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Navigating Applied Artificial Intelligence (AI) in the Digital Era: How Smart Buildings and Smart Cities Become the Key to Sustainability

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Abstract: This paper aims to understand the critical path of digital transformation in construction by investigating major drivers for technical innovation, e.g., in smart cities. Despite available new technologies, increasing societal, environmental pressure, and data complexity, the branch lacks a will to innovate and qualified personnel. The study identifies the potential of innovation and the pillars of sustainability to define ways to responsibly use data-driven, smart technologies in smart cities throughout their holistic life cycles. The mix of expert interview surveys and structured literature analysis is the basis to examine the status quo and innovative approaches. It enables to critically investigate limitations and human, societal and environmental impacts. This study's findings offer orientation in navigating innovation for resilient, agile ecosystems with the dynamic ability to adapt to changing environment and to grow with the change and achieving the sustainable development goals toward preservation and upgrade of buildings instead of new construction. The key challenge for sustainable technical innovation is to exploit human and societal potential. The study allocates the lack of research in this field and inadequate education as most significant limitations and critically evaluates that a disruptive culture of thinking may enable the sustainable design of smart cities. This study is unique as it develops a comprehensive, transparent Corporate Digital Responsibility Policy Framework and provides orientation to assume ethical, societal, environmental responsibility as part of creating resilient, agile environments.

Keywords: construction, CDR, digitization, BIM, AI, digital twins, smart cities

1. Introduction

Creating smart cities includes both new construction of high-tech infrastructure and buildings and integrating intelligent building automatization systems into existing buildings according to modern standards and sustainable development goals (SDGs) and also in line with climate and ecological strategies. The author's primary research on Corporate Digital Responsibility (CDR) in Construction 4.0. investigates the complexity of influencing factors on all human, societal, technological, economical, and legal levels along technical feasibility which develops at high speed. This phenomenon is new and represents a key challenge for both human and digital transformation in the digital era. Based on the latest state-of-the-art methods, this study approaches such challenge by applying the qualitative method using expert interview surveys and a structured literature analysis. For the holistic approach, the study assesses major drivers for technical innovation and critical elements of risks and chances of designing and implementing new technologies in construction such as digital twins, artificial intelligence (AI), and Metaverse without neglecting its responsible use. Newly developed methodologies, e.g., deep learning techniques (Mokayed, 2023), have led to improved performance responding to users' needs. Driving the evolution of the field enabled real-life applications of AI in recent years (Liu, 2023).

This paper aims to resolve the complexity of technological innovation, and the key elements of a secure handling of data as basis for trustful innovation and a harmonious human and digital transformation. This paper addresses AEC Industry Architectural Engineering and Construction decision-makers and data legislation to critically reflecting sustainable data security and cybersecurity strategy as part of sustainable smart cities. Its smart intelligent functioning bases on sensible personal data of customers and citizens. In order to fully understand the interacting key factors and to enable the derivation of new approaches, innovative technologies

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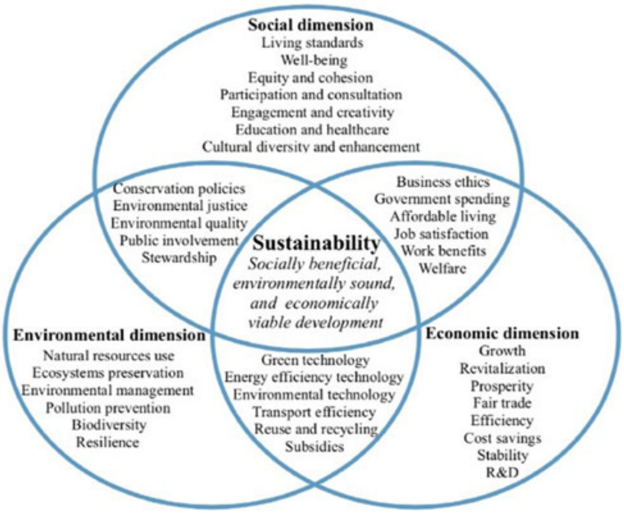
are examined in the study. Also, its potential and appropriate framework conditions are evaluated to meet the requirements of a smart building and smart city and to build socially sustainable according to the circular building life cycle.

This study aims to answer the key question on how smart buildings and smart cities become the key to sustainability. It focuses on how to navigate applied AI in the digital era in construction. The study also explores how innovative technologies shall be embedded into designing and operating smart cities and buildings to improve quality of life and human well-being and achieve an overall societal responsibly shaped and economic sustainable city. So far, this gap has not been sufficiently researched although many approaches were made in parts of a smart city system such as circular economy or resilience. The study puts its focus on the existing buildings and infrastructure that make up the majority of the built environment. Here, the challenge lays in adapting existing structure to sustainable standards and upgrading to intelligent smart ones, while avoiding demolition and new construction. Navigating AI and using such new technologies in the context of holistic life cycle sustainability means responsibly dealing both with innovation, environment, and natural resources. A considerable amount of work has been devoted to assessing diverse fields of action and effectively identifying suitable approaches. However, there is still a lack of developed, applicable AI and an existing strong resistance and unwillingness of the majority of companies in construction to define their corporate digital strategy. This is a behavior typical for the branch and represents the strongest barrier in combination with lack of knowledge and lack of orientation. As part of a larger research, such existing gaps have been analyzed and led to the policy framework of CDR in construction. An excerpt of the gaps in the context of smart cities and smart buildings allows sufficient assessment of needs and potential to draw new conclusions and answer the key question as basis for future research.

This paper recognizes diverse multidisciplinary fields of sustainable growth of smart cities by analyzing its limitations and human, societal and environmental impacts. Innovative approaches were found in the fields of smart building and smart Cities in order to capture the key toward sustainability in the digital age (Figure 1). This paper is one of the resulting fields of interest of this primary research, summarized in one chapter of the author's recently published book (Weber-Lewerenz, 2022) and was specifically selected to transfer new knowledge, share with the scientific community, and make new findings accessible beyond discipline boundaries. The herein described methodological approach belongs to the larger research with focus on CDR in construction. The selected method and the survey questionnaire had no focus on the specific field of smart cities and smart buildings. All the more surprising were the interviewees' outlook and first experiences on smart construction, potential, needs, and risks of new technologies as part of shaping smart cities, shared in the interviews. These compact additional data were documented, assessed, evaluated, and interpreted separately. As this so-called "side" field with its new findings revealed as enriching the scientific community, the authors decided to dedicate this paper to the topic.

Smart, intelligent communication and building operation has gained strength inspired by the Industry 4.0 environment. However, the fragmented and traditionally conservative construction industry faces complex issues and the pressure on this branch grows steadily to find new ways of coping with the responsibility to reduce CO_2–emissions, achieve SDGs, and shape circular economy

Figure 1
Key approaches toward sustainable cities (Bibri, 2021)



sustainably – guided by human and ethical values. Existing studies and scientific literature do not reflect the urgent need to guarantee the narrow interfaces of multiple involved disciplines such as Engineering, Technology Ethics, Philosophy, and Information Technology. Profound holistic analysis of the pillars of sustainability of innovative technology in construction is still missing and, thus, lays new grounds for this research focusing on the existing gaps. Thus, filling in this scientific niche not only broadens knowledge but adds value to the scientific community.

