CHAPTER 1

Deep Renovation: Definitions, Drivers and Barriers

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Abstract This chapter defines the key elements of the deep renovation life cycle. Investment in deep renovation is driven by various rationales, including societal, economic, environmental, energy security, quality, opportunistic, and catalytic motivations and benefits. At the same time, both deep renovation and digital technology adoption to support deep renovation are impacted by challenges presented in humans, organisational processes, technologies and external environments. This chapter explores the key drivers and barriers to deep renovation and associated digitalisation. It establishes the motivation for the remainder of the book.

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1.1 Introduction

The 2022 Intergovernmental Panel on Climate Change (IPCC) assessment suggests that climate-resilient development is already challenging at current warming levels and that the window for action to address climate change is narrowing. Restricting warming to around 2°C (3.6°F) still requires global greenhouse gas (GHG) emissions to peak before 2025 at the latest and be reduced by a quarter by 2030 (IPCC, 2022). This is a significant challenge. In the words of UN Secretary-General António Guterres, "the climate emergency is a race we are losing, but it is a race we can win" (UN, 2019).

The European Union (EU) is not sitting idle. As part of the European Green Deal, the EU has raised its ambition to reduce GHG emissions by 2030 from its previous target of 40% to at least 55% below 1990 levels, as well as increasing the share of renewable energy by 32%, and improving energy efficiency by 32.5% (European Commission, 2022). The renovation of EU building stock is particularly critical in supporting these goals. Buildings are among the most significant sources of energy use within the EU: existing structures currently account for 40% of all energy consumption and 36% of GHG emissions (European Commission, 2020a). In particular, it is estimated that over 75% of the EU's residential building stock has poor energy performance, the majority of which will be still in use by 2050 (European Commission, 2021a). To meet its climate change goals, the EU seeks to achieve a decarbonised EU building stock by 2050. To achieve this, it has recently put in place measures to consolidate its existing goals, encourage the use of digital technologies and smart applications in building operations, and strengthen the links between achieving higher renovation rates, funding and energy performance certification (European Commission, 2021a). Deep renovation is key to achieving this goal.

The remainder of this chapter will explore narrow and broad definitions of deep renovation including the rationales for undertaking deep renovation. Recent research by Lynn et al. (2021) suggests such rationales not merely are related to environmental sustainability but include a wide range of different stakeholder motivations including economic, energy security and opportunistic rationales, amongst others. Notwithstanding these rationales, the widespread deep renovation of building stock, particularly in a constrained time frame, faces significant barriers not least human, organisational, technological and environment context challenges. We discuss how these barriers may surface across the life cycle of a deep renovation project. Advances in technologies, not least information and communications technologies (ICTs), are central to accelerating the renovation life cycle and overcoming the existing barriers to deep renovation. We conclude with a summary of the remainder of this book which looks at the main digital innovations disrupting and transforming the construction sector.

1.2 Deep Renovation

"Deep renovation" has become somewhat of a buzzword in recent years, albeit an obscure one. There remains little consensus on the term's definition and, although widely adopted in academia, industry and legislation, definitions vary significantly on local, regional and international levels (Shnapp et al., 2013). While deep renovation (sometimes referred to as deep energy renovation, deep retrofit or deep refurbishment) may be defined simply as renovation efforts which capture the "full economic energy efficiency potential of improvement works […] of existing buildings" and lead to high energy performance levels (Shnapp et al., 2013), the core concept of deep renovation is categorised into *broad* and *narrow* definitions:

- *Broad*, referring to the use of different simultaneous building envelope and installation system renovation measures into one integrated strategy across the entire building life cycle (Agliardi et al., 2018);
- *Narrow*, relating to performance levels of refurbishments that reduce building energy consumption by a significant proportion to energy levels observed before renovation works began (Sibileau et al., 2021).

D'agostino et al. (2017) take a more quantitative approach, categorising deep renovation efforts by performance impact as presented in Table 1.1. This offers a relative numeric classification of deep renovation efforts, although an exact quantitative reference value for deep renovation energy reductions remains unavailable (D'Oca et al., 2018).

