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ARTICLE

Innovation Empowerment in Construction 4.0 by the Corporate Digital Responsibility (CDR)—Approach. A New Field of Scientific Research for the Digital Breakthrough

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ABSTRACT

The Architecture, Engineering and Construction Industry (AEC) undergoes digital transformation, one of the major drivers for technical innovation and dynamism to all working processes. Emerging technologies were only used to a limited extent due to the lack of will to innovate and the unavailability of appropriate orientation guiding users with a more comprehensible framework. The research defined a new gap in scientific research with the concept of Corporate Digital Responsibility (CDR) in Construction 4.0—a term representing the digitization of the branch. The traditionally conservative, highly fragmented industry is predestined for this given the advanced technology, human potential and appreciation of values. Understanding the complex possibilities of innovation and recognizing the potential impact on the sustainability of buildings and the built environment promotes the adoption of corporate responsibility. The implementation of digital strategies, secured by an adapted legal framework, would accelerate the overall human, societal and digital transformation. This primary research investigates the challenges affecting the adoption of Artificial Intelligence (AI). The study highlights in which fields CDR can significantly catalyze innovation to achieve efficient, economic construction life cycles. The study used a mix of methods with a structured literature analysis and expert interview surveys enabling a critical-reflexive analysis of key factors. It evaluates the key tasks to master technological feasibility. By assessing multiple expert perspectives, the study takes stock of the acceptance of new technologies. The findings are expected to inspire corporates, researchers and practitioners across disciplines. Necessary corporate steps are outlined in the study to lay the path for defining their own digital strategy. The study shows that new research questions require a holistic approach.

Keywords: Construction; CDR; Innovation; Digitization; AI; Digital transformation; Human transformation; Ethics; SDGs

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1. Introduction

Digital technologies and AI in Civil Engineering enable us to reflect on what we expect from them, allocating their support to human work, increasing safety, and determining ways to deal with risks and unintended consequences. When AI technology meets human interaction—with human, societal and environmental impacts—ethical and moral questions arise. Increasing technical feasibility leads to an increase in ethical social responsibility [1,2]. This debate is not new, but such a new approach in Civil Engineering offers a new area of scientific research. It is only since 2020 and 2021 that the interest in researching practically applied value-based engineering and scientific publications significantly increased [3,4].

Despite emitting 40% of global CO_2, consuming 50% of the global raw materials and 40% of energy [5], and a lack of skilled personnel, only each fifth company applies Building Information Modelling (BIM), not consistently throughout all working and project processes, the Construction branch still maintains a culture of resistance to change [6] and to using digital methods [7] and AI [8,9] though playing a pivotal role in achieving sustainability goals. The complexity of data, communication and reciprocal interdependencies between diverse factors of a project challenges the branch [10]. The branch's poor reputation is due to the overly manual nature of documentation and the absence of adequate digital adoption linked to decreased quality of work processes [11]. The irresponsible cost, time and quality management, limited availability of resources, inefficient supply chains [12] and low promotion of decarbonization are increasingly problematic [13]. Digital technologies and AI could improve and ease human work significantly. AI enables object and image identification, forecast and simulation modeling, machine and deep learning, augmented reality, Metaverse, ChatGPT, data structuring and smart communication in buildings and cities. These technologies, among other targets and not limited to urban infrastructure and environments, aim for transparency, ease human work, and increase efficiencies in all fields to achieve Sustainable Development Goals (SDGs). The study found that the application of digital technologies and AI significantly improves sustainable buildings and building life-cycles through efficient energy, building material and waste management, which directly impact the sustainability of architectural structures. For example, up to 20% of energy savings may be achieved through AI-based, self-learning technologies and CO_2 optimization using predictive maintenance. Additionally, AI optimizes the efficiency of processes by structuring complex data as a basis for human decision-making, building and infrastructure operations such as smart buildings. New technologies help to prevent cost and time overruns, e.g., by predictive monitoring and forecast models. They increase building safety by detecting safety hazards. In addition, AI and digital technologies enable highly efficient environmental impact assessments. Using sensors, detection and predictive modeling, these technologies help to identify potential environmental risks and propose remedial measures. Facilitating human work, structuring complex data, visualizing projects and providing real-time data are the advantages of AI. European and global AI strategies represent milestones to strengthen the sustainable application of AI (**Figure 1**).

Data and technical feasibility get more and more complex, and human, ethical, societal, environmental and legal impacts increase. So does the societal and environmental pressure on the branch to build sustainably [14,15]. This study investigated both how to adapt to these new human and technical changes responsibly and why the will to innovate [16] is key to success. People change and enable digital technological innovation [17]. Adapting the work of Franklin and Barratt [18,19], technology can add or remove value to work and life and have unintended consequences. Construction is a specific branch bearing high potential to develop and implement innovative technologies in agile environments [20] but also carrying an even greater obligation to meet its social, human, economic, and environmental responsibilities [21] and achieve the SDGs [22]. The study considers morals and values to offer guidance for dealing responsibly with digitization and AI [23], but

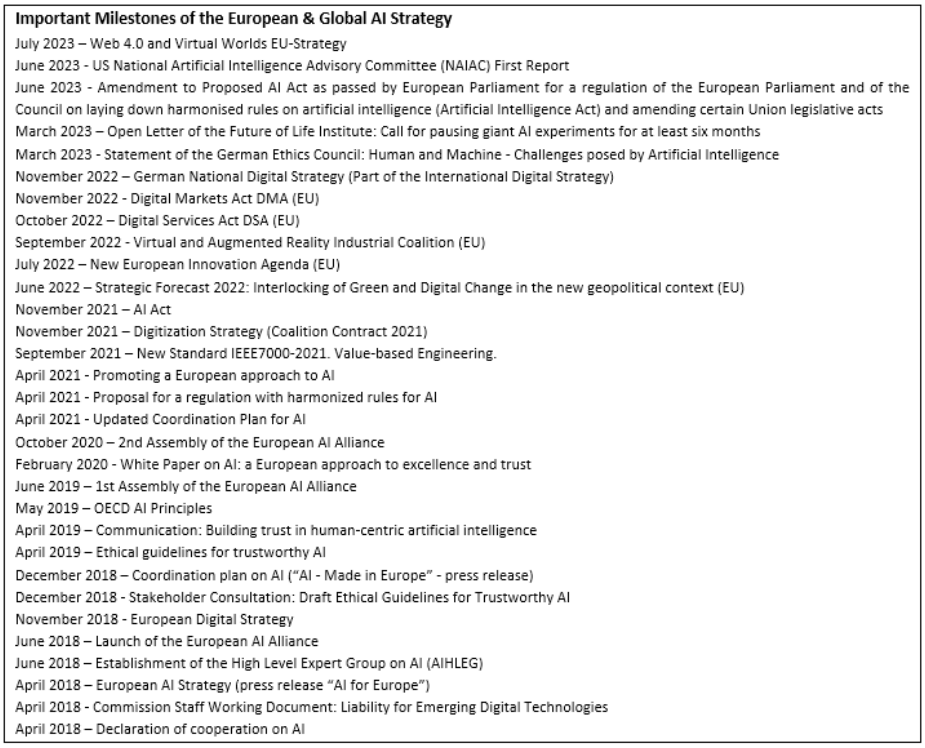

Figure 1. European and global AI strategy milestones.