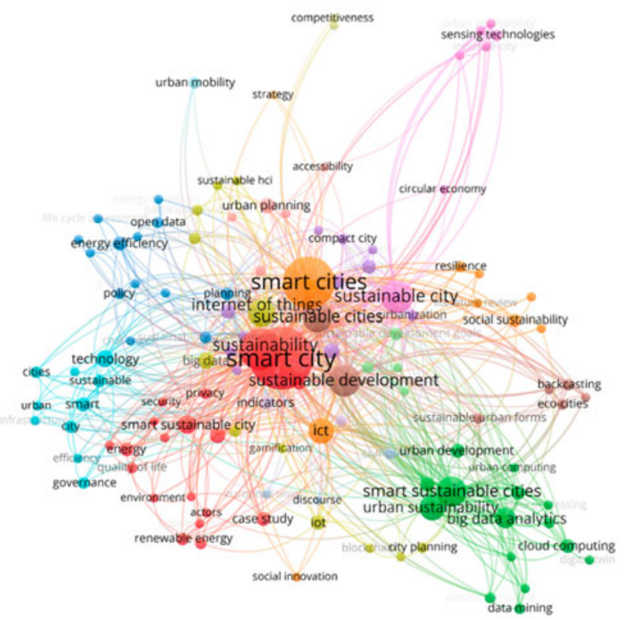
This study investigates the experiences from user practice and highlights how new intelligent technology and flexible, agile methods – the ones that are continuously fed with most up-to-date data and trained with customer data toward increasing construction management efficiency – such as digital twins, AI, artificial intelligence of things (AIoT), cloud computing, blockchain technology (Arangiaro et al., 2022), and Metaverse, which comprises digital technologies for learners to interact with other users with avatars in virtual environments, enable multisensory interactions with digital objects and people such as virtual reality (VR) and augmented reality (AR) (Bibri, 2022; Bibri & Allam, 2022). Such technologies offer new potential to increase efficiency, safety, and sustainability without neglecting ethical and environmental issues.

The building sector causes almost 40% of global CO_2–emissions (Costa & Ribeiro, 2020) and is therefore key to achieving climate neutrality by 2050. Existing buildings represent a larger share of buildings compared to new construction of buildings – a fact leading to high responsibility to integrate, upgrade, and operate them as per smart cities standards (Sodiq et al., 2019). Innovative building technologies in existing buildings support independent monitoring, control, analysis, and optimization of energy consumption throughout holistic life cycles of buildings and infrastructures of smart cities, reducing CO_2, and minimizing the use of resources. Innovative technologies catalyze shaping resilient, agile ecosystems as part of the digital age (Mourtzis, 2021).

These technologies are powerful tools for integrating existing buildings and upgrading them to smart cities standards because they enable smart networking between new and existing buildings, infrastructure, and facilities by applying digital planning, constructing, and the overall holistically safe and economical operation. Digital twins offer new technical possibilities for significantly more efficient life cycles, for reducing operating costs, minimizing natural resources, and reducing waste so as to reach sustainability goals. This study refers to practical use cases based on expert interviews from a larger research project (Weber-Lewerenz, 2021a). The study additionally analyzed the state of scientific research on sustainable smart cities in general and, thus, found the significantly increasing research in this field (Figure 2, Janik et al., 2020). In terms of a bibliometric analysis, the study identified the fields "sustainability," "sustainable development," "smart city," "internet of things," and "urban sustainability" with named innovative technologies as most critical key of success of sustainability in smart cities. It assessed holistically new ways to responsibly use data-driven, smart technologies.

Traditional cities are high consumers of non-renewable energy resources, poor management, and pollution control. Achieving economic and environmental sustainability as cities grow requires people to cope with multiple technical, social, societal, economic, and organizational both pressures and principles forming an ethical framework for orientation (Figure 3). Figure 3 visualizes the complexity of the key factors of socially sustainable development, their interdependencies, their interplay, ethical principles, and goals of sustainable cities. Figure 3 visualizes the complexity of the key factors of socially sustainable development, their interdependencies, their interplay, ethical principles, and goals of sustainable cities. Sustainable cities and communities belong to SDG #11. Eight further SDGs represent essential pillars for achieving sustainability of smart cities, SDG #11: affordable and clean energy (SDG #7), decent work and economic growth (SDG #8), industry, innovation, and infrastructure (SDG #9), reduced inequalities (SDG #10), responsible consumption and production (SDG #12), climate action (SDG #13), and life on land (SDG #15), for example, climate action delivers resilience to sustainable cities and communities, and neutral cities mean assuming responsibility for climate action.

Figure 2
Scientific landscape of smart sustainable cities (Janik et al., 2020)



Mammoth tasks lie ahead in the construction sector. High-tech-aligned smart cities pose multi-objective problems. Smart design, smart construction, and smart operation (BMWI, 2021) increasingly come into focus in construction. The smart cities' development not only refers to new construction, furthermore it includes the integration of existing buildings, mobility, and a city's infrastructure. Approaching smart cities modeling including the preservation of monuments requires new integrative options. Green energy technologies are examples of how existing buildings can be upgraded to modern smart city standards (Winkowska et al., 2019).

The study is based on the experts' most recent information and tendencies. It leads to new findings in applying new intelligent techniques for integrating existing buildings in smart cities. Urban requirements and services belong to the societal and ethical responsibilities in the frame of the UN sustainability development goals. This study addresses science and education, decision-makers, designers, and specialist planners, as innovative fields of application are defined in the planning of the smart cities of tomorrow, which are responsible for livable cities for today's and tomorrow's society. The main goal of the larger research project lays in the identification of the pillars of sustainability, not limited to digital transformation: society, environment, and economy. The study equally considers urban mobility using aspects of social science to address the complex legal issues in decision-making for humane, safe and resilient cities and societies. Digital twins are recognized as the most comprehensive and holistic method for recognizing these complex, interdisciplinary aspects.

Because a city gets its face and identity through its buildings. They offer living and working space and create added value. The feeling of well-being depends on a safe design. The integration of the building stock is part of the value-added chain, in which history meets modernity connected with each other and thus values can be preserved. Preserving existing buildings avoids new construction and thus significantly reduces CO_2. To reduce the branch's CO_2–emissions in Germany to zero by 2045, the goal is to halve the amount by 2030 (International Energy Agency, 2021). The expectation on smart cities' emissions are high: a reduction by a minimum of two-thirds by 2035 and to reach 90% by 2050 (Razmjoo et al., 2021). However, only by fully using the potential of digital solutions this aim can be achieved. The significance consists in that such smart city infrastructure technologies aim both for improved productivity and efficiency but especially for increased resilience to adapt to social changes. In view of the diverse challenges in dealing with climate change caused by natural disasters, it is clear that cities and buildings will have to be planned and built even more "with nature" in the future. As current examples show (e.g., entire cities wiped out by floods, such as Ahrweiler Germany 2021), the reduction of surface sealing, intelligent wastewater management, and warning systems are particularly important when planning smart cities. These measures with smart technologies recognize global climatic changes and ensure flood protection, stability and safety of tunnels, bridges, and dams. The adaptation goes far beyond the newly required building materials and standards that are adapted to the requirements of climate change (e.g., acid rain, heat periods).

