INVESTIGATING THE CHALLENGES AND PROBLEMS ASSOCIATED WITH THE IMPLEMENTATION OF DIGITAL TECHNOLOGIES FOR PROMOTION OF SUSTAINABLE HOUSING IN THE UK.

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Abstract

This research work investigated the challenges and problems associated with the implementation of DTs for promoting sustainable housing in the UK. It engages qualitative research techniques in investigating the application of DTs for promoting sustainable housing practices inthe UK, with a view to highlighting the effect of DTs for promoting sustainable housing initiatives in UK. The specific objectives of this study are to: identify the key DTs driving sustainable housing initiatives in UK, explore the effects of these DTs on energy efficiency, environmental sustainability, and overall housing quality in the UK, assess the challenges and problems associated with the implementation of DTs for promoting sustainable housing in the UK, and determine the enablers and strategies for effective integration of DTs for promoting sustainable housing practices in UK. The study adopted Thematic Analysis assumptions in its data analysis. The method of data collection were through semi-structured interviews as primary sources. Other information were drawn from extensive literature reviews of journals, textbooks, printed publications, internet sources and write-ups relevant to the study, from secondary sources. The result from the data analysis shows that there are various DTs that aid sustainable housing practices. To acknowledge the roles these DTs play in promoting sustainable housing practices in thebuilding industry, the knowledge of their application and in-depth understanding on their use is critical. The study recommends that future research should focus on addressing key barriers to the implementation of DTs for sustainable housing worldwide since the present study focuses on DTs application for promoting sustainable housing in the UK.

Keywords: challenges, problems, implementation, digital technologies, housing and UK

Introduction

There has been an upsurge in the rate at which researches are conducted on construction industry such as sustainable development and construction projects delivery. Also, the rapid growth of the global population, together with significant rural-urban migration resulting from the increased rate of poverty, contributed greatly to an unprecedented rise in resource consumption, exacerbating climate change, leading to multifaceted socioeconomic and environmental challenges worldwide. Consequently, a lot of countries of the world are faced with the challenges of building projects delivery, especially in the area of promoting sustainable housing, using digital technologies (DTs) available. These challenges menace the balancing of economic viability, social acceptability, technical feasibility, and environmental compatibility, which characterize good

sustainable housing. They also hinder the utilization of modern conventional housing delivery method like the application ofDTs for promoting sustainable housing. Thereby causing numerous housing projects that cost too much and take longer time to complete. No wonder why Lewis and Conaty (2012)contend that there is need for urgent and coordinated global action to handle the escalating threat coming from climate change to both present and future generation. They explained that government of countries of the world are faced with the challenges of balancing economic development with environmental sustainability, confronting issues of climate change mitigation and adaptation in both developed and developing nations. The focus of this research work is therefore, to examine the application of DTs for promoting sustainable housing in the United Kingdom (UK) with particular reference to the objectives of the study.

Digital technologies (DTs), encompassing electronic instruments, systems, devices, and resources for data creation, storage, or processing, have gained recognition from scholars as essential tools for enhancing sustainable housing practices. Identified DTs for promoting sustainability in housing, include smart home solutions, Building Information Modelling (BIM), Internet of Things (IoT), Big Data (BD), among others (Al-Emran & Griffy-Brown, 2023; Rane, 2023). These technologies offer various benefits, such as optimizing energy consumption, minimizing waste, facilitating collaboration in design and construction, collecting real-time data for analysis, and providing accountability in sustainable housing data.However, it is also essential to notetheir negative effects, as shownin Al-Emran and Griffy-Brown (2023). Therefore, gaining a comprehensive understanding of how these technologies could be effectively used by individuals and organizations is crucial for achieving improved sustainable housing practices. The problem of the study is accounting for the key DTs driving sustainable housing initiatives in UK, exploring the effect of these DTs on energy efficiency, environmental sustainability, and overall housing quality in UK, assessing the challenges and problems associated with the implementation of DTs for promoting sustainable housing practices in the UK, and determining the enablers and strategies for effective integration of DTs for promoting sustainable housing practices in UK.Using qualitative research technique, the study analyses the data for the study gathered through semi-structured oral interview and multiple case studies adequately.