Deep renovation involves the use of multiple energy-saving measures. Bruel et al. (2013) summarise these measures as (1) energy-efficient building elements such as windows, heating, ventilation and air conditioning (HVAC), air filtration, lighting and appliances; (2) renewable energy sources like solar hot water, solar photovoltaic (PV) panels, passive solar energy, shading, wind, heat pumps, biomass and biogas; and (3)

Table 1.1 Categorisations of deep renovation measures

Deep renovation class	*Description*
Minor	Reduces final energy consumption levels by up to 30% by implementing one to three improvement measures and costing an average of 60 €/m2
Moderate	Involves more than three improvements to existing buildings resulting in energy reductions of 30–60%
Deep	Enabled through high-grade improvements that result in energy savings ranging between 60% and 90% and costing between 140 and 330 €/m2
Major	Covers renovation works on more than 25% of the building envelope and costs more than 25% of the value of the existing building
Nearly Zero Energy Buildings (NZEP)	Results in buildings which perform significantly better in energy use (with +90% of improved final energy saving) and rely on renewable energy sources (RES) ideally produced within or near the building itself

community energy sources such as district heating systems. Each of these measures alone improves energy performance in buildings and may be employed in combination with traditional technology and construction solutions (D'Oca et al., 2018). However, deep renovation is distinct from other energy-efficient retrofits in that these elements become *fully integrated* within the renovation process.

1.3 Rationales and Benefits of Deep Renovation

In 2018, EU renovation rates barely exceeded 1% and were significantly below the objectives set in the Energy Efficiency Directive (Directive 2012/27/EU) and the revised Energy Performance Building Directive (Directive 2018/844). Only 11% of the EU building stock undergoes renovation on a yearly basis (European Commission, 2021a). Reaching the 2030 and 2050 goals requires a significant acceleration and greater understanding of what drives stakeholders to adopt and implement a deep renovation strategy. An attempt at this is made in Table 1.2.

Aside from advancing building quality and area net-worth in comparison to other buildings through state-of-the-art aesthetic, safe and easy-to-use building elements, deep renovation reinforces economic stimuli in the form of employment and reduced reliance on international energy imports

Table 1.2 Stakeholder rationales towards adopting deep renovation practices

Stakeholder group	*Description*	*Rationale towards adopting deep renovation practices*
Energy solutions and construction technology providers, and independent software vendors (ISVs)	Develop and market (1) technologies that support and deliver residential deep renovation projects and (2) software solutions for building information modelling, deep renovation process management, building and infrastructure management and maintenance, and/or related technology management	Aim to improve, extend or complement existing product or service offerings in a cost-effective way, increase competitiveness through value-added products and services, and generate incremental revenues with comparatively little upfront R&D investment
Housing development and construction companies	Buy, license and use technologies and systems developed by third parties to deliver high energy performance	Aim to differentiate themselves from competitors by providing superior services and buildings and generating more profit from these projects while delivering better performance and value for their clients
Architects	Design and plan the renovation and construction of built environments while using a variety of software tools and related databases to model and design built environment projects	Require specific skills, tools and knowledge for gathering environmental and cultural considerations, both pre- and post-occupancy, as well as implementing specific sustainable designs and smart technologies
Construction finance companies and crowdfunding platforms	Provide capital to construction companies for financing projects, possibly from alternative sources of capital such as crowdfunding platforms	Traditional sources of capital cannot fully meet the financial demand of deep renovation works and are oftentimes constrained by regulation. Deep renovation crowdfunding may offer faster, transparent and more secure options for all stakeholders

(*continued*)

Table 1.2 (continued)

Stakeholder group	*Description*	*Rationale towards adopting deep renovation practices*
Building owners	Own and manage residential buildings	Aim to renovate their building stock cost efficiently while minimising disturbance to occupants and overall renovation time Aim to increase energy efficiency and environmental performance to meet or exceed national standards, meet domestic or European policy goals, maximise occupant satisfaction and ultimately increase the value of the property
Occupants	Reside in the building in question, often during the course of renovation works	Require renovation solutions which offer the best value for money in the form of long-term energy performance. Sometimes, reducing environmental impact and meeting or exceeding international standards for energy performance is a priority
Research centres and projects	Attract government and industry funding to carry out research on existing renovation solutions, the economic and business impacts of novel solutions, or the industry adoption of novel technologies and processes	Focus on specific elements of the (deep) renovation life cycle as a research field and, in doing so, operate within pre-defined boundaries and aim to influence a large number of stakeholders
Investors and licensors	Invest or license technology and other research outputs for commercial purposes	Aim to differentiate themselves from competitors by providing superior, better-performing technologies to their clients