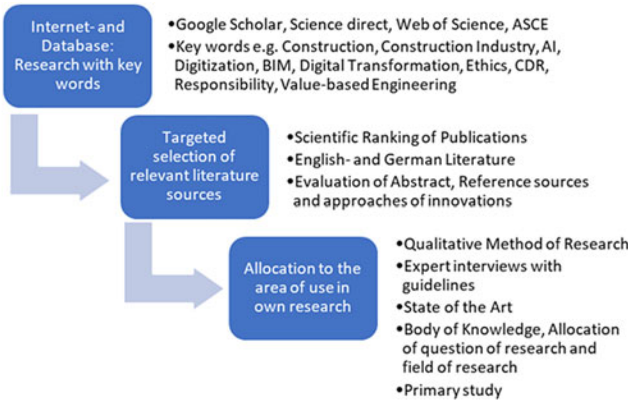
2. Research Methodology and Materials

Innovation champions represent catalysts of digital transformation as they apply innovative technologies leading to

Figure 3
Ethical framework for sustainable cities (Pastor-Escuredo et al., 2022)

sustainable smart building and smart cities life cycles and resilient ecosystems (Goralski et al., 2019). Best practices inspire their users to shape the future innovatively. This primary study uses the qualitative method with interview surveys and an extensive literature review (Mayring, 2015). The proposed problem on how to navigate applied AI in construction and the field research method of this study to assessing are different from existing methods. In 2019, when this research started in civil engineering for the first time, there was limited comparative research in other disciplines (Weber-Lewerenz, 2021b). This finally led to determining a method beneficial for this new field of research. AI research in construction and architecture is still in its infancy, which is why there are 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. Thus, due to this lack of data the quantitative method cannot be applied. The existing data set results of expert interview's responses were interpreted and evaluated following the hermeneutic approach (Buber & Holzmüller, 2007; Grondin, 1994; Lueger & Hoffmeyer-Zlotnik, 1994). Those refer to the experts' motivations, experiences, recommendations, and tendencies shared in the survey. In addition, such a quantitative evaluation would only reflect an insufficient analysis of the actual current situation, the possible solution approaches, and future trends. Assessing the mutual dependencies between human and digital transformation represents itself an open challenge requiring a "next generation" research method to access new knowledge and deepen research in complex environment of developing AI and further digital methods. However, the data won during this research lead to the conclusion that there is a significant gap between the development of new proposed AI solutions for smart construction and existing methods applied in day-to-day construction practice. The

Figure 4
Structured literature analysis



interviewees note the reasons for the resistance or lack of will to innovate and lack of pressure to re-orient as orders still remain satisfying and missing individual corporate digital strategies requiring adequate data infrastructure and knowhow. Furthermore, the study's focus is on applied sciences and not to derive a theoretical model. In order to get to the bottom of the research question and the associated challenges holistically, a mixed methods approach to be used has emerged as the most suitable. Such method is the most effective one when the objective of the research is to define gaps in the body of knowledge and identify future research trends (McGowan & Sampson, 2005). Expert interview surveys with partially open questions, direct observations in combination with a literature analysis and Internet and database research have been performed. The literature review helped to summarize existing research in closely related fields of interest and providing a conceptual framework that facilitates direct future work toward deepening research (Torraco, 2016). Having increasing access to continuously increasing available quantity of experience and data sets from 2021 to date enables quantitative studies and case studies as part of the state-of-the-art (Abdirad & Mathur, 2021; Belle, 2023; Prabhakar et al., 2023).

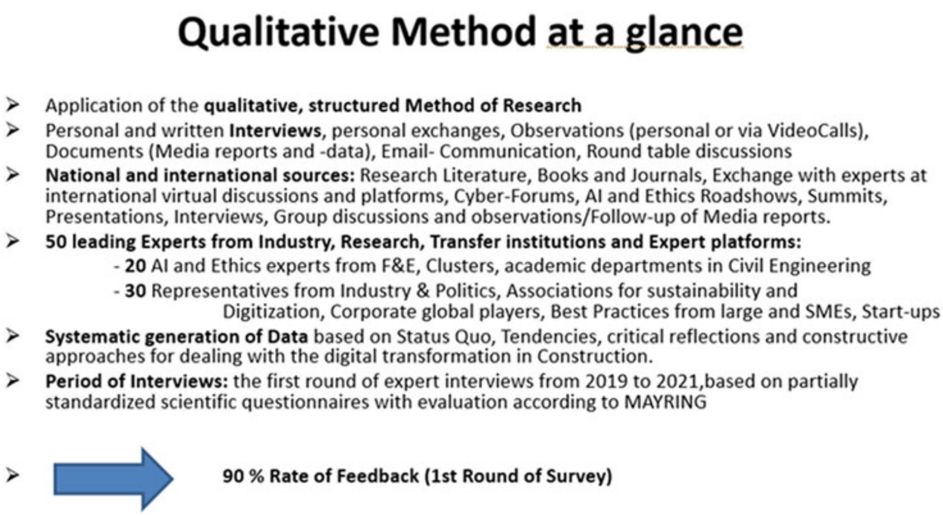
The study examines the status quo, tendencies and defines missing framework conditions for a "healthier" human–technology interaction (Grunwald, 2010). Such interaction is the basis for developing technologies that support humans best, are applied responsibly, and aim to increase the share in the value chain.

Fifty expert interviews were conducted over a period from 2019 to 2021. A comprehensive literature and database research was implemented with a structured literature analysis (Figure 4), supplemented by interview surveys with selected interdisciplinary experts, with a response rate of 90% (Figure 5).

The interview surveys are based on partially standardized scientific questionnaires and field notes. In order to approach the research gap in this primary study, open questions were considered the most suitable approach to retrieve comprehensive, new in-depth insights. These were gained by the interviewed experts sharing back-ground information, developments and tendencies they foresee, but moreover, their personal assessments. In this way, information that has not previously been taken into account becomes apparent and can be included in the status quo in the scientific recording. In addition to experts from the fields of innovation, digitization, technology development, representatives of German and international Civil Engineering associations, chambers of crafts and construction associations, and departments in ministries that were set up specifically for digital transformation, there were research and educational institutions and institutes involved in ethics and AI. The empirical values and observations and the lack of framework conditions contributed to the systematic generation of data. The experts' motives for action, the needs they define, and critical reflections helped to develop constructive solution approaches. Literature sources that deal with similar research questions in other disciplines proved to be particularly informative for the construction industry (Ågerfalk et al., 2022; Emaminejad & Akhavian, 2022; Wang & Guo, 2022). This study aims to anchor the construction industry in the global interdisciplinary scientific discourse.