Source: Bianca Weber-Lewerenz.

Construction 4.0 still lacks orientation in navigating new technologies knowing its risks and limitations, e.g., by ethical principles. High level institutions call for reflecting human-machine interaction [24] and even pausing giant AI developments [25]. Education and access to new knowledge [26,27], awareness, trustworthiness, safety and societal responsibility [28] represent the main pillars of overcoming conservative attitudes [29], strengthening innovation, improving efficiencies, achieving SDGs and shaping a sustainable environment [30,31]. It is said that AI in Construction will have a share of around 4.51 billion euros by 2026 [32]. The study found that ethical considerations are vital at the design stage of digital methods and AI as society becomes more and more reliant on technology. Consequently, with this research, a scientific niche in "Ethics in AI in Construction" has been defined. The research concludes that CDR lays the groundwork for value creation, efficient life cycles, sustainable ecosystems, protection of resources and strengthening diversity and inclusion. To address the identified gap and answer the research question of "*How shall a framework of corporate digital responsibility (CDR) be designed to support ethical digital innovation in Construction?*", it is paramount to critically investigate the specific objectives of this study: 1) Critically review the digital methods and AI applications, 2) identify challenges affecting the will to innovate and adopt innovative technologies, 3) understand the potentials, risks and impacts and 4) identify key elements and their interrelationship to set up a comprehensive, value-based CDR policy framework.

The study is divided into five steps: introduction, with a brief overview of the Construction Industry, new technological trends with their impacts, ethical observations and scientific approaches in technical fields. The second step establishes systematic review methods leading to the third step to assess and evaluate the information and, finally steps four and five, the results, discussion and conclusions.

2. State of the art

To fully grasp the gap in research, the study de-

scribes technical and ethical backgrounds and the milestones in the history of BIM and AI. Expert interviews with an interdisciplinary dialogue were carried out with representatives from construction practice, various disciplines, education, research and politics in order to open up this new field of research.

Many scientific articles on construction-specific challenges and the application of emerging technologies have been published, but more with technical decision support [33], operational [34-35,7] and safety focus [36]. Very little other research investigated the human factor and impacts of technology on society. Recent literature research focuses on new technical approaches for optimizing construction productivity and cost efficiencies [37,38], digital transformation balancing economic, environmental and societal impacts [39], e.g., through new digital business models [40], mostly from a stakeholder's perspective [41]. Ethics and social responsibility in Civil Engineering are broadly discussed in the context of holistic and comprehensive sustainability [42] rather than focusing on responsible development and application of innovative technologies to fully exploit their broad potential across the branch. When this research started in 2019, there was no literature in Construction investigating the human factor of digital transformation, nor analyzing unintended consequences of digital innovation. No literature was available to identify key elements that strengthen the human acceptance of innovative technologies in corporate environments, or on the concept of CDR tailored to Construction. No literature in the field could be found researching the multiple ethical, societal, and humane aspects of how a sustainable digital transformation enables reaching SDGs and to what extent the branch assumes its societal and ethical responsibility. **Figure 2** puts focus on such niche by visualizing the phases of development of the field of interest from its early beginning: Focus is given to column "CDR—Applied Ethics in AI in Construction". For each stage of the involved scientific field—from "AI" to "Ethics in AI" to "AI in Construction" to "CDR—Applied Ethics in AI in Construction"—the upper row introduces the corresponding state-of-the-art titled "Status of Research" while the bottom row titled "Discourse of Research" presents both results of ongoing research and shortly defines needs of missing scientific research. The left-hand side columns "Status of Research" and "Discourse of Research" are selected titles to split thematically and differ between the upper (status) from the lower sections (further required research). In the context of CDR, literature references and milestones are discussed, and ethical observations, gaps and limitations are critically argued to derive its first manifesto customized to CDR in Construction. In its last column, this figure highlights a potential new field of further research investigating "Use Cases", eventually by construction processes. This one has been crystallized as critical by the interviewees due to the expected practical corporate benefits. The interviewed experts focus on human, trust and societal responsibilities in all technical innovation considered as enablers of digital transformation. Further research could strengthen such approaches.

This study's primary contributions advance the body of knowledge with the first CDR policy framework [43]. This research aims for the ethical positioning to shape a human-focused digital transformation. It is all the more ground-breaking since it is dedicated to construction with an overlapping area such as AI ethics, which in other industries is sometimes awash with literature but seems to offer little that is new. This new field investigated the previously less recognized potentials and also the new risks, e.g., data transparency, protection of human and individual rights and natural resources, and adequate infrastructure (data capacity, high speed transfer, energy consumption for increased storage ventilation and cooling). This work assesses the ethical issues involved in digital transformation by setting up an interdisciplinary cooperation network with scientific representatives e.g., in ethics, philosophy, theology and law working already in the field of AI technologies and therefore their expertise in the designated interface is considered as adding value. It is also the first expert survey in the branch with respect to human and societal dimensions in AI and the overall transformation. It supports a deeper understanding of

