transitioning 3DCP from an experimental technology to a viable, scalable construction method. Although skepticism remains, targeted measures such as cost reductions, regulatory reforms, and structured training programs could significantly improve adoption rates. Bridging the gap between academic research and industry requirements will be essential in determining whether 3DCP can evolve into a scalable and viable solution for the modern construction sector.

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Appendix

Appendix 1: Online Survey

Hemmende Faktoren des 3D-Betondrucks im deutschen Wohnungsbau

Sehr geehrte Teilnehmerinnen und Teilnehmer,

Ich lade Sie ein, an dieser Umfrage teilzunehmen, die im Rahmen meiner Masterarbeit im Fachgebiet digitale Transformation und globales Unternehmertum durchgeführt wird. Ziel dieser Studie ist es, die hemmenden Faktoren bei der Einführung des 3D-Betondrucks (3DCP) in Deutschland besser zu verstehen. Ihre Einschätzungen helfen, die identifizierten Barrieren aus wissenschaftlicher Sicht zu validieren und neue, bislang möglicherweise übersehene Hindernisse zu identifizieren.

Ihre Antworten sind komplett anonym und werden vertraulich behandelt und nur für wissenschaftliche Zwecke verwendet.

Dear participants,

I invite you to take part in this survey, which is conducted as part of my master's thesis in digital transformation and global entrepreneurship, to assess the inhibiting factors of 3D concrete printing (3DCP) adoption in Germany. Your insights will help to validate previously identified barriers and uncover new, underexplored challenges.

Your responses are anonymous and will be treated confidentially and used for academic purposes only.

* Indicates required question

Luca Sprio

B.A. Real Estate Management



Ich beschäftige mich mit Technologien und ineffizienten Prozessen. Wo andere Probleme sehen, sehe ich Chancen. Wie können digitale Lösungen die ineffizienten Prozesse der heutigen Zeit nachhaltig verändern? Welche Technologien verändern unser Verständnis von Wertschöpfung? Diese Fragen treiben mich um und genau deshalb bin ich hier: Um mich fachlich mit Ihnen auszutauschen, zu lernen und gemeinsam Innovationen zu schaffen.

My mind is set on technologies and process inefficiencies. Where others see problems, I see opportunities. How can digital solutions revolutionize today's inefficient processes? Which technologies are changing our understanding of value creation? These questions drive me and that's exactly why I'm here: to exchange ideas, learn from others and create innovations together.

1. Zustimmung | Consent *

Bitte bestätigen Sie, dass Sie an dieser Umfrage teilnehmen und Ihre Antworten für wissenschaftliche Zwecke verwendet werden dürfen.

Please confirm that you consent to participate in this survey and that your responses may be used for academic research purposes.

Mark only one oval.

Ich stimme zu | I consent

Ich stimme NICHT zu | I do NOT consent

Branchenhintergrund*Industry Background***2. In welchem Berufsfeld sind Sie tätig? ******What is your occupation?****Mark only one oval.*

- Architektur | Architecture
- Bauwesen | Construction
- Bauleitung | Construction Management
- Immobilienentwicklung | Real Estate Development
- Handwerk | Skilled Trades
- Materialherstellung | Material Manufacturing
- Maschinen- & Anlagentechnik | Machinery & Equipment Engineering
- Öffentliche Institutionen | Public institutions
- Forschung & Entwicklung | Research & Development
- Other: _____

3. Geben Sie Ihre Erfahrung in Jahren in Ihrem Fachgebiet an.***Indicate your experience in years in your area of expertise.****Als ganze Zahl eingeben | Enter as a whole number*

4. Haben Sie bereits Erfahrung mit 3D-Betondruck? ****Do you have experience with 3D concrete printing****Mark only one oval.*

- Ja, umfangreiche Erfahrung | Yes, extensive experience
- Ja, einige Erfahrung | Yes, some experience
- Nein, aber Interesse am Thema | No, but interested
- Kein Interesse am Thema | No interest in the subject matter

Wahrnehmung von 3D-Betondruck (3DCP) Barrieren*Perception of 3D concrete printing (3DCP) Barriers*

5. Welche der folgenden Barrieren behindern Ihrer Meinung nach die Einführung des 3D-Betondrucks in Deutschland am stärksten? *

Which of the following barriers impede the introduction of 3DCP in Germany?