The Internet research for the combined search terms construction, AI, digital transformation and ethics on the platforms ResearchGate, Web of Science, and Google only revealed the publications by the author, who is specifically dedicated to this interdisciplinary interface research. Other sources of literature either focus only on a certain specific area or are unrelated to the subject. Therefore, the

Figure 5
Qualitative method at a glance



scientific community's own publications offer important access to further research. Thus, references to previous peer-reviewed publications by the first author not only offer a possibility for a basic understanding of the newly discovered research object but also reflect the state of research to date (state of the art). They allow the research question to be embedded in the national and international research. As a result, the first author's publications are cited increasingly among the international scientific community highlighting the efforts in leading this field of research (Bednárová & Serpeninova, 2023).

Highly beneficial for gaining knowledge were the interview surveys. Research on the practical basis of large companies and Small and Medium Size Entities (SMEs) led to the finding that AI is still in its very early researching and implementation phase. Tendencies and the interviewed experts' individual evaluations make up a large part of the answers. Expert interview surveys were designed and conducted to gain more information on implementation projects of digitization and AI in companies in the construction industry. For the selection of the interviewed experts, the design of the interview survey, and questions with categorization, the main research question was largely guided by the previously determined research objective in the new research field: Where shall CDR be allocated and how shall the adequate ethical framework be shaped to support digital innovations and fully exploit the potential of digitization and AI?

3. Results

As already mentioned in the introduction section, lack of orientation, knowledge, and openness to innovation define new strategies to responsibly use AI and digital methods for designing and operating intelligent, smart cities and buildings. This section summarizes the data won by the literature and Internet database research, by the experts' experiences shared in the interviews and by the ongoing public discussion in the field of research. The herein suggested framework bases on a disruptive culture of thinking leading to a digital revolution in the construction branch, discussed in this section. Some innovation examples serve as practical examples to demonstrate the innovation champions or best practices' role model function to inspire other companies. The study aims for the full understanding of its attached framework conditions, existing or newly required regulations or guidelines, achieved European and global AI strategies' milestones. Thus, it introduces new innovations by presenting the complexity of data networking, communication, as well as the capacity of technical development and multiple fields of legal issues in which such new technologies and ways to apply are embedded to derive responsible handling with the example of smart cities.

3.1. Digital revolution in construction

Digital twins and AI applications implemented in practice contribute to an eye opening effect. The interviewees consider these as signposts for the digital transformation in construction and the sustainable design of environment and society, living and urban environments. It is these values of practical experience that build the trust of the citizens, Building and infrastructure users and operators. To the interviewees expertise, there is a high potential in responsibly applying AI to create more transparency and economic and environmental benefits and maintain societal human values and rights in designing a sustainable urban space in harmony with people and society. The evaluation of the expert interview survey and further research analysis lead to the conclusion that, in order not to lose sight of the diverse impacts caused by digitization and AI, interdisciplinary processing is crucial for success and to pursue the questions that make up this new scientific niche. AI and urban information modeling (UIM) (Stanford University, 2016) represent technologies with significant productive and economic benefits and methods to increase the share of the value chain. Linking UIM with Building Information Modelling (BIM) data leads to a framework that allows many urban data streams to be brought together. Such framework significantly expands the idea of BIM extensively expanded to urban scale, toward comprehensive information modeling of urban functioning, technical relationships that make up smart city living and environmental protection. For decision-makers, such a model offers the opportunity to better understand the impact of decisions and changes based on visual simulations. On the execution and user side of the interviewees, such extended approaches of BIM offer the possibility of integrating engineering tools to improve planning and proactive measures in the maintenance of smart cities. As the habits of citizens, ways to gain renewable energy, sensor-networked city districts and multimodal transport marketplaces, change constantly toward an ecosystem using secure digital identities to enable citizens register with smartphones for services, car sharing or online shopping; further research about blockchains is highly recommended. To the interviewees, the biggest challenge lays in the increasing complexity of data networking and communication, as well as the capacity of technical development and multiple fields of legal issues, for example, referring to the protection and security of data protection and on how to adapt standards and norms. Innovative new business models and channels represent options to exploit new potential responsibly. The following samples briefly describe the interviewees' motivations, practical experiences, observed tendencies, and recommendations and their suggested approaches for concrete improvements. In line with most recent political calls for action, innovative technologies and their potential to tackle long overdue fields of inefficient processes and the long-overseen potential of smart construction, as well as the pillars of the responsible handling – part of the larger research on CDR in construction – are presented.

3.2. Practical application: Innovation champions demonstrate on how to integrate existing buildings, circular and resilient cities

AI-based technologies that complement digital twins enable, for example, automated compliance checking (Amor & Dimyadi, 2021): adherence to contracts, compliance with legal and operational requirements, BIM supported compliance management for building permits, automated checking procedures for sustainability compliance (to assess sustainability-related standards by help of BIM conformity checks, proof of concept) (Kasim et al., 2013), compliance with public concerns (environmental aspects), building regulations, completeness of documents required for the construction project, and building material conformity tests. Digital twins recognize such compliance requirements by virtually adoption into existing environment. Improvements can be conducted in real-time simulation. Multiple disciplines involved independent of their location can contribute to their expertise in real time. Agile, interdisciplinary, inclusive, and intercultural collaboration environments are enabled by digital twins. Digital twins structure increasingly complex data and shape transparent and efficient decision-making processes. All operational and structural data throughout a building's life cycle are collected and stored by BIM. Efficient, economic, and secure operation and maintenance of existing buildings can be significantly improved by implementing smart technologies. Digital twins combined with AI-based systems automatically adopt the behavior of a building and offer decision-making forecasts for smart city strategies. Three main goals are under focus: circular economy and transforming resilient cities (Federal Ministry of the Interior, Building and Homeland, 2021). The circular cities declaration (European Union, 2021) is an agreement to achieve sustainable digital transformation in municipalities. To achieve the European Green Deal step-by-step, it is important to understand that smart networking and intelligent operation catalyze new urban infrastructure. Urban circular economy not only may lead to climate neutrality but especially requires the overall re-thinking of urban design and the change of the citizens' behavior. This idea rests on decoupling the use of resources from economic monetary focus. It aims to maintain value and utility of products, materials, and nutrients on a long-term basis. By minimizing the consumption of new material resources and routinizing circular waste management, the value chain can be enlarged significantly: in cities more than 75% of natural resource are used and cities in the European Union (EU) are responsible for 50% of global waste. Signatory cities like Aachen, Germany, are committed to transforming toward a circular economy as outlined by the UN's Agenda 2030 and Climate Strategy 2030. Marzia Traverso, Head of the Institute of Sustainability in Civil Engineering (INaB) and Kathrin Greiff, Head of the Department of Anthropogenic Material Cycles (ANTS), both at RWTH Aachen University in Germany contribute their multiple expertise and support the Center for Circular Economy to shape a circular city of Aachen, fully committed to plan a more resilient urban future. Against this background, the Governing Smart Cities Report (Merritt et al., 2021) critically investigates policy benchmarks for responsible development of smart cities recognizing ethical values. Embedding ethical responsibility strengthens the trust of citizens but also of building designers, users, and operators. Trustworthy AI with a regulatory framework enhances both innovation and responsible development and use of AI in the sense of the common good. Such guidelines mean milestones of digital and AI strategies in Europe (Figure 6) and globally.