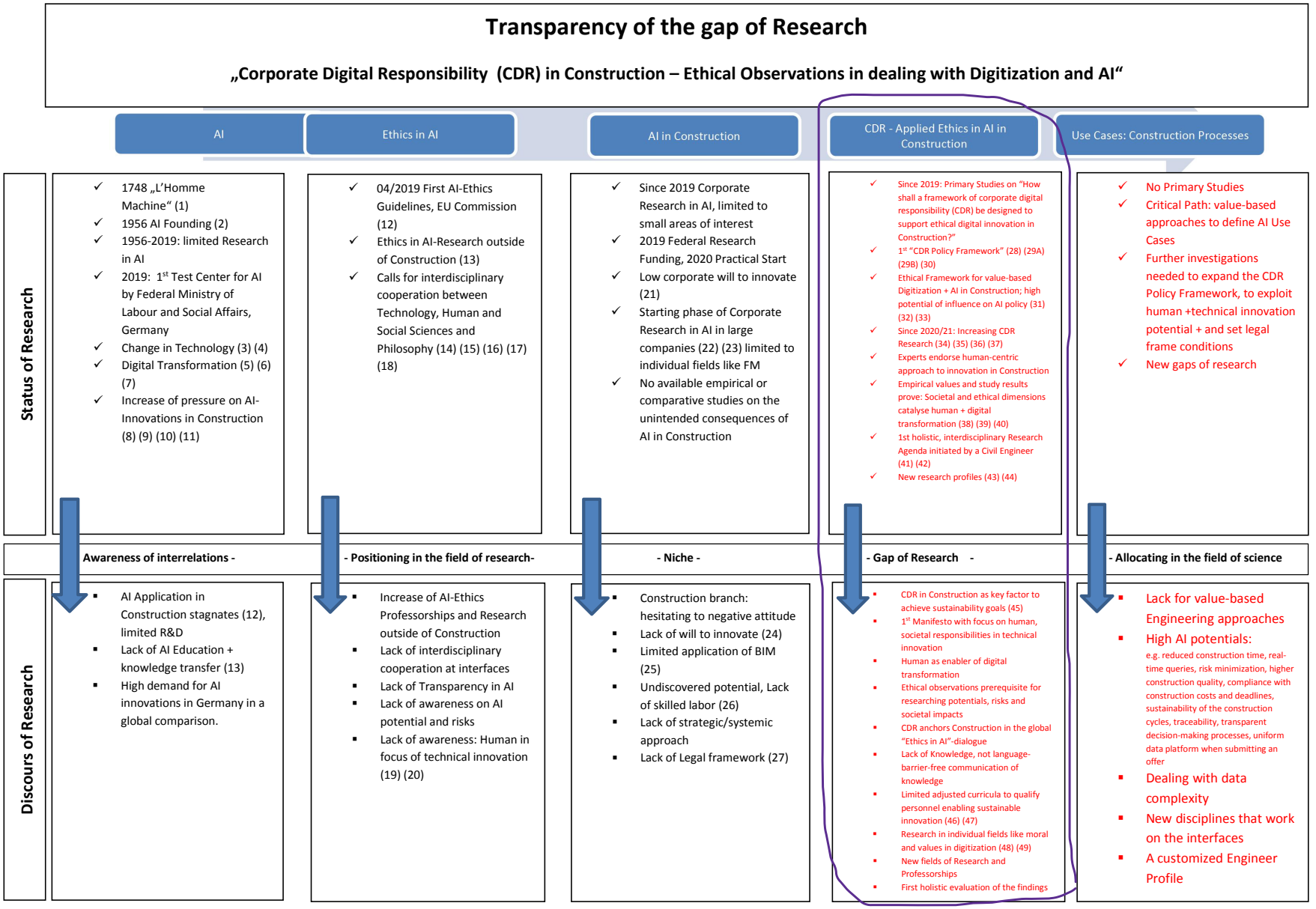
Transparency of the gap of Research
„Corporate Digital Responsibility (CDR) in Construction – Ethical Observations in dealing with Digitization and AI“
AI
Ethics in AI
AI in Construction
CDR - Applied Ethics in AI in Construction
Use Cases: Construction Processes
Status of Research
✓ 1748 „L'Homme Machine“ (1)
✓ 1956 AI Founding (2)
✓ 1956-2019: limited Research in AI
✓ 2019: 1st Test Center for AI by Federal Ministry of Labour and Social Affairs, Germany
✓ Change in Technology (3) (4)
✓ Digital Transformation (5) (6) (7)
✓ Increase of pressure on AI-Innovations in Construction (8) (9) (10) (11)
✓ 04/2019 First AI-Ethics Guidelines, EU Commission (12)
✓ Ethics in AI-Research outside of Construction (13)
✓ Calls for interdisciplinary cooperation between Technology, Human and Social Sciences and Philosophy (14) (15) (16) (17) (18)
✓ Since 2019 Corporate Research in AI, limited to small areas of interest
✓ 2019 Federal Research Funding, 2020 Practical Start
✓ Low corporate will to innovate (21)
✓ Starting phase of Corporate Research in AI in large companies (22) (23) limited to individual fields like FM
✓ No available empirical or comparative studies on the unintended consequences of AI in Construction
✓ Since 2019: Primary Studies on "How shall a framework of corporate digital responsibility (CDR) be designed to support ethical digital innovation in Construction?"
✓ 1st "CDR Policy Framework" (28) (29A) (29B) (30)
✓ Ethical Framework for value-based Digitization + AI in Construction; high potential of influence on AI policy (31) (32) (33)
✓ Since 2020/21: Increasing CDR Research (34) (35) (36) (37)
✓ Experts endorse human-centric approach to innovation in Construction
✓ Empirical values and study results prove: Societal and ethical dimensions catalyse human + digital transformation (38) (39) (40)
✓ 1st holistic, interdisciplinary Research Agenda initiated by a Civil Engineer (41) (42)
✓ New research profiles (43) (44)
✓ No Primary Studies
✓ Critical Path: value-based approaches to define AI Use Cases
✓ Further investigations needed to expand the CDR Policy Framework, to exploit human +technical innovation potential + and set legal frame conditions
✓ New gaps of research
- Awareness of interrelations -
- Positioning in the field of research-
- Niche -
- Gap of Research -
- Allocating in the field of science
Discours of Research
▪ AI Application in Construction stagnates (12), limited R&D
▪ Lack of AI Education + knowledge transfer (13)
▪ High demand for AI innovations in Germany in a global comparison.
▪ Increase of AI-Ethics Professorships and Research outside of Construction
▪ Lack of interdisciplinary cooperation at interfaces
▪ Lack of Transparency in AI
▪ Lack of awareness on AI potential and risks
▪ Lack of awareness: Human in focus of technical innovation (19) (20)
▪ Construction branch: hesitating to negative attitude
▪ Lack of will to innovate (24)
▪ Limited application of BIM (25)
▪ Undiscovered potential, Lack of skilled labor (26)
▪ Lack of strategic/systemic approach
▪ Lack of Legal framework (27)
▪ CDR in Construction as key factor to achieve sustainability goals (45)
▪ 1st Manifesto with focus on human, societal responsibilities in technical innovation
▪ Human as enabler of digital transformation
▪ Ethical observations prerequisite for researching potentials, risks and societal impacts
▪ CDR anchors Construction in the global "Ethics in AI"-dialogue
▪ Lack of Knowledge, not language-barrier-free communication of knowledge
▪ Limited adjusted curricula to qualify personnel enabling sustainable innovation (46) (47)
▪ Research in individual fields like moral and values in digitization (48) (49)
▪ New fields of Research and Professorships
▪ First holistic evaluation of the findings
▪ Lack for value-based Engineering approaches
▪ High AI potentials:
e.g. reduced construction time, real-time queries, risk minimization, higher construction quality, compliance with construction costs and deadlines, sustainability of the construction cycles, traceability, transparent decision-making processes, uniform data platform when submitting an offer
▪ Dealing with data complexity
▪ New disciplines that work on the interfaces
▪ A customized Engineer Profile

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Figure 2. Gap of research.