Conceptual Review

Key DTs Driving Sustainable Housing Initiatives

The building and construction sector contribute39% of worldwide carbon emissions due to large usage of materials, energy, and waste generation (World Green Building Council, 2018). With the urbanisation and growing population, DTsbecome very important in designing and operating sustainable housing in UK and beyond.Various DTs aid sustainable housing practices. Out of these DTs, some are tagged the key ones, which require in-depth understanding of their uses to reach desired sustainable housing practices. Some of these key DTs include among othersBIM, IoT, BD, Clouds, Artificial Intelligence (AI), Digital Twins (Eadie, Browne, Odeyinka, McKeown & McNiff, 2013; Ullah, Sepasgozar, & Wang, 2018; Shabha, Barber, & Laycock, 2021; Al-Emran & Griffy-Brown, 2023). Figueres and Rivett-Carnac (2020) emphasized the necessity of using them thoughtfully and strategically, since they will contribute to the reduction of global Greenhouse Gas (GHG) emissions.

To properly harness the roles these DTs play in raising sustainable housing practices, an in-depth understanding of howthese DTs function in promoting sustainable housing initiatives is needed. This is because, the knowledge of the application of these DTs and in-depth understanding

on the use(s)are important for the development of sustainable housing practices, the geographical location of where they are used notwithstanding.However, Gürdür Broo, Lamb, Ehwi, Pärn, Koronaki, Makri, and Zomer (2021) warn that the use of these DTs may aggravate the current global climate crisis if not carefully regulated through governance and guiding principles. Consequently, this study provides an overview explanation of each ofthekey identified DTs, together with its functions, benefits, guiding principles, and potential applications for promoting sustainable housing initiative worldwide and in UK in the section below.

Building Information Modelling (BIM)

BIM is an innovative technology that evolved in recent years. BIM is defined as the process of creating, storing, managing, exchanging, and sharing building information in an interoperable and reusable manner; it also necessitates the creation and use of computer-generated models to simulate various phases of a project (Azhar, Hein, & Sketo, 2008; Vanlande, Nicolle, & Cruz, 2008).It allows for more efficient and sustainable building designs (Wong & Fan, 2013). BIM plays numerous roles in advancing sustainable housing initiatives worldwide and in the UK. It is consistent with the concept of integrated project delivery, allowing stakeholders to collaborate in order to reduce waste and maximise efficiency throughout the project lifecycle (Kymmell, 2008; Glick & Guggemos, 2009). By enabling collaborative workflow(s) among architects, engineers, contractors, and other stakeholders, BIM streamlines communication and decision-making processes, enhancing efficiency and effectiveness for sustainable housing projects (Azhar, 2011). The above comments and reasoning from scholarssuggest that BIM plays animportant role in advancing sustainable housing initiatives worldwide by fostering collaboration, enhancing communication, and facilitating efficient project delivery.Drawing upon the above assertions, research into the extent of BIM's contribution to sustainable building design is considered valuable since it raises awareness of the technology's capabilities and promise for sustainable housing development.

However, several guiding principles support the efficient use of BIM to promote sustainable housing. These principles include integrating sustainability considerations throughout the BIM process, collaborating with project stakeholders, and adhering to industry standards, and best practices to ensure interoperability and data consistency (Cao, Wang, Li, Skitmore, Huang, & Zhang, 2015; Ilhan, & Yaman, 2016).Adhering to these guiding principles helps stakeholders to maximise the benefits of BIM while improving the sustainability performance of housing projects.