The modeling of city data offers a crucial basis for optimizing and following economic, ecological, and social criteria. It enables automized code review processes: building regulations and urban planning data, which are digitally modeled, can be retrieved from municipalities. By using the information collected, a digital building model can be automatically checked. But the management of geographic information is not supported or allowed by BIM tools. Thus, the coupling between and geographic information system (GIS) is necessary (Altıntaş & Ilal, 2021). Geometric and semantic data can be stored using a proof-of-concept GIS application. Using such a model for automated code review demonstrates how GIS data complement BIM data to achieve an even more holistic digital twin.

One aspect that is rarely considered is how to deal with listed and historical buildings. The preservation of monuments requires new ways to achieve smart building standards. Digital methods and AI support the visual simulation of damaged parts, e.g., of historic buildings as part of smart cities. The application of modern technologies leads to creating digital twins to be able to connect the designated to-be-modernized buildings with its surrounding smart environment. Such technical applications facilitate measurement work and reconstruction, as well as cuts of building components, tailored fitting with re-manufactured components and forecast modeling as a basis for planning and controlling investments. VR and AR enable virtual "walk throughs" in historic buildings.

Figure 6
Milestones of the European and global AI strategy

Important Milestones of the European & Global AI Strategy

March 2023 – Open Letter of the Future of Life Institute: Call for pausing giant AI experiments for at least six months
March 2023 - Statement of the German Ethics Council: Human and Machine - Challenges posed by Artificial Intelligence
November 2022 – German National Digital Strategy (Part of the International Digital Strategy)
November 2022 - Digital Markets Act DMA (EU)
October 2022 – Digital Services Act DSA (EU)
July 2022 – New European Innovation Agenda (EU)
June 2022 – Strategic Forecast 2022: Interlocking of Green and Digital Change in the new geopolitical context (EU)
November 2021 – AI Act
November 2021 – Digitization Strategy (Coalition Contract 2021)
September 2021 – New Standard IEEE7000-2021. Value-based Engineering.
April 2021 - Promoting a European approach to AI
April 2021 - Proposal for a regulation with harmonized rules for AI
April 2021 - Updated Coordination Plan for AI
October 2020 – 2nd Assembly of the European AI Alliance
February 2020 - White Paper on AI: a European approach to excellence and trust
June 2019 – 1st Assembly of the European AI Alliance
May 2019 – OECD AI Principles
April 2019 – Communication: Building trust in human-centric artificial intelligence
April 2019 – Ethical guidelines for trustworthy AI
December 2018 – Coordination plan on AI ("AI - Made in Europe" - press release)
December 2018 - Stakeholder Consultation: Draft Ethical Guidelines for Trustworthy AI
November 2018 - European Digital Strategy
June 2018 – Launch of the European AI Alliance
June 2018 – Establishment of the High Level Expert Group on AI (AIHLEG)
April 2018 – European AI Strategy (press release "AI for Europe")
April 2018 - Commission Staff Working Document: Liability for Emerging Digital Technologies
April 2018 – Declaration of cooperation on AI

VR glasses support digital online site visits and provide renovation simulations as well as fire protection concepts and new acoustic. BIM has become an indispensable method. Increasing technical feasibility means societal, human responsibility. With 40% of the total primary energy consumption and a third of total greenhouse gas emissions, there is high pressure on the construction branch. However, the majority of existing buildings do not comply with green design, low carbon emissions, and environmental standards to reach sustainability. The network researching cultural heritage includes diverse expertise leading to the development and test of new technologies as to improve conservation of cultural assets and restoration. Furthermore, it intensifies exchange of knowledge between practice and research. It may also strengthen the importance of cultural heritage in the public consciousness.

Assuming social responsibility – beyond digital era – means to understand that cultural heritage is not a renewable resource and therefore needs to be consciously preserved. Three selected best practices, outlined below, serve as role models.

3.2.1. Innovation examples: Metaverse City and VR to plan buildings and cities

Digital twins and VR consistently drive positive empirical values for the planning of monuments giving full access to the client, customers, and all project participants in real-time performance. The customer is able to establish an emotional bond with the project by walking through buildings and city districts. Involved in most of the stages of a project from the very beginning, all phases are transparent and trust-building. This method increases trust into high quality, efficient performance of the project. The visibility on a uniform communication and data platform clarifies the impacts of customer changes from the earliest project phase onwards on cost and timeline. Hereby, overall cost transparency but also real-time controlling is ensured.

Metaverse and other AI methods catalyze efficient and productive project processes but require data security and new knowledge. Metaverse expands its influence in multiple industries and offers ways to fully exploit the potential in AEC Industry toward sustainable innovation. Metaverse models take digital and virtual planning, design, and operation to the next level. It increases efficient interaction between all project participants. Such technology increases transparency by visualizing circular economy, urban services, and people-centric innovations in the form of a parallel virtual world. Metaverse simulates energy and water optimization, infrastructure operations, and technical interaction, with a particular focus on achieving sustainability. Metaverse represents the digital extension of the smart city ecosystem recognizing environmental, economic, and social sustainability of the urban resources (Allam et al., 2022).

The construction industry is increasingly investing in the use of innovative technologies such as digital twins and AI-supported workflows. Metaverse belongs to the next generation: a digital platform that is immersive, navigable in a 2D- or 3D-landscape and enables shared social interaction. Many current Metaverse applications rely on blockchain technology and the Web3 infrastructure built on top of the blockchain. Metaverse provides a network of interconnected virtual worlds characterized by presence, persistence, immersion, and interoperability. Such virtual environments are used for the planning and visualization of buildings in real time and before the actual construction work. The technology implements construction planning standards, simplifies the understanding of space and size, facilitates planning decisions for customers and clients, enables better identification of connections, helps to avoid human error, offers end-to-end transparency of the cost impact of plan changes through virtual modeling of all factors, simulates the value proposition, and offers participation through traceability of the construction implementation. Those involved in the construction project can access and communicate with one another any time, from any location, on a uniform platform – worldwide, which saves additional time and money. Cross-trade and interdisciplinary collaboration is ensured, and overlaps can be identified more quickly; changes to plans and designs can be made immediately in an integrated environment. Such a virtual world, combined with the feeling of exchanging and interacting with one another and data in a digital environment and physically present (presence), is particularly worthy of protection. In addition, the participants have the persistent ability to actively engage in virtual environments over a longer period of time, to make progress, and to continuously build new relationships (persistence). The participant is completely immersed in this virtual world, which feels more and more believable (immersion) and is increasingly removed from the real world.