(*continued*)

Table 1.2 (continued)

Stakeholder group	*Description*	*Rationale towards adopting deep renovation practices*
EU institutions, policymakers, and funding and standardisation bodies	Formulate or influence policy in EU institutions and national and local government and include regulators, international bodies and other political bodies	Are driven by set national and international climate targets and, in an effort to reach these targets, regulate and secure funding for the advancement of deep renovation projects
Media and industry analysts	Create content to influence stakeholders and possibly perform primary and secondary market research within an industry such as information technology and telecommunications	Disseminate content surrounding the latest developments and technologies in renovation and construction industries with a growing interest in sustainable and energy-efficient practices

(Jochem & Madlener, 2003; Baek & Park, 2012; Bruel et al., 2013; Ferreira & Almeida, 2015; D'Oca et al., 2018; European Commission, 2020). Currently, approximately 34 million Europeans are impacted by energy poverty or the inability to afford adequate heating or lighting (European Commission, 2020b). As such, deep renovation supports citizens in participating in a greener society first-hand while simultaneously improving energy security, health and accessibility for society's most vulnerable citizens (Baek & Park, 2012; Bruel et al., 2013; Ferreira & Almeida, 2015; European Commission, 2020). Deep renovation works lastly deliver improved consumer service on public, community and commercial levels (Jochem & Madlener, 2003; Baek & Park, 2012; Guerra-Santin et al., 2017; Klumbyte et al., 2020).

If properly integrated, deep renovation efforts create resilient and green living spaces while promoting high energy performance and lower waste and pollution levels (Baek & Park, 2012; Bruel et al., 2013; Ferreira & Almeida, 2015; Haase et al., 2020). From a wider perspective, such efforts lead to improved quality of life for building occupants, increased revenues and decreased technological and operational costs through superior products and services, improved security, quality and control over full project life cycles, and more durable buildings in the long term (Mainali et al., 2021). Perhaps most importantly, deep renovation may positively influence public attitudes towards climate change mitigation works, substitute existing, climate-damaging methods in the traditionally conservative construction sector and improve the uptake of novel and existing ClimateTech and CleanTech measures (Baek & Park, 2012; Mainali et al., 2021).

1.4 Barriers to Deep Renovation

Prior literature presents an extensive range of theoretical lenses by which to explore technology adoption and use, typically from an adopter-centred or innovation or organisation-centred perspective. These lenses are summarised in Table 1.3.

Table 1.3 Theoretical overview of technology adoption and use

Perspective	*Theory*	*Description*	*Source(s)*
Adopter-centred	Theory of Reasoned Action (TRA)	Posits that human behaviour is determined by intention, which in turn is influenced by attitude (towards the behaviour) and subjective social norms (e.g., normative beliefs, demographic variables and personality traits)	Fishbein and Ajzen (1977)
Adopter-centred	Theory of Planned Behaviour (TPB)	An extension of TRA in that it includes the element of perceived behavioural control, that is, facilitating or impeding factors which influence the performance of a behaviour in question	Ajzen (1991)
Adopter-centred	Technology Acceptance Model (TAM)	Reflects elements of TRA, but specifically concerns levels of acceptance across end-user computing technologies including perceived usefulness and perceived ease of use	Davis (1985, 1989)
Adopter-centred	Unified Theory of Technology Acceptance and Use (UTAUT)	Defines determinants of user acceptance and usage behaviour based on performance expectancy, effort expectancy, social influence and facilitating conditions	Venkatesh et al. (2003); Venkatesh et al. (2012)

(*continued*)

Table 1.3 (continued)