Source: Bianca Weber-Lewerenz.

the human-technology interaction between humans and technology in Construction. Recent activities and initiatives in the field of "Ethics in AI" e.g. by the German Ethics Commission [44], the European Union and the United Nations, and the Catholic Church [45] represent important strategies inspiring considerations in construction as part of the AI Strategy.

Major differences between this and other earlier review papers on this topic could not be drawn since such a topic represents a novelty in construction and has not yet been researched within this scientific discipline. The gaps this research addresses are recognized based on evidence in research and practice. While there are bibliometric reviews of sustainability and general ethical management in the construction industry, there is no holistic approach but a focus on technology and sustainability assessment methods. Therefore, the present study aimed to systematically review the literature in the field of ethics in AI in construction. In addition, it discusses the further development of qualitative methods of ethics in AI in construction and presents the state of the art in the surrounding area. It defines the gaps identified in the literature, which, however, only make up a very small part of this literature. The study evaluated and assessed ethical observations made in construction and defined key elements to apply emerging technologies to assume responsibility as a branch. The study's authors addressed ethical and societal questions towards ethicists, philosophical scientists, and theologists. Because of their engagement in debating AI ethics and human-technology interaction, it becomes clear that their considerations add value to this investigation and broaden the holistic scientific discourse. It is an essential part of ethics to evaluate human action and to methodically reflect on moral action. Certain values are an important prerequisite for achieving other values, so-called "enablers" of other values along the value chain. Circular economy, smart cities, and climate protection are just a few areas of interest in terms of ecological transformation, not only requiring improvements via technologies but also successful human transformation. Thus, this research studied new approaches to fully exploit the branch's human and technological innovation potential. Since its early stage, the published research findings raised awareness highlighting the diverse impacts and were able to add value to the scientific community. This study complemented previous work performed outside of Construction Engineering disciplines and without societal, humane, value-based considerations applied to Construction. However, because of the results' relevance to the overall sustainability in construction, the new approaches could only be defined by evaluating these previous results in comparison with developments and tendencies in Construction. Additionally, the status of research consists of limited application fields of AI—far away from its broad untapped potentials—and is limited by the lack of empirical or comparative research on the unintended consequences of AI and other innovative technologies and the lack of corporate individual digital strategies. In an early market phase, scientists are usually more familiar with the challenges of new applications than representatives from practice—due to the lack of practical experiences and users. This study designed and conducted expert interviews to investigate the status of corporate implementation of responsible digitization, get familiar with corporate practices and assess the degree of their assumption of responsibility towards the human factor. Such data are of particular interest for these scientific considerations. The reasons are diverse why experts consider recommendations and observed trends important for holistic understanding and share them in the surveys. One reason is, that the research field establishes a new territory. Only a minority of companies use BIM routinely. AI does not yet belong to daily working routine, but is often used for research purposes in test runs. Here, large companies take full advantage of their own research department in the first stages of developing new technologies having the required financial background. Thus, corporate case studies helped to analyze the niche of research by applying the qualitative, structured research methodology.

The observations made on practical applications provided adequate sources for this research. As a peripheral area, the scientific field is still new, and,

at the start of this research, there was only theme-related literature in other scientific disciplines, such research design with expert interviews seemed to be the most suitable method enabling new findings such as the motivations behind the use of technologies and the ethical societal impacts. Not only can evaluations of the results of such methods critically inform tendencies, human needs, and critical reflections on which technology makes sense, but also inspire new scientific approaches. Comparisons help to draw conclusions and make final generalizations basis for formulating trends. Public hybrid conferences and joint interdisciplinary scientific studies dealing with similar research questions were used as inputs for this research. It led to mapping key factors partly transferrable to the construction industry. The validity of the results could be confirmed by the exchange with scientists.

Technical and ethical backgrounds of the study

Offray de La Mettrie [46] introduced the term "man machine" into literature, broadly seen as the earliest time using the term "AI". Charles M. Eastman has been considered a BIM pioneer since around 1970 [47]. Working with BIM results in a uniform platform with project visualization, accessible to all project participants offering efficient project life cycles and processes. The term "AI" was first used in 1956 by John McCarthy, and other scientists for the first AI conference [48], who defined it as "the science and technology of creating intelligent machines" and "the science of making machines do things that would require intelligence if done by a human". A number of ethical guidelines have been published in recent years, but as normative recommendations aimed at exploiting the "disruptive" potential of new AI technologies. However, this research found that especially in the Construction Industry, ethics and values are key to maintaining a "healthy", sustainable machine-human interaction.

Technology is not value-free. Ethical, societal observations in technology are made in an interdisciplinary environment that mirrors the research question itself, based on the theories and approaches from human-technology interaction, Ethics in AI and robotics [49,50], digital and corporate ethics and philosophy. Ethical and technical perspectives enable a holistic approach to answer the research question. The following studies were very helpful in developing the CDR approach: Armin Grunwald and Hans Jonas [51-53], Technology Assessment [54], Technical Ethics [55], Value-based Engineering [56], BIM and the Digitization in Construction [57], Aristoteles and "Nicomachean Ethics" [58], Corporate Responsibility in Digital Change [59], Digital Ethics [60]. Ideally, the human-centered engineering approach helps to get to the bottom of the problem comprehensively as ethical, societal, and democratic values are the pivotal point of sustainability of all concerned fields of digital transformation. The research's new findings led to a joint study with the Fraunhofer IAO Stuttgart [61]. The "*Excellence Initiative for Sustainable, Human-Led AI in Construction*" was founded in 2020 to give the research field a name and promote its expansion [62].

The study transferred reflections of Ethicists and Philosophers onto the branch and—with similar assessments shared by Nothelle-Wildfeuer [63]—demonstrates the practice-orientation. Moreover, this research builds bridges between Engineering and Ethics.

3. Methodology

3.1 Data collection

The lack of research, application and users of AI in civil engineering, which is rather limited compared with other industry branches, represents additional challenges [64-65]. In early market phases, scientists assess new technologies and methods' opportunities differently than practitioners. With the start of this research in 2019, comparative research in other disciplines was limited [66]. AI research in AEC, being still in its infancy, offers very few empirical values from research and even less from application. Thus, an existing data set cannot be assessed as part of a quantitative method. Moreover, such evaluation would lead to insufficient analysis of

the status quo, solution approaches and trends. With this open challenge itself requiring a "next generation" research method mutual dependencies between human and digital transformation enable the access to new knowledge. Furthermore, the focus of this research is on applied sciences without deriving a theoretical model. With the objective to define gaps in the body of knowledge and identify future research trends, such a method is the most effective approach. It assesses the recent methods to evaluate the tendencies of suitable applied methods in this field [67-72]. This study applied expert interview surveys, direct observations and a literature analysis. The literature review supported to summarize existing research in closely related fields of interest [73-74]. It provided a conceptual framework facilitating direct future work to deepen research [75].