Drawing upon the foregoing, it is gathered that BIM has diverse applications strategy for promoting sustainable housing initiatives globally and UK in particular. In terms of design, BIM enables the creation of energy-efficient building models that optimize daylighting, ventilation, and thermal performance. During construction, BIM enables optimal coordination of building components, reducing material waste and construction delays. In building operation, BIM aids with facility management tasks such as energy monitoring, maintenance scheduling, and lifecycle cost analysis.Generally speaking, BIM serves as a powerful tool for advancing sustainability withinthe housing sector, offering innovative solutions for design optimization, construction efficiency, and long-term building performance management.

Internet of Things (IoT)

The phrase "Internet of Things" (IoT)was first introduced by Kevin Ashton in 1999. It refers to a collection of physical devices that are connected to the internet and capable of perceiving

various physical properties of the environment, including temperature, humidity, illumination, and other relevant features (Wortmann & Flüchter, 2015). Al-Fuqaha, Guizani, Mohammadi, Aledhari and Ayyash (2015) assert that IoT devices can gather, transmit, and analyse data on energy consumption, indoor air quality, water usage, and other environmental factors in residential buildings. These devices can monitor and operate a wide range of systems and appliances, optimising their performance for energy efficiency and sustainability.

However, various guiding principles facilitate the appropriate use of IoT to promote sustainable housing. These include data privacy and security concerns, which are critical for securing sensitive information acquired by IoT devices (Mahmoud, Yousuf, Aloul, & Zualkernan, 2015). Interoperability and compatibility among various IoT devices and platforms are critical for ensuring seamless integration and functionality (Borgia, 2014; Al-Fuqaha et al., 2015). Also, user-centric design concepts should be used to guarantee that IoT solutions are intuitive and simple to use for residents and building occupants (Ullah et al., 2018). These imply that adhering to these guiding principles, such as data protection, interoperability, and user-centric design, is critical for achieving sustainable housing outcomes with IoT.

Nevertheless, it is gathered from the foregoing that IoT technology has a wide range of uses for promoting sustainable housing initiatives in UK, and worldwide at large. This study supports Al-Fuqaha et al. (2015) assertion that IoT devices improve energy management by controlling heating, ventilation, and air conditioning (HVAC) systems, lighting, and appliance usage, resulting in lower energy consumption. Smart metering and energy monitoring systems offer real-time tracking of energy consumption, which aids in conservation efforts. Besides, IoT sensors monitor indoor air quality and ambient conditions, allowing for prompt ventilation and pollutant removal to improve occupant health and comfort (Zanella, Bui, Castellani, Vangelista, & Zorzi, 2014). Water management systems integrated with IoT technology identify leaks and optimise water usage, helping to conserve resources (Mekonnen & Hoekstra, 2016). Hence, through embracing IoT technologies, housing stakeholders can significantly improve sustainability results, thereby contributing to healthier and more environmentally friendly built environments in UK and across the globe.

Big Data (BD)

BDrefers to massive amounts of data that standard software cannot process (Winson-Geideman, Krause, Lipscomb, and Evangelopoulos, 2017). Winson-Geideman and Krause (2016) aver that this data is frequently connected and spans multiple databases, and extracting valuable knowledge from this digital data stream is a critical component of BD analytics. Although, there are different definitions for big data, they all share three data-mining characteristics: large data volume, processing speed, and data coverage (Chen & Lu, 2018). The use of BD analytics in sustainable building allows stakeholders such as architects, engineers, and facility managers to make more informed decisions by offering real-time insights into energy consumption trends and environmental impacts (Rane, 2023). Specifically, in sustainable building, BD analytics are critical in evaluating the lifecycle of materials, helping in the selection of ecologically beneficial choices (Ullah et al., 2018). This implies that BD has the potential to greatly impact decision-making processes and promote sustainability initiatives in the housing industry.