Perspective	*Theory*	*Description*	*Source(s)*
Innovation or organisation-centred	Diffusion of Innovation (DOI)	Includes constructs like relative advantage, ease of use, image, visibility, compatibility, results demonstrability and voluntariness of use to define individual technology acceptance	Rogers (1995, 2003)
Innovation or organisation-centred	Technology-Organisation-Environment (TOE) Framework	Identifies the degree to which technological, organisational and environmental aspects influence the process of adopting and implementing a technological innovation	Tornatzky and Fleischer (1990)
Innovation or organisation-centred	Human-Organisation-Technology Fit (HOT-fit)	Used to evaluate information systems based on human (i.e., user satisfaction and system use), technological (i.e., system, information and service quality) and organisational (i.e., environment and structure) dimensions	Yusof et al. (2008)

Although the individual arguments for shortcomings in acceptance towards deep renovation measures lie beyond the scope of this chapter, it is worth noting that the success of deep renovation efforts is impacted by adopter-centred factors, technology-related factors, organisational factors and external environmental factors. The following sections elaborate on these potential reasons for failure.

1.4.1 Human Barriers to Deep Renovation Adoption and Use

Barriers to accepting, supporting and adopting climate-friendly technologies and practices in buildings are manifold. Hesitancy can be traced back to restrictive social norms and household characteristics, short-termism and lack of clarity surrounding the negative consequences of climate change, as well as inadequate knowledge or reservations about the existence or use of new technologies (Van Raaij & Verhallen, 1983; Curtis et al., 1984; Scott, 1997; Abrahamse et al., 2005; Organisation for Economic Co-operation and Development, 2011; Mills & Schleich, 2012;

Huebner et al., 2013; Giraudet, 2020). Demographics such as age, education, household composition and geographical location have equally been shown to affect the adoption of energy efficiency technologies. For example, Mills and Schleich (2012) find that families with young children (unlike elderly household members) are more likely to adopt energy-efficient technologies, as are those with higher education levels. Interestingly, data suggests a high degree of country heterogeneity with respect to adoption, use and attitudes towards household energy-efficient technologies and energy conservation practices (Mills & Schleich, 2012).

In their ethnographic study of the occupants and users of a multi-dwelling residential building in Italy, Prati et al. (2020) find that enhanced quality of life and long-term financial savings were the primary motivators for accepting and supporting deep renovation projects for tenants. However, the economic burden does not fall on tenants, suggesting a need for a *multi-stakeholder approach* to deep renovation projects particularly where there is a divergence in ownership and occupancy. While levels of normative legitimacy may be relatively high amongst tenants (considering the largely accepted moral obligation of preserving the environment), pragmatic legitimacy may be restrained by conflicts between building owners' self-interest, perceived utility, and financial and time requirements of renovation works. Research suggests that barriers influencing the self-interest and utility involved in deep renovation measures include occupant disturbance and a lack of awareness, understanding and trust in deep renovation and new technologies (D'Oca et al., 2018; Prati et al., 2020; European Commission, 2020). Further individual adopter factors include performance expectancy, effort expectancy and social influence (Fishbein & Ajzen, 1977; Ajzen, 1991; Davis, 1985, 1989; Venkatesh et al., 2003, 2012).

Psychological (and oftentimes geographical) distance to the climate crisis is a key barrier amongst consumers in mitigating the effects of climate change and maintaining pro-environmental behaviours (Spence et al., 2012). In one scenario, this may result in building owners and occupants failing to adopt energy management measures in an individual building and within the context of that building's location and climate. As a consequence, this usually leads to unnecessarily high energy and emissions levels (Jochem & Madlener, 2003). In this context, *short-termism* has had a particularly negative impact on the adoption of deep renovation projects. For example, there is a substantial literature base which acknowledges that the adoption of energy-efficient measures is related to cost (Curtis et al., 1984; Abrahamse et al., 2005; Organisation for Economic Co-operation and Development, 2011). Consumers are more likely to adopt low-cost or no-cost measures much unlike deep renovation projects. As Mills and Schleich (2012) note, such behavioural changes may only have transitory effects, while energy savings resulting from technology adoption tend to have more long-term effects. Consequently, although the adoption of energy-efficient technologies can have a significant impact on the wider environment, it does not necessarily compensate energy savers and thus presents a significant challenge in persuading the public to act (Mills & Schleich, 2012). Particularly in the context of multi-dwelling residential buildings, this may cause mismatches between individual needs and beliefs and those of the wider collective (D'Oca et al., 2018).