An additional challenge consists in the branch's structure and traditional behavior: This requires particularly close practical and corporate culture relevance, tailored to the typically small-scale Construction Industry. Current performed research on CDR in other fields such as Business Ethics [76-77], Communication and Media Ethics [78], Finance [79], Digital Ethics [80] and Information Communication and Technology (ICT) [81] do not provide an adequate understanding of CDR transferrable to Construction.

3.2 Expert interviews

The interviewed experts' familiarity with AI in Construction as well as with ethics, their corporate role, or in digital fields, research, development, and education, and their knowledge of processes, decision-making structures and tendencies were selection criteria for identifying and recruiting them for participating in the study. Both this chosen process and involving cross-discipline expertise led to new empirical values. These were evaluated against the background of explicitly stated criteria, such as the compatibility with social values and sustainability. Following the hermeneutic approach [82], expert surveys were developed and conducted to obtain more discussions on emerging technologies. Questions on how they define their digital strategy and to which degree they assume societal, political, environmental and digital responsibilities were included. Holistic approaches were derived contributing to the CDR concept. For systematically generating data, information was obtained about the current status of corporate implementation of technological innovations and the degree of success. In this scientific investigation, the is of particular interest. This applies to corporate experts' knowledge of management, project and decision-making processes and structures. The interviewees' shared knowledge makes up the majority of interview responses. and helped to identify impacts on people and society, to derive concrete constructive approaches. This research required some deviation from applying only one method for generating data thoroughly in this early phase of technical innovations [83-85]. A mix of qualitative methods emerged as the most beneficial methodical approach [86-87]. To relate it to the anticipated outcomes [88] and allocate the question of research in this niche, broad data were collected to define fields of problems. The applied method has been discussed in detail in a former article by the authors in this journal [89]. For an extract of the main expert interview questions, reference is made to the same publication.

The high degree of open design for the interviews and focus on practical aspects was another benefit [90]. Fifty expert interview surveys as part of the applied qualitative method were conducted over a period from 2019 to 2021 with a response rate of 90% by selected national and international experts from areas of innovation and digitization. Representatives of Engineering Associations, newly formed corporate and governmental departments for digital transformation, academic institutions, and Ethics and AI Institutes. The young age of the interviewees, between 30 to 45 years old, academically trained in new innovative fields of Engineering and IT mirrors the early phases of AI and digitization. Focus was put on 20 AI and ethics experts and 30 representatives from politics and business. The main research question guided the design of the interview survey questions. The questionnaire was developed along the main fields of interest: Digitization, AI, ethical observa-

tions, standards and guidelines, the potential of new technologies, corporate behavior regarding innovation, responsibilities, limits of new technologies and curricula. The focus was on the motives and expectations of the respondents. The interviewees' responses to further improve the structure of the questionnaire and sharpen some questions.

The evaluation was carried out as a summary content analysis [91] following an inductive procedure to draw a general conclusion [92]. The interview responses were documented in writing. Selected text passages were assigned to different categories, e.g., the interviewee's branch, role, qualification and technologies (e.g., AI, BIM, digital methods, others). These were split into subcategories: status of R & D (individual corporate timelines), innovation, practical experiences, expectations and trends. The collected data was reflected, and the content was analyzed [93]. Connections and similarities between the determined data were analyzed based on an interpretative evaluation following the hermeneutic approach [94-95]. A prescript and postscript were created to match pre-interview expectations with received responses. Similar results were obtained when the interviews were repeated with similar questions.

The study's analysis of recurring, particularly concise statements resulted in a very practical-oriented approach to defining key factors enabling human and digital transformation and needs for action. The study gained deep insights into critical reflections on allocated fields of responsibilities [96]. With the help of corporate and group comparisons, similarities and differences between individual respondents could be worked out, and final generalizations could be derived [97]. An important aspect of the success of the interviews was the simplicity and clarity of the survey, the results were easy to evaluate, data analysis was very straightforward, and the costs were relatively low.

3.3 Literature and data analysis

To identify existing AI applications and digital methods, their potential and impacts, database queries were run on Scopus, Google Scholar and WebofScience. Directly ranging from 1960 to 2023 modern AI research can be traced to the 1950s [98]. Over 60% of AI application research in Construction was done in the last decade [64]. **Figure 2** contains additional literature references which are listed separately from the general literature appendix in order to ensure that this presentation is self-explanatory. The inclusion criteria consisted of selecting publications based on abstract, title or full-text articles delivering values of experience in the applied areas in Construction. The research process included the definition of a database, the definition of review inclusion criteria and search parameters, the definition of the review exclusion criteria and content analysis. Databases with broad coverage of relevant academic articles were selected. The search terms "Construction", "Corporate Digital Responsibility", "Digital Twin", "AI", "BIM", "Innovation", "Smart Cities", "Smart Buildings", "Metaverse", "Augmented Reality", "Virtual Reality", "Ethics", "Responsible Digitization", "Value" and "Moral" were used to establish the conceptual boundaries of the review. Each article (article, conference paper, or review) should contain at least one search term. It finally led to selected literature dedicated to assessing innovative technologies' practical applications, impacts and existing cultural boundaries that both reduce the will to innovate and, thus, hinder the adoption in corporate environments. Cross discipline literature nourished new knowledge of the societal, ethical reflections on new technologies applied in Construction [99-101]. Filtering was done excluding literature not part of the fields of Engineering, digital transformation, ethics, technology ethics, or not written in English or German. The second criterion was the removal of articles in which the search terms only appeared in the references section. With a group of philosophers, theologians, ethicists, technology assessment experts and experts from the fields of AEC—only a few in this technical conservative industry were open for ethical, value-based reflections—the research started mapping out the terrain and debating the approach to a conceptual framework for the new field "Ethics in AI in Construction" anchoring the Construction

branch in the general scientific debate on trustworthy AI. A start of this progress has been made, as an Internet search in this field results in the publications of the author appearing immediately. Other resulting literature sources are either dedicated only to certain areas or too far from the subject.

This led the research to identify the research gaps through best practice use cases. Following Kitchenham [102], real-life experiences and observations provide adequate resources to meet the study's objectives.

4. Results and discussion

4.1 Results

This method helped to best allocate the CDR approach in construction but is subject to certain limitations. It was not always possible to classify answers in one category. Another limitation is that the results are derived from the perspectives of the 50 respondents. Different results could have been achieved by a study with a larger group of interviewees. The interviewees' statements were repeated very quickly, and let us conclude that a theoretical saturation was reached, thus, a larger sample would not have significantly influenced the results. Each potential review topic was discussed, and a feasible or not feasible responding approach was determined.