The effective application of BD in sustainable housing initiatives requires adherence to some guiding principles. This include prioritising sensitive information protection and adhering to

data protection standards throughout big data collection, storage, and processing is critical for ensuring the confidentiality and security of personal data (Al Nuaimi, Al Neyadi, Mohamed, & Al-Jaroodi, 2015). Maintaining the accuracy, dependability, and integrity of big data sourcesis critical for generating meaningful insights and supporting informed decision-making processes. This includes also, ensuring data completeness, consistency, and timeliness (Manyika, Chui, Brown, Bughin, Dobbs, Roxburgh, & Hung Byers, 2011). Nonetheless, abiding to ethical norms in big data techniques is critical, involving avoiding biases and prejudice in data analysis and protecting individual privacy rights (Al Nuaimi et al., 2015). Adhering to ethical norms increases stakeholder trust and credibility, emphasising the importance of ethical considerations in encouraging openness and accountability in sustainable housing initiatives.

Furthermore, continuous developments in BD technologytogether with ongoing research and development, offer more groundbreaking uses in promoting many areas of sustainable housing projects in the UK and worldwide. This includes self-driving construction equipment led by real-time data and AI-powered design solutions that anticipate human demands and preferences (Ullah et al., 2018). Through analysing data from smart metres and IoT devices, BD can optimise energy use, cut carbon emissions, and improve building efficiency, all of which contribute to sustainable housing practices. BD platforms also enable community participation in sustainable housing projects through crowd-sourced data collecting, citizen science initiatives, and online engagement platforms (Manyika et al., 2011). This enables inhabitants to actively participate in and profit from sustainability efforts, emphasising the importance of community involvement in driving sustainable housing initiatives forward.

Challenges and Problems of Implementing DTsfor Promoting Sustainable Housing

The importance of economic growth and sustainable housing development is widely recognised as arising from the development and implementation of DTs (Ma, Grubler, & Nakamori, 2009). DTs have the capacity to greatly enhance the sustainability of housing globally. However, there are still challenges that hinder their broad implementation and integration in the housing industry. For instance, the adoption of DTs is a gradual process that requires changes in behaviour, which may not always be related to technology. Many firms are hesitant to embrace these changes because, they involve altering established practices without any financial incentives (Dowson, Poole, Harrison, & Susman, 2012; Edirisinghe, London, Kalutara, & Aranda-Mena, 2017; Ullah et al., 2018; Črešnar, Dabić, Stojčić, & Nedelko, 2023).

Sequel to that, it is necessary to understand the obstacles, challenges, prerequisites, and what are involved in the acceptance of DTs in the housing sector, and implement them for advancing sustainable housing in the UK and on a global scale. This study also has challenges associated with the implementation of DTs for promoting sustainable housing in the UKas one of its objectives. These challenges coming from the integration ofDTs such as AI, IoT, BD among others,for promoting sustainable housing in the AEC industry as identified by Rane (2023) include; technical, practical, ethical and social challenges.

Technical Challenges

Rane (2023) views technical challenges as issues including data integration and interoperability, data security and privacy, andfinally, scalability and performance. The diversified and broad nature of data poses a basic problem on integrating DTs such as AI, IoT, and BD in the AEC sector to promote sustainable housing (Perkins, Couto, & Costin, 2020; Wu, Li, & AbouRizk,

2022).DT-enabled sustainable housing projects generate massive amounts of data, such as architectural blueprints, engineering plans, building designs, and sensor data from IoT devices (Rane, 2023). Harmonising various disparate data sources to ensure smooth integration and interoperability is a big technological challenge, since it necessitates aligning diverse data formats, standards, and protocols in order to extract valuable insights.With the growth of networked devices in the IoT ecosystem, ensuring data security and privacy becomes critical (Patel & Patel, 2020; Braun, Fung, Iqbal, & Shah, 2018; Alaloul, Liew, Zawawi, & Kennedy, 2020). Sustainable housing projects include sensitive information, and any breach could have serious consequences. AI algorithms and big data analytics frequently rely on massive datasets, which raises concerns about data privacy and unauthorised access (Rane, 2023). As a result, maintaining data security and confidentiality while enabling data-driven decision-making is an enormous challenge for the AEC industry and sustainable housing stakeholders in UK.