Notably, *solution aversion* to climate-friendly measures, which occurs when problems are ignored due to dissatisfaction with proposed solutions, may also impact openness towards deep renovation efforts (Campbell & Kay, 2014). *Tangible solution aversion* in particular applies to the deep renovation context. Poortinga et al. (2004), for example, warn that environmental attitudes may be too limited in explaining environmental behaviour and related technology adoption—particularly because addressing climate change results in tangible lifestyle changes for building occupants. For this reason, deep renovation solutions must pay attention to promoting the cost of non-action and life-quality benefits in ways that can be received by different audiences in different climate and building-type contexts.

1.4.2 Technological Barriers to Deep Renovation Adoption and Use

Technology-related adoption factors include, amongst others, innovation characteristics, availability, ease of use, compatibility, results demonstrability and quality-driven factors (Tornatzky & Fleischer, 1990; Rogers, 1995, 2003; Yusof et al., 2008). Key focus points over previous years have shifted from the technical suitability of deep renovation technologies primarily to the *integration* of energy-saving technologies throughout deep renovation projects (D'Oca et al., 2018). This includes building envelopes, HVAC systems and RES-powered systems (D'Oca et al., 2018). Today, the main technological challenge to deep renovation lies in the complexity associated with integrating technically viable, context-appropriate technologies according to desired outcomes and regulatory standards (Attia et al., 2017). Because of this, one could posit that meeting standards of deep renovation requirements, for example, the Passive House Standard, is less a matter of the technological state of the art, but rather technical awareness, availability and know-how (Innovate UK, 2013; De Gaetani et al., 2020). In its worst case, a lack thereof can lead to missed opportunities, inadequate performance and dissatisfaction with deep renovation as a concept.

The issue of integrating technologies into the building renovation process becomes particularly complex when one considers the abundance of domains, stakeholders and outbound dependencies to systems, regulations and geographical characteristics related to the deep renovation process. This is an issue of *interoperability*, that is, "the ability of two or more systems or components to exchange information and to use the information that has been exchanged" (ISO, 2013). The definition of interoperability has morphed somewhat over time, initially used to describe "a feature of information systems that enabled information exchange" to any system which is able to collaborate with another system (Turk, 2020). Its value becomes evident in enabled communication, coordination, cooperation, collaboration and distribution (Grilo & Jardim-Goncalves, 2010). Unfortunately, the range of heterogeneous applications and systems used by different stakeholders varies across the project life cycle. An example of this is Building Information Modelling (BIM), which presents a plethora of varying software tools designed for energy simulation, planning and management (El Asmi et al., 2015; Arayici et al., 2018). Lacking interoperability (particularly when combined with the dynamic nature of construction projects) becomes an issue in that data flows and value generation are negatively affected by data mismatches, data quality issues and inconsistent sector standards and processes (Curry et al., 2013; Arayici et al., 2018; Shirowzhan et al., 2020). While interoperability with other systems, for example, Geographic Information System (GIS) and Augmented Reality (AR)/Virtual Reality (VR), has been increasingly prioritised, knowledge and practice gaps for integrating stateof-art technologies remain (Shirowzhan et al., 2020).

This is not to say that the technological status quo does not face quality or performance issues in itself (Attia et al., 2017). Primarily the adoption and use of software- or cloud-enabled solutions is inflicted by poor on-site connectivity and latency, lack of integration across supply chains, inconsistent data flows and inadequate worker skills (Almaatouk et al., 2016; Bello et al., 2020). A further by-product of the Internet of Things or smart or otherwise connected products is copious volumes of data—all originating from end points with varying capabilities, connectivity levels, requirements and priorities. Due to the idiosyncrasies of individual buildings and living spaces, owners and occupiers, and the environment in which they are located, this requires taking into account both local and more global considerations (Venkatesh, 2008).