Bitte bewerten Sie jede Kategorie

Please rate each category

Check all that apply.

	Überhaupt nicht Not at all	Wenig Slightly	Mäßig Moderately	Bedeutend Notably	Stark Extremely
Fachkräftemangel Skillset gaps	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fehlende Qualifikationen/Kompetenzen Lack of qualifications/skills	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Regulatorische Unsicherheit Regulatory uncertainty	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Risikoaversion/Risikovermeidung Risk aversion/risk avoidance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde Investitionsbereitschaft Poor investment readiness	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Anschaffungskosten High up-front costs	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Materialkosten High material costs	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unklare langfristige Kosten- Nutzen-Bilanz Unclear long-term cost-benefit ratio	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mangelnde Zusammenarbeit zwischen Stakeholdern Lack of collaboration among stakeholders	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hohe Fragmentierung der Branche High industry fragmentation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Traditionelle Baupraktiken und etablierte Methoden Traditional construction practices and established methods	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wahrgenommene Qualitätsprobleme Perceived quality concerns	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Prozesskomplexität Process complexity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lieferkettenprobleme Supply chain inefficiencies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Unsicherheit über langfristige Wirtschaftlichkeit Economic uncertainty and unclear ROI	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Fehlende industrielle Standards Lack of industrial standards	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fehlende oder unklare Bauvorschriften und Genehmigungsverfahren unclear or missing building regulations and approval procedures	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Öffentliche Image und Wahrnehmung Public image and perception	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kundenakzeptanz Customer acceptance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

6. Bitte erläutern Sie, welche spezifischen Aspekte der oben genannten Barrieren den größten Einfluss auf Entscheidungsträger im Wohnungsbau haben. *
- Please elaborate on which specific aspects of the aforementioned barriers you believe have the greatest impact on decision-makers in residential construction.*

Unterschätzte oder nicht erforschte Faktoren

Under-Explored or Unresearched Factors

7. Gibt es weitere Barrieren für die Einführung von 3DCP im Wohnungsbau, die bisher nicht ausreichend berücksichtigt wurden?
- Are there any additional barriers to the adoption of 3DCP in residential construction that may not have received sufficient attention?*

8. Welche Maßnahmen sollten ergriffen werden, um diese Barrieren zu überwinden? *
- What measures should be taken to overcome these barriers?*

12. **Bitte wählen Sie Ihre Altersgruppe aus. ***
Please select your age group.

Mark only one oval.

- 65+
- 55 - 64
- 45 - 54
- 35 - 44
- 25 - 34
- 18 - 24

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Abschlussfragen

Final Questions

9. **Inwieweit zieht Ihr Unternehmen oder Ihre Organisation eine Investition in 3DCP innerhalb der nächsten fünf Jahre in Betracht?**

To what extent is your company or organization considering 3DCP as a potential investment within the next five years?

Mark only one oval.

1 2 3 4 5

Gar Definitive Investitionsabsicht | Definitely planning to invest

10. **Haben Sie weitere Kommentare oder Anmerkungen zur Einführung von 3DCP im Wohnungsbau, die Sie mitteilen möchten?**

Do you have any additional comments or suggestions regarding the introduction of 3DCP in residential construction?

Demografische Daten

11. **Bitte wählen Sie Ihren höchsten Bildungsabschluss. ***
Please select your highest level of education.

Mark only one oval.

- Kein Abschluss | No formal education
- Realschule | Intermediate Secondary School
- Abitur | High School Diploma
- Berufsausbildung | Vocational Training
- Bachelorabschluss | Bachelor's Degree
- Masterabschluss | Master's Degree
- Dokortitel (Ph.D.) | Doctorate (Ph.D.)
- Keine Angabe
- Other: _____