Determining the topic to be feasible depended on the setup of this research in Civil Engineering, and the availability of high-quality first-hand practical expertise. Some investigated areas needed further modification, e.g., adjustments to education and curricula, diversity and inclusion, digital infrastructure and customized digital strategies in relation to the size of the company. Feasible topics met all outlined criteria, e.g., SDGs, societal and human values. There are sufficient studies in other disciplines to justify the review in Construction and make a novel contribution without replicating an existing review. With its strengths and limitations, the research shapes a transparent, structured process with given key factors, in this CDR policy framework. Its implementation offers orientation to define a corporate digital strategy and catalyze responsible digital innovation towards reducing the environmental footprint of construction infrastructure, its energy usage and overall environmental sustainability. CDR aims to engage stakeholders and decision-makers in order to successfully master human and digital transformation in the branch. However, the approach of CDR recognizes the identified field of tension between expectations and fears facing new technologies (**Figure 3**) and specifically aims to allocate the requirements of the Construction branch, thus, the process may not be generalizable to other disciplines.

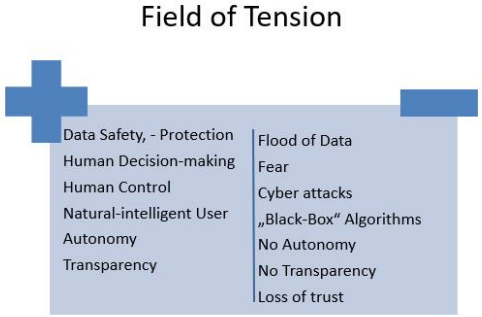

Figure 3. Field of tension.

Source: Bianca Weber-Lewerenz.

Modifications of the processes of digital and human transformation aim to improve sustainability. In order to keep the approach manageable this research used only one round of interviews and preliminary searches. Hence, some uncertainty about the evidence base for the different topics remains; feasibility can only be estimated based on available research. Furthermore, the selected stakeholders were limited to a small number of Best Practices considered as leaders in researching innovative technology. A broader panel of stakeholders would have likely provided additional input. Finally, as outlined, all described key elements were set against national and global strategy papers, political and societal initiatives compounding the challenges of providing timely systematic reviews for practitioners and policymakers.

This primary research is a transparent, structured approach to identify and prioritize a comprehensive CDR policy framework customized in construction strengthening the value-based corporate digital strat-

egy (**Figure 4**). The study identified key factors catalyzing profitability, efficiency and safety in a branch that lacks the will to innovate, qualified personnel, and has limited access to new knowledge.

Joint interdisciplinary scientific studies and co-authoring themed books gave access to new sources dealing with similar research questions. The research findings gained with greater reliance on the qualitative aspect underpinned by interpretation, significantly supplemented the current state of research and enhanced the broader discourse. The exchange with experts confirmed the validity of the results as unchanged at any time.

Some scientists therefore assume that this research will play a leading role [103]. Disciplines like medicine, law, information and communications technology (ICT) [104], social sciences, theology, ethics and philosophy recognized that discussing emerging technologies from a cross-disciplinary perspective is a prerequisite to conducting scientific holistic research. The research critically argues that technology's social and ethical impacts [105] have been neglected and now, with new technologies, need more attention to recognize the impacts of corporate cultural change in engineering and increase the will to innovate are prerequisites for resilience, agility and growth of companies [106]. With this research Civil Engineers made ethical, social and legal observations in the context of digital transformation in Construction towards a new way from the technical perspective to philosophically question the branch's rapid technical innovations recognizing long-term effects on humans and society, adding to the increasing pressure to assume responsibility. The survey inspires to companies practice-oriented solutions to move the branch's innovation forward. Interviewees from science and practice emphasized the need for bringing together the three correlating aspects "construction—new technologies—human factor" as the most productive and favorable approach to ensure the most success-critical factors of trust and knowledge. A professor of social psychology claims that many managers believe that human capital talk is psychotic nonsense. Others see that creativity, motivation and innovation are only possible through the involvement of employees and a corporate culture that relies on partnership and ethically oriented leadership [107]. This underlines the research's findings as the technological change in society has severe impacts on the change in economic value relevance. The increasing

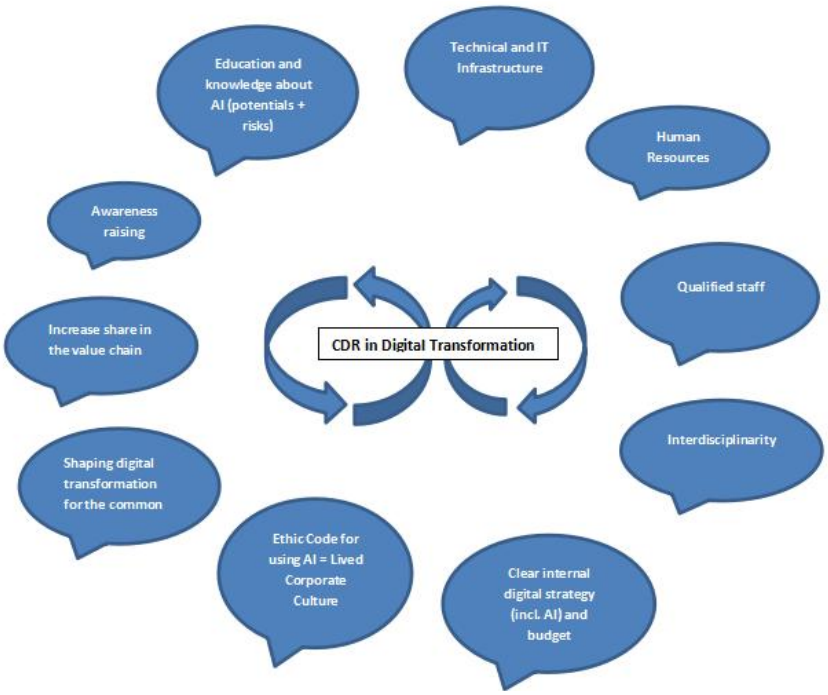

Figure 4. Key factors of CDR in digital transformation in Construction.

Source: Bianca Weber-Lewerenz.

importance of people as the core resource in the corporate value chain is positively recognizable. The voluntary corporate communication of intangible values in annual reports could strengthen the assumption of corporate responsibility. The CDR concept supports such a confidence-building approach. Adding value requires creating value, and vice versa. Transferred to the context of digital transformation, maintaining value-based engineering, which is the core of the new standard IEEE 7000-2021 [108], represents an asset. One, that creates new measurable profit and transparency on how and where one must invest in the human resource in order to create such assets and to responsibly shape technical and human change. Thus, CDR aims to practice a credible partnership of ethics (humans) and AI (technology) and increase their human capital index. Recognizing the unequally fast-growing technological development, evaluating the status quo demonstrates the increasing importance of such an approach [109] requiring further research. These principles are expected to be taken up by legislators and those who set the standards. When assessing the future viability of companies, intangible assets and human capital have gained importance. Reputation, innovative strength and competitiveness, know-how and competence, diversity, equal opportunities, inclusion and integrity are considered as indicators of how the company assumes digital responsibility in dealing with fundamental human rights, its environmental footprint and sustainability. It is an indicator of entrepreneurial success far beyond capital and profits. Particularly in times of crisis, it becomes apparent who successfully masters these challenges and can rely on innovative entrepreneurial skills. Two figures point out some areas from the perspective of the interviewees: **Figure 5** shows the result, when discussing technological feasibility, and **Figure 6** shows allocating limitations and ethical observations. Expectations of technological progress and research are high, and so is the related human need for orientation.