The participants of the 3rd Symposium Future of Construction 2022 emphasized that "sustainability and a successful digital transformation in Construction can only succeed through human-centered work, close interface work with integral teams – away from "silo thinking". This requires a fundamental rethinking of the AEC Industry, innovative ways and the exchange between research and user practice" (Universität Stuttgart, 2022). AI, VR, and Metaverse support human work with increasingly sophisticated technology and simulate the planned project in design and application of all technical interfaces. It not only allows to reduce resources and operator costs, keep in time, maintain high quality, and improve efficiency but also offers consistent data structuring without data loss and a visualized representation of scenarios (Ernstsen et al.; 2021). Smart city citizens are connected to smart urban ecosystems in many ways, e.g., through the use of smartphones and mobile devices, cars and apartments are networked in terms of data technology. Coupling devices and data with a city's physical infrastructure and services can reduce costs and improve sustainability. For safe data application in a Metaverse system is important to protect such extremely sensitive data.

3.2.2. Innovation examples: New smart building solutions by BOSCH to operate existing buildings (Bosch, 2021)

"Bosch Energy and Building Solutions" represents smart intelligent building operation providing more safety and human well-being. But how can existing buildings get upgraded to smart cities standards? The study identifies new approaches to designing future urban environments applying AI technologies. They enable intelligent technical building equipment with real-time monitoring, regulating, analysis, and optimization of energy requirements to reduce consumption toward self-thinking, self-regulating buildings. Such technical feasibility ensures new building and human interaction, e.g., by remote maintenance, minimizing human errors by structured data, routinizing, and standardizing processes. This study considers knowledge networking and across all digital borders as success-critical factors. Furthermore, lean construction, responsibly dealing with natural resources and using innovative technologies to improve construction cost-efficiencies and productivity, is the most critical key elements. The value chain can only be expanded with a holistically thought-out concept that includes all cycles and sustainability factors.

4. Discussion

Though substantial sustainability improvements can be achieved by responsibly using innovative technologies, and the fields of application are diverse, the view and motivation to succeed need shifting focus on equivalent measures to ensure the supportive framework conditions. The dialogue with experts from this study encouraged full consideration of issues of sustainability on the legal, political, economic, corporate, societal, human level, which builds the core of this research. Obviously, these aspects do not neglect recognizing the unintended effects, the "dark" side, that such digital and human transformation have. The above-mentioned perspectives are assessed in the following subsections resulting in the evaluation of limitations and a basis to offer recommendations for future in-depth research. In this section, the authors focus on some selected discussion points.

4.1. Innovation is driven by educational and legal framework

Education and legislation have been selected as – both highlighted in the interviews, the public debates, and the literature research – they appeared as key drivers of innovation and the most success critical pillars of urban sustainability.

Education. AI and digital methods set new milestones requiring new knowledge and the adaption of education as part of the compass for "Building Forward Better" and to transforming the attractiveness of the construction branch by diverse, inclusive, agile, and resilient working environments. BuildingSMART Germany designed a program to certify BIM professionals (buildingSMART, 2021). It ensures global quality standards for BIM qualification. To strengthen education, adjustment of teacher's qualification and curricula are mandatory. Professorship advertisements request qualifications in digital urban designing and planning, such as smart cities. They also call for an understanding of societal needs, climate engineering, and educate sustainable building life cycle – based on BIM. Resource conservation also requires energy consulting by qualified energy efficiency experts. Transformation of smart design and operation lead to revised municipal organizational structures adding new departments like Digital Technology Departments and Boards for Smart Cities. Among the international pioneer cities are Copenhagen, Amsterdam, Barcelona, Vienna, and Singapore. Critically questioning the new urban agenda also means searching for the definition of a sustainable building life cycle management (Council of the European Union, 2016; United Nations, 2016)? Two key challenges consist in developing livable cities and empowering designers and operators of the urban environment (Federal Institute for Building, Urban and Spatial Research in the Federal Office for Building and Regional Planning, 2017).

Legal regulation. To facilitate the transformation of existing into smart cities, the EU aims to support adequately by its previously compiled regulations. A smart building's technical performance can be monitored and regulated via IoT technology aiming to increase energy efficiency. Smart methods minimize time-consuming processes. They are also able to store a building's energy performance on cloud platforms. These lay grounds for drawing conclusions and applying adequate measures. Such cloud interface significantly contributes to improving the certification of existing buildings in terms of energy efficiency.

Building sustainability requires knowledge of how Cradle-to-Cradle works: it makes full use of the environment, recycling, and re-use instead of reducing severe impacts. Figuratively, this concept considers waste as food and uses renewable energies. Digital twins automatically generate real-time visualized types and quantities of materials; data are stored and can be retrieved for reusing the recycled material. Cradle-to-Cradle is based on the idea of building according to the material life cycle and should therefore be made a contractually binding obligation. Urban design should aim to drastically reduce using mineral raw materials both during construction and operation of buildings. Using resource-saving lightweight construction and using reusable, recyclable building materials offer concrete practical approaches.

4.2. The dark side of digitization and AI

Will Construction Industry 4.0 create new raw material requirements (Pilgrim, 2017)? Digitization and AI have social and ecological impacts on the raw materials sector. Economic growth is difficult to decouple from resource consumption. Resource consumption already exceeds the limits of our planet. Innovative technologies catalyze the decrease of resources and raw materials used. Four times the current lithium production, three times increase in heavy rare earths, and a one and a half times increase in light rare earths and tantalum are expected. Due to the increased use of electronics, the global demand for copper will grow between 231% and 341% by 2050 (Elshkaki et al., 2016). According to the DERA study, in 2035 up to 34% of the global indium production may be used exclusively to produce displays (Deutsche Rohstoffagentur, 2016).

Digitization and AI require new machines (robots, automation technology), higher data speeds (fiber-optic cables, routers, high-performance microchips, sensors, data transfer infrastructure), and data storage with larger volumes, i.e., significantly higher data capacity (data clouds, IoT, AIoT), to achieve real-time transmission with error-free network communication. These must be newly produced and – due to the high heat production during operation – computers and storage continuously cooled and rooms air-conditioned. The entire infrastructure requires expansion; dismantling and recycling must be recognized in the planning phase (overall life cycle). Damaging health effects created by continuous radiation during the operation of these innovative technologies has not yet been adequately researched: fully functioning smart cities require uninterrupted, intelligent networking of buildings, e-mobility, smartphones, etc. with data clouds, IoT, and the expansion of multiple base stations. This only works with a high and uninterruptible power supply and the acceptance of the additional energy consumption, the high intensity of electromagnetic radiation (networking among the devices, radio), and CO_2-production. The end-to-end full automation of buildings requires hardware such as machines and sensors, thus an increasing production of the necessary inventory materials and with the corresponding consumption of resources. The fifth generation of mobile data transmission (5G) requires broadband expansion using fast fiber optic networks. 5G combines the previous mobile communications standards, Wi-Fi, satellite, and landline networks into a holistic communication network (Höfer et al., 2020). It leads to the conclusion that digitization may become an energy guzzler, because in 2025 data centers will account for around 4–11% of global energy consumption; at the same time, high energy saving and waste heat utilization potentials are forecast.