1.4.3 Organisational Barriers to Deep Renovation Adoption and Use

Organisation-related barriers to deep renovation include organisation size and structure, adequacy of resources, top management support and perceived indirect benefits (Tornatzky & Fleischer, 1990; Rogers, 1995, 2003; Yusof et al., 2008). Because of the multi-stakeholder nature of deep renovation projects, existing resources, technical competencies and innovation levels amongst management and operational teams vary and must be considered (Yusof et al., 2008). Resource allocation, financial investment and employee competency all have the potential to hinder deep renovation uptake. For example, research finds that inadequately trained professionals and construction workers within the realm of energy efficiency present a significant barrier to project success (Innovate UK, 2013; Attia et al., 2017; D'Oca et al., 2018; Vavallo et al., 2019).

From an organisational perspective, financial barriers are amongst the most highly cited in literature (Cooremans & Schönenberger, 2019; Bertoldi et al., 2021). This is accelerated by the complexity of deep renovation, particularly in multi-residential buildings such as social housing or other fragmented ownership models (D'Oca et al., 2018). Procurement policies which prioritise price over the quality of renovations, combined with high upfront investment costs and challenging access to funding, may negatively affect deep renovation efforts initiated by the public sector (European Commission, 2017; Van Oorschot et al., 2019; D'Oca et al., 2018; European Commission, 2020). In its worst case, this can result in project delays, underwhelming energy performance and heightened costs—finally leading to reduced consumer trust in public sector efforts overall and specifically deep renovation projects (D'Oca et al., 2018).

1.4.4 *External Environment Barriers to Deep Renovation Adoption and Use*

The external environment, including building and environmental regulations, policies and standards, heavily impacts deep renovation. Environmental factors encompass all external pressures on deep renovation initiatives, including regulatory, competitive and financial pressures, as well as related support from public bodies and partners (Tornatzky & Fleischer, 1990). For those involved in the supply chain, keeping up with changing regulatory requirements can be a significant challenge particularly under changing political administrations.

Legislation and regulation are highlighted as potentially obtrusive to deep renovation efforts in that these are often complex, unclear and time-consuming (European Commission, 2017; D'Oca et al., 2018; European Commission, 2020). One reason for this is that the context of local governments, and more specifically local energy issues, is often ignored in EU regulations or other intergovernmental treaties. Here, central governments are mainly targeted and expected to oversee the implementation of climate objectives (European Commission, 2017). Because they are responsible for the implementation of energy-saving measures, local entities have specific insights into the barriers they face and must therefore become more closely involved in the development of deep renovation strategies, regulations and targets (European Commission, 2017). In a cross-European report, main local barriers to deep renovation were found to be primarily fiscal and financial (i.e., referring to lack of technical skills for funding applications, poorly designed or lack of incentives, limited borrowing capacity, complex financial schemes and unfavourable accounting rules), followed by legislative and strategic barriers such as an incomplete overview of building stocks, limited training in deep renovation practices and lack of technical capacity required for such projects (European Commission, 2017). As previously identified in Sect. 1.2, one final clear strategic barrier was deemed to be the lack of a uniform definition of deep renovation itself (European Commission, 2017).

1.5 Conclusion

This chapter introduces deep renovation, which involves renovation works that capture the full potential of energy- and cost-saving adjustments to existing buildings, along with its benefits and the human, technological, organisational and external environment barriers associated with deep renovation projects. Deep renovation has the potential to transform the construction and renovation industry in its integrated use of multiple energy-saving measures. Projects simultaneously offer relief for vulnerable residential consumer groups, further desperately needed climate-friendly and potentially net-zero energy practices, and heighten the long-term durability of buildings. Each chapter of this book is dedicated to exploring the impact of a specific digital technology on the implementation and delivery of deep renovation projects. Chapter 2 is dedicated to embedded sensors, one of the (if not the most important) enabling technology in the digitalisation of deep renovation. In fact, the use of sensor networks and connectivity represents a key prerequisite for measuring, and therefore optimising, the energy performance of an existing building and for efficient construction management. This chapter presents the role of sensor networks in the field of deep renovation, introduces the concept of smart buildings and smart homes and their main advantages and benefits, and highlights some of the main challenges and concerns associated with the use of sensor infrastructures which are mostly related to the volume, access and use of data captured by sensors on an ongoing basis.