As a result of the evaluated interview surveys, the following indicators for embedding AI in Construction could be summarized. They show a general idea of the interviewees' allocated positive impacts of AI in the construction branch, against the status quo that only a small part of them actually develop, apply or deal with another form of AI.

Figure 5. Digital transformation in Construction.

Source: Bianca Weber-Lewerenz (created by Word Cloud).

Figure 6. Discussing limitations and ethical observations in Construction.

Source: Bianca Weber-Lewerenz (created by Word Cloud).

The indicators for embedding AI in Construction are diverse and complex:

- Minimize errors where people fail,
- Structured data complexity,
- Routine and standardized machine processes,
- Increase Cost and Time efficiency towards sustainable, responsible resource management,
- Increase knowledge and communication,
- Increase safety, transparency and quality of Construction,
- Monitor climate targets,
- Achieve SDGs,
- Increase new job profiles,
- Increase efficiency and attractiveness through innovation,
- Increase the branch's reputation,
- High social contribution to the change towards a climate-friendly society.

The evaluation concluded that the protection of

values and human rights can only be guaranteed and the human, technology and society interactions broadly accessed by the CDR policy framework, beyond voluntary commitments and guidelines. CDR is anchored in knowledge, trust and transparency with implications for value-based decision-making, and societal and environmental sustainable innovation strategies promoting responsible practices in Construction. Drawing the comparison that digital twins' simulation of buildings or smart cities means simulating human-oriented living and working environments [110] clarifies that social, societal, and cultural aspects beyond technical feasibility need attention. The research was able to refute the hypothesis that only software developers can supply data for the development of algorithms for AI applications in Construction. Expert interviews indicated that the industry itself can supply useful data. Although some interviewees perceive AI as "far away" from the branch and argue on the uniqueness of each project, ethical and moral aspects of technical innovation imply the increasing societal and environmental responsibilities of the branch.

4.2 Discussion

Recognizing the availability of new digital methods and AI tools to enlarge data networks, such technologies foot on recent fields of application. The newly won experiences enable to research its new potentials such as collaborative design, new business models and broadening CDR. These may finally lead to achieving SDGs, efficiency and high quality in more agile, resilient environments (**Figure 7**).

In the context of technical decision-making processes interviewees stress the complexity of weighing up potential and damage. However, applying innovative digital technologies responsibly means increasing the efficiency, profitability and safety of project life cycles. The CDR approach provides an orientation for a new culture of learning and thinking in corporate environments guided by ethical principles. One may critically argue that the discussion is not reserved for one discipline which would hinder the inclusive, diverse, agile working environment that companies expect in order to master the challenges. Corporate responsibility is increasingly influ-

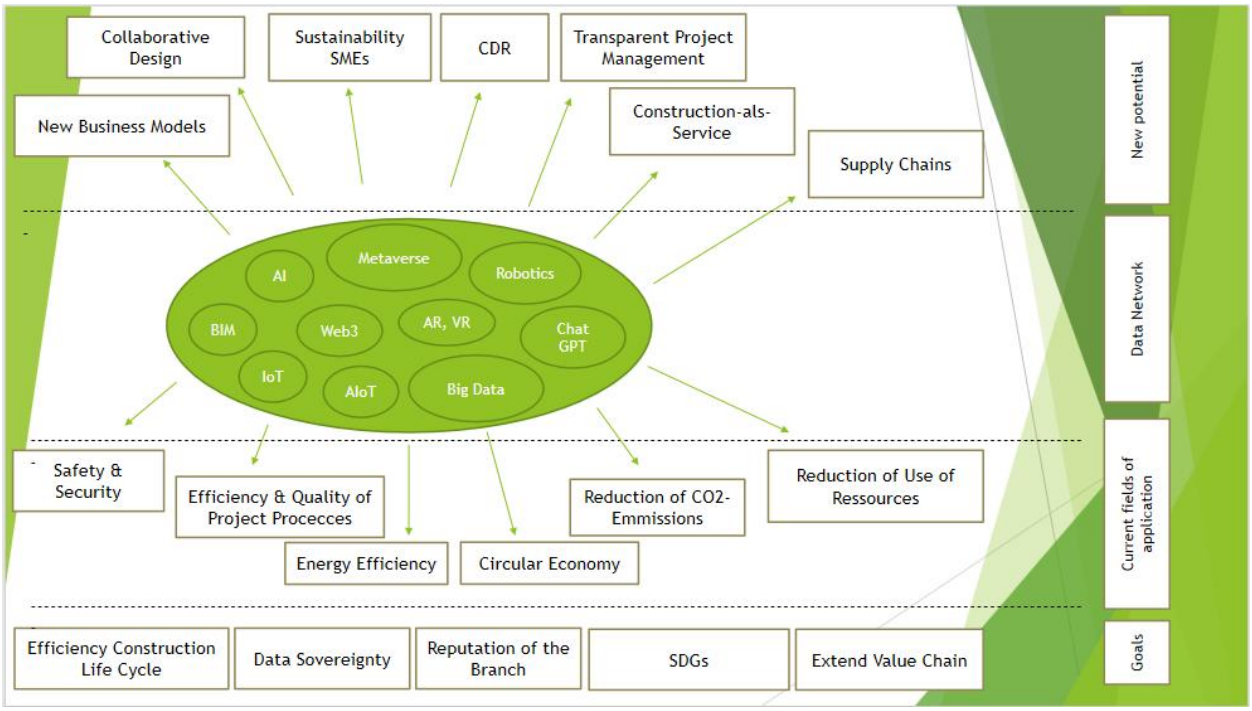

Figure 7. Data network value chain in Construction.

Source: Bianca Weber-Lewerenz.

enced by societal expectations to reach political, environmental, climate and sustainability goals. Some interviewees argue that ethics and value guidelines already exist. However, the research found that like the complexity of technical feasibility and its impacts on ethical orientation is subject to continuous change. The interview results put focus on the needs and hurdles in the Construction Industry:

- Value-based research and development and the sensible use of innovative technologies.
- CDR communication of ethics without language barriers.
- CDR as a living corporate culture.

Technical progress affects fundamental rights, human rights, occupational safety, data protection and data security in different ways. New measures apply to ensure security, data protection and transparency. Therefore, it is important to emphasize that AI in Construction helps solve many problems, but does not create new problems if risks are taken into account. This research's new insights help to break down prejudices and reservations.