The digital value chain is being taken ad absurdum. Where is the economic benefit? How do we want to reduce our ecological footprint and operate sustainably if we are increasingly consuming raw materials, accepting inhumane mining work, abuse of people, and the environment and long-term damage to health in order to develop and use even better, even more economical, and even more innovative technologies (Rüttinger, 2016)? The danger not only lies within the consumption of resources but also in the increasingly complex risk areas of data misuse: where there is a lot of data available and openly accessible, the protection and security of data transfers and access is one of the success criteria for sustainability. For the most part, municipalities are administratively unable to handle approval processes digitally (Fiedler, 2022). Declarations of intent by the German government on digitization do not correspond to the current situation and the practice of public administration. In addition, cities, municipalities, and states invest in grid expansion, acquisition of digital media and competent experts who can operate them. It also requires modernization and maintenance of the school and kindergarten facilities and new teaching materials as modernization of care facilities, conservation and maintenance of buildings worthy of protection lag far behind.

To shape this transformation sustainably and take the next steps responsibly, the design of the digital transformation must recognize where innovative technologies make sense, where to preserve resources, to allocate where new technologies support people in their work and make processes more efficient, and to promote social awareness of values. It requires a clear definition where innovative technology is just an empty promise, a concealment of major security risks or even exploitation. There is a strong danger of becoming part of so-called greenwashing, i.e., propagating superficial advantages and high benefits, which, however, come at the expense of violations of human, personal and data rights, environmental exploitation, and resource consumption harmful to both people and society as a whole. This is far from sustainability and value-based action. The research “CDR in Construction 4.0” investigates the question of how such a countermeasure can succeed; the Excellence Initiative for Sustainable, Human-Led AI in Construction aims to strengthen this awareness. The Scientific Advisory Council of the Federal Government and the German Federal Office for Radiation Protection (German BfS) warn against unlimited digitization that is not aligned with sustainability criteria.

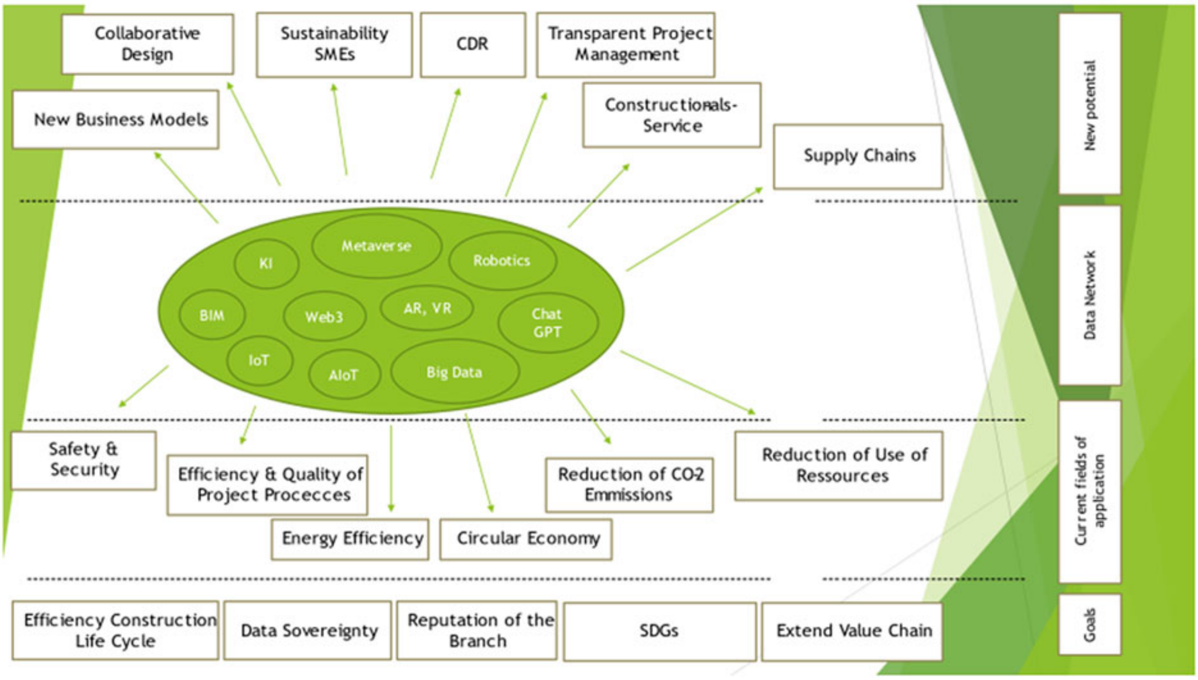
4.3. Limitations and further research

This study allows new insights on the state of scientific research on sustainable smart cities. The holistic assessment of innovation, factors critical to success, and supportive framework conditions has not been enough researched and therefore reveals a new field of research. One limitation consists in the access of limited literature and internet databases. The study is based on a relatively small circle of 50 interviewed experts only. Conclusions and evaluations could only be drawn on such small quantity of interviewed experts. This small quantity was fulfilling the study’s time, cost, and text limits. A larger survey would thus be more representative and is highly recommended to investigate the field of interest in depth. An additional limitation represents the still small available experts in construction dealing with digital transformation, AI, digital methods, and ideally acting as role model, as best practice, to interview and introduce in this study. Overall, though such limits, the challenge consisted in getting these limited experts engaged and sharing their insider knowledge to provide full access and transfer new knowledge between research and practice, as well as between large companies and SMEs. The following section provides a full understanding of the further complexity of the branch’s own barriers, limitations of technologies itself, lack of legal protection, and deriving aspects for further research. The study also suggests deepening the analysis of the severe impacts of AI on human and society. The increased technical feasibility leads to assuming more social responsibility but also the need to shape an applicable legal framework to ensure data sovereignty. What makes a construction site unique is the quantity and complexity of data, its copyrights, and further transfer speaking of the complex data interfaces and maintenance and archiving of data. Compliance with the general regulations for data protection is hardly controlled and even less prosecuted. To ensure copyrights and data sovereignty, it is crucial to determine: Who controls and prosecutes how personal data are dealt with who has the appropriate earmarked usage rights for access building data? Who controls data clouds and protects their data? Who checks the declarations of consent before communicating data? How are such processes and data safety maintained outside of companies, like at home office? Smart cities’ citizens data get part of intelligent urban ecosystems in multiple complex ways since smartphones, mobile devices, connected cars, and apartments smart home systems belong to the overall smart city concept. Coupling devices and data with a city’s physical infrastructure and services can reduce costs and improve sustainability. Thus, the protection of such sensitive data is crucial and represents a significant limitation of innovation if mislead, misused, or lacking protection. A legal framework in the construction branch catalyzes both innovation and sustainability. Figure 7 underlines such findings and visualizes the diverse interdependencies of data networks, new technologies with both its new potential and current fields of application, and the main goals to enlarge the overall value chain.