Chapter 3 focuses on BIM, which leverages the large volume of data generated by sensor networks to manage "[…] the information on a project throughout its whole life cycle" (Hamil, 2022). Chapter 3 explores the evolution of BIM from its emergence in the early 1990s to recent developments and describes different BIM "dimensions". The chapter continues by presenting how BIM enables multi-criteria decision-making in the context of building renovation, and deep renovation more specifically, and how it can help to identify, optimise, validate and communicate different renovation scenarios and corresponding costs, timelines and effectiveness. The chapter concludes with a discussion of two main sets of barriers to BIM adoption, namely interoperability and the lack of ontologies that are specifically designed for renovation work which undermine the potential for process automation.

Another way of leveraging the vast amount of data generated by sensors is to develop models that evaluate the energy performance of an existing building and estimate how changes in external and internal conditions would affect such a performance. This technique is called Building Performance Simulation (BPS) and is the main topic of Chap. 4. More specifically, this chapter provides an overview of the main approaches and applications of BPS in the context of deep renovation and discusses how to integrate simulations with real-time monitoring and diagnostic systems for building energy management and control.

Chapter 5 is dedicated to the application of Big Data and analytics in the deep renovation with a particular focus on Machine Learning and Artificial Intelligence and the changes they have enabled in the various phases of the renovation project life cycle, from the renovation design to post-renovation monitoring and assessment. The chapter presents a series of use cases and applications of Big Data in construction and discusses the main advantages and benefits (e.g., alternative design automation, the development of accurate performance prediction models, higher efficiency and reduced environmental impact of the renovation work), as well as the main barriers and challenges (human, technological and organisational) to the wider adoption of Big Data and analytics in deep renovation.

When it comes to capturing data about the physical structure of an existing building, detailed information can be gathered by adopting 3D scanning tools and techniques which enable the creation of a digital twin of the building. Chapter 6 introduces this novel technological paradigm in more detail, describes the main steps and approaches to creating digital twins and presents three main use cases for digital twins in the built environment, namely condition monitoring, facility management and environment simulation. The chapter concludes with a discussion of the main challenges associated with adopting and using digital twins which are mostly related to the high cost and effort required to create the digital twin.

Chapters 7 and 8 turn the attention to the construction phase of the renovation life cycle. In fact, Chap. 7 focuses on additive manufacturing (often referred to as 3D printing) which is the process of fabricating three-dimensional objects following a specific computer design. Additive manufacturing has attracted growing attention from the construction sector in recent years as it promises lower waste and costs, and it provides the opportunity to create complicated large-scale structures and integrate functional building elements such as pipes and storage units within the structure itself. These benefits are discussed in more detail alongside some practical challenges (e.g., equipment costs, skills and lack of standardisation) that are adversely impacting the diffusion of this technology.

Chapter 8 focuses on the use of intelligent equipment and robots (IER) in construction sites. This chapter discusses the maturity of IER technologies that are currently available in the market, describes how they can be used both on-site (e.g., inspection, construction and maintenance) and off-site (e.g., factories) and discusses the key concerns and barriers to adoption which are mostly related to high costs, lack of skills, human-robot interactions and security.

The issue of security is not only relevant in the context of IER, but it is a recurring concern across the entire renovation life cycle. This topic is discussed in more depth in Chap. 9 which provides an overview of relevant cybersecurity frameworks, standards, guidelines and codes of practice. These include, for example, relevant International Organization for Standardization (ISO) and American Institute of Certified Public Accountants (AICPA) standards, the NIST Framework for Improving Critical Infrastructure Cybersecurity, and the European Union Network and Information Systems (NIS) Directive. The chapter concludes by highlighting the need for a contingency approach to assess and manage cyber risk in the context of building renovation, as a one-size-fits-all approach may not be desirable or feasible given the variety of stakeholders involved in this kind of projects.

The final chapter discusses how novel financial technology (fintech) solutions such as crowdfunding, peer-to-peer lending and blockchain-based mechanisms such as tokenisation can help building owners and construction companies overcome one of the main barriers to deep renovation, access to capital. The chapter outlines the main advantages and benefits of these alternative sources of finance, as well as the challenges associated with each of these funding mechanisms, and concludes with a call for further research on both demand side (fund seekers) and supply side (investors) incentives and dynamics or indeed on the responsibilities of platforms that enable and facilitate these transactions.

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