This research lays the groundwork in Civil Engineering for researching new value-based approaches for achieving the UN SDGs and improving the branch's reputation. The interviewees noted technical innovation and adequate qualification are the pillars of success and sustainability. Despite ample interdisciplinary research, the discourse in the branch is still hesitant. However, this work recognizes the biggest limitations: AI is in its early development stage with rare experiences only available in a few large companies. The quantity of interviewed experts was small at the stage of conducting the interviews. Ethical observations could only be made outside of the Construction discipline, with Ethicists, Philosophers and social scientists, who are not familiar with the Construction branch. The majority of large and SMEs are still unable to handle projects consistently digitally though the pandemic proved that resilience and flexibility are key for being able to work without significant interruptions.

As the research deepens, the central question remains: How shall a framework of corporate digital responsibility (CDR) be designed to support ethical digital innovation in Construction? The result is that there cannot be one uniform framework applied to the branch, but instead CDR enhances individual corporate strategies with legal, educational, and societal guidelines. There are no quantitative systematic studies on this subject that target classifying the main characteristics of studies published in the literature. In addition, almost every scientific field individually and independently research sets its own standards. The Construction Industry still remains largely passive. Though Digital Twins and AI have been developed, there are no experiences with predictive methods increasing time and cost efficiencies, productivity, quality of construction, energy management and environmental protection. In recent years, ethical standards have been developed listing principles that technology developers should adhere to whenever possible and ensure corporate governance and compliance. However, do these ethical guidelines answer the new questions arising from developing and implementing technical innovation? Do these have an impact on assuming responsibility in the field of AI in Construction? The short answer is no. This research recommends potential fields of needed legal regulations as part of the CDR Policy framework to assume responsibility as a branch, as the EU Commission is striving for with the Digital Innovation Agenda 2022 [111], the Strategic Foresight 2022 [112] and the Task Force for Digital Common Goods [113]. The research finds that digital self-determination is increasingly considered as a task for the entire legal system to protect personal and project-related data and avoid data misuse. Thus, clarification is crucial to establish criminal law enforceable regulations as to who, where, for what and to what extent bears rights and obligations and is liable in case of disregard. In Germany there are no uniform standards regarding digital technologies and clients' and contractors' methods differ from project to project. Thus, faster problem solving cannot be achieved. To overcome these obstacles, accelerate digital transformation, create more jobs in innovative technology areas and increase cost and resource efficiency in the

construction lifecycle it is important to understand the impacts of and setting up adapted legislation: Legal certainty in AEC drives innovation and sustainability in equal measure. The study suggests setting a milestone with CDR that catalyzes efficient life cycles of buildings and improves ecological footprints [114].

According to Kiron, corporate digital responsibility is supported by a lived culture of values guided by ethical principles, but they are only used to a limited extent [115]. Value-based decision-making processes in corporate culture should be institutionalized globally [116]. The cultivation of a dynamic, agile, open and innovative corporate culture strengthens curiosity for additional knowledge, for constant innovation. The study's ethical observations are consistent with the views of the experts interviewed, but reveal broader ethical implications. Since the branch plays a crucial role in achieving the SDGs, the study goes a step further. It questions the existing legal framework, which is not in line with today's technical feasibility and is not in line with human, social and environmental values, but in particular, it establishes the direct link between the efficiency of the Construction Industry, building and material life cycles and the overall impact on people, society and environment. CDR represents the essential value-oriented orientation necessary for promoting a sustainable ecosystem in the digital age. The key is the sensible use of AI and the capture of company values (human, knowledge, innovation, share of added value to the society), and not the use of technology for the sake of technical progress and, as was the case for a long time, not purely profit-oriented. Therefore, a new thinking culture is required. If company management trains new technologies, communicates opportunities and risks and acts value-based, it generates new value and motivates new innovation. It lays fertile ground to use innovation for competitiveness and growth and to accelerate the achievement of the SDGs. The conclusion can be drawn, that the design of the societal, social, ethical and legal framework affects the overall dynamic of industry and society as a whole. The CDR approach in Construction 4.0 shifts focus from technical design to human, societal responsibility. It anchors the Civil Engineering discipline in the global "Ethics in AI" debate. It considers trustworthy AI and adjusted curricula as the most success-critical pillars of sustainable human and digital transformation. The research's approaches go beyond previous scientific investigations on general morals and values in digitization and define new fields of research. Due to the interdisciplinary exchange and the necessary close cooperation at interfaces, the otherwise usual disciplinary boundaries are no longer applicable. The human, social gain can now be presented even more transparently, as human values enable innovation and sustainable business growth in the Construction Industry.

5. Conclusions

The following key points emerged from the expert interviews, the literature analysis and the development of the CDR concept. The study found that trustworthy, responsibly used AI empowers human and technical innovation. Hence, this CDR policy framework has the transformative potential to drive ethical and responsible digital transformation in the Construction Industry. In fact, this research has practical implications for the Construction Industry and beyond, as it catalyses the transfer of knowledge into the application as well as the education sector and provides the key elements of practical expertise. It represents a value chain itself. The study's results support the need for the applied CDR. It strengthens resilient, agile and sustainable ecosystems that are not only limited to corporate environments but also serve to align decision-making and innovation with the common good. This CDR concept pursues a long-term strategy towards guiding the people shaping Construction with value-based reflections in dealing with modern technologies and the associated transformation processes. The constant cross-disciplinary search for new, innovative approaches remains the core of expanding this scientific niche. The methodical approach revealed practical corporate pioneers in the Construction Industry. However, the complexity of technical feasibility, data security and protection of social and human values can only be dealt with sustainably with the help of

ethical and legal orientation. To cope with changed corporate environments and job profiles the study recommends adapting curricula and rebooting ethics education. The construction industry could set a milestone with an innovative agenda and take credit for its entrepreneurial, social, legal and political responsibility.

Further in-depth research is recommended in the field of data sovereignty, human rights and diversity, and trust in technical innovation. The suggested CDR concept could elevate the branch to the next higher level of shaping sustainable ecosystems.

A novelty with this study is that for the first time ethical, societal observations in dealing with Digitization and AI are made, unexpectedly, from a civil engineer's perspective, but Complementing interdisciplinary discussion on technologies impacts. The growing awareness in the construction branch on innovations, new knowledge and the fact that the human factor is critical for utmost orientation and confidence-building measures, turned out to be the pivotal point of a sustainable digital transformation.

Author Contributions

This research article has been conceptualized and written by Bianca Weber-Lewerenz, supervised and reviewed by Prof. Marzia Traverso (Ph.D.). Both authors have done revisions of the draft.

Conflict of Interest

The authors declare having no conflict of interest.

Ethical Statement

The first author of this study conducts external research, is company-independent and is not financially supported by third-party funds, companies or other institutions. This enables neutral, critical, and inclusive research and promotion of ethical debate about AI technologies.

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