Digital self-determination is more and more considered as the responsibility of the overall legal system to protect personal data and of the project. An adequate legal policy framework could significantly strengthen the protection against data misuse, cyberattacks, and secure the handling of data. Having full access to user data and to smart technical building automation, smart buildings, demonstrates the need for urgent action and criminally enforceable regulations as to who, where, for what, and to what extent rights and obligations attach and are liable for disregard, should have priority. In Germany, there is a lack of uniform BIM standards. The methods that customers and contractors use vary from project to project. The standards’ inequality leads to the fact that solutions to the problems cannot be obtained faster. Adapted legislation may lead to overcoming these boundaries to fully exploit the potential of innovative technology. Paul Nemitz notes that the focus of the main advisor for judicial policy to the European Commission lies on ensuring that EU companies “[. . .] will have a level playing field. AI-Act shapes a more trustworthy and safer technological landscape” (Nemitz, 2021). Anyone who constructively embeds these rules in their actions develops a more sustainable profit perspective and strengthens responsible engineering and innovation.

The study concludes that statutory requirements by the state are necessary to securely handle data. The “White Paper on Artificial Intelligence” by the EU Commission in 2020 (Kilian, 2020) called for the protection of fundamental rights and values the careful differentiation between human and AI and its careful handling. An important step was made in July 2018, when the German government affirmed in its AI strategy paper the development of a transparent and ethical AI. This moves forward with its € 3 billion plan in November 2018 sent an important signal. The Data Ethics Commission DEK (Data Ethics Commission of German Government, 2019) addressed the state as to assume responsibility and get engaged with defining ethical standards for the digital

Figure 7
Value chain data network in construction



space as this may secure German and European digital sovereignty in the long term. It is therefore not only an expression of ethical responsibility beyond the pure requirement of political foresight. One important step was the General Data Protection Regulation (GDPR) as of May 25, 2018 (European Union, 2018).

Following the CDR concept protecting human and democratic values requires the design, maintenance, and protection of trustworthy technologies; it increases trust and, thus, the acceptance of data-driven technologies. Such foresighted concept promotes innovative ecosystems. Engineers, architects, designers, and craftsmen not only design working and living environments but also form technical innovation and human and societal changes in the Construction Industry 4.0 (Araújo et al., 2022; Rosha & Lobanova, 2022; Venkatesh et al., 2022). More technological possibilities in life and at work means "a greater responsibility on the part of people for technology-based innovations . . . and for the sustainable preservation of the earth . . . " (Kirchschläger, 2021). The digital construction plan by BMVI (Bodden & Dittschar, 2020) is the first of its kind to complete the digital project life cycle in the public sector for all traffic and infrastructure projects.

The other side is that the implementation and application of new technologies have diverse impacts but also imply responsible action. Ensuring secure data and project communication, protecting copyright, and ensuring cybersecurity in construction require legal regulations, e.g., by a legal policy framework. The Chinese law regulating the protection of personal data (Usercentrics, 2021) as of 1st of January 2022 adopted some contents of the GDPR.

5. Conclusion and Recommendations

This study concludes that best practices represent role models in the construction industry offering orientation in navigating innovative technologies, holistically assessing their potential, and risks allowing to create humane, safe, sustainable smart cities.

A major finding is that dynamic, agile companies are able to quickly adapt to changing environments, to grow with the change and achieve the SDGs. Complexity of data and communication continuously increases, so does the search for secure ways of handling and protecting data transfer. Therefore, a disruption of thinking, learning, and approaching new innovative technologies in construction is essential to develop digital strategies – for both as corporate entity and city and society as a whole, to get familiar with technical methods, to use them to increase efficiency and productivity and to participate in shaping smart cities. One major finding consists of the recognition of CDR policy framework as orientation navigator to act responsibly and maintain values and rights in the digital era, but also to be able to recognize both when an innovative technology is a must to apply, as part of sustainable strategy, and when and how AI implies risks and unintended effects requiring adaptive measures. New measures for data protection requirements new legal standards adapted to the protection of people and society. Corporate innovation depends heavily on customized educational content and curricula, as well as legal safeguards for secure data exchange. Research and development are requested to create new methods and ways to improve processes and safe work and develop new technologies to support human work best. But they are also requested to ensure a transparent flow of new knowledge, ideally without scientific language barriers to provide full access to practice to let them apply and further explore such technologies. The construction branch is requested as a whole to critically review its economic, environmental, and societal performance, investigate its status quo of efficiency, productivity, and sustainability, and define a uniform digital strategy with enough space for individual corporate strategies. Especially when interviewed experts call for data protective measures and sustainable construction, this research recommends enlarging the perspective, catalyzes innovation, and assumes the long overdue responsibility as a branch, not limited to data sovereignty, but a branch driving economy. The study recommends further in-depth research work in this field. Humans in the construction branch not only design and constantly improve technical innovation but also shape human transformation. Furthermore, the study allocates fields of responsibility for developing trustworthy, human-led AI recognizing the "dark" side of the technical feasibility. This success-critical factor has not yet been adequately researched and represents a significant limitation of practical application. Previous studies, e.g., by the Fraunhofer Institute Austria in 2022 (Fuchs et al., 2022), highlight that sustainable technology development and increase in the maturity of AI applications depend on new qualifications, transfer of knowledge, and adjusted curricula. The study investigated one of the limitations hindering innovation and efficient working practices. Interviewed experts highlight the need for a radical re-thinking in the AEC Industry. This would significantly accelerate achieving sustainable technical, social, and environmental goals.

In its statement of March 20, 2023, the German Ethics Council specifies the value-based human–machine interaction, especially in AI application fields and all the associated challenges for people, society, education, business, and legislation. The responsible use of innovative technologies in the construction industry, such as digital twins, AI, AIoT, Internet of Energy (IoE), Metaverse, Web3, and Gaia-X, is therefore the linchpin and acts like a catalyst in the value chain. It strengthens resilient, agile, and sustainable ecosystems.

The key challenge consists in exploiting the potential of smart cities, coping with increasing cyberattacks, preserving human and societal values, and reducing CO_2–emissions. Both the buildings' preservation and upgrading existing facilities to smart cities' standards have highly positive impacts as their focus lays in avoiding using new material and resources but instead build according to a building's circular life cycle. Interviewees consider this field as having highly positive impacts on the environmental sustainability and economic benefits in line with exploiting the full potential of most modern technologies. The study recommends further investigation into defining measures to adapt to new climatic conditions due to climate changes. These have a profound impact on the human organism, animals, and plants. Debating sustainability usually occurs about new construction, but what about existing infrastructure and urban space? However, it requires a critical understanding of consumption of natural resources by using technical innovation. Digital twins and AI help to increase efficiency and sustainability and achieve the 17 SDGs. Designing, building, and operating smart cities require a disruptive new culture of thinking as part of the overall culture of Construction 4.0.

Thus, with this research, the first author's "Excellence Initiative for Sustainable, Human-Led AI in Construction" anchors construction into the global AI and ethics dialogue for the very first time and further expands this new scientific niche.

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Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

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