Given the different scales of sustainable building construction projects, integrating AI, IoT, BD, and other DTs to manage large and complicated projects present scalability and performance challenges. As observed by Rane (2023), DT systems have to be scalable to handle the rising number of data created over various project phases. Nonetheless, real-time processing and analysis are critical for proactive decision-making and require high-performance computer infrastructure. To overcome these issues, it is necessary to ensure the smooth integration of varied digital systems, protect data integrity and privacy, and scale up DTs to manage large-scale sustainable housing projects both in UK and globally.

Practical Challenges

Practical challenges refer to real-world issues and difficulties associated with interdisciplinary collaboration, cost and return on investment (ROI), and change management within AEC organisations (Rane, 2023). These barriers (challenges) have a direct impact on the successful adoption and implementation of digital solutions in real-world settings for sustainable housing projects. AI, IoT, BD, and other DTs necessitate collaboration amongst several disciplines such as architecture, engineering, data science, and computer programming. Consequently, bridging the gap between these professions and promoting good interdisciplinary collaboration is critical.

Rane (2023) highlights that incorporating modern technology in sustainable housing projects incurs significant upfront expenses, such as infrastructure setup, training, and software development. AEC firms, particularly smaller ones, may find it difficult to justify these investments unless they have a clear knowledge of the long-term benefits and ROI. Also, the adoption of AI, IoT, BD, and other DTs requires a mindset transformation within sustainable housing AEC organisations. This suggests that personnel must adjust to new tools, processes, and decision-making approaches in order to achieve positive sustainable housing outcomes. Therefore, effective change management strategies are required to tackle resistance, provide proper training, and build a positive attitude towards DTs adoption in order to promote sustainable housing projects globally and in UK.

Ethical and Social Challenges

Ethical and social challenges are DTs issues that affect individuals, communities, and society and necessitate the use of moral frameworks by sustainable housing stakeholders, to make decisions or take actions (Rane, 2023). These challenges include workforce displacement, bias and

fairness, as well as regulatory and legal frameworks. However, the use of AI technologies, such as automated design and building procedures, may raise concern about job displacement (see Rane, 2023). While these technologies improve productivity, they may diminish demand for some manual jobs, thereby displacing labour. Therefore, balancing the benefits of automation with the preservation of job prospects is an ethical challenge that needs to be addressed in DT-enabled sustainable housing practices in UK and across the world.

Discovered from Rane's researches,AI algorithms and other DTs, which are frequently trained on historical data, may inherit biases from the data. As a result, biassed algorithms in the AEC sustainable housing company may lead to discriminatory behaviours, influencing decisions about project approvals, resource allocation, and urban planning. So, guaranteeing fairness in AI and other DT algorithms and eliminating biases requires thorough study and ethical considerations. Similarly, the report found that rapid advances in AI, IoT, BD, and other DTs exceed the creation of complete regulatory frameworks. The lack of standardised regulations generates uncertainty regarding liability, intellectual property rights, and accountability. Also, developing strong legal frameworks that manage concerns such as data ownership, liability for algorithmic choices, and intellectual property is needed for the responsible integration of these DTs into the AEC sustainable housing sector in UK and across the world.

Empirical Review

Ibem and Aduwo's study is related to this present study in the sense that both studies are interested on measures or strategies that can facilitate sustainable housing initiatives globallymaintenance, though, this present research is focused on the UK. This delimitation, instantiate their difference. The two studies also differ in their method of gathering data for the study. While Ibem and Aduwo's (2015) data for their study is through a systematic review of existing literature only, the study at hand, in addition to review of existing literature, collected data from semi-structured interviews and multiple case studies. However, both studies recommend strategies for the implementation of sustainable housing practices in the building construction industry worldwide.

Rane (2023) adopts a comprehensive and exploratory research approach to investigate the integration of AI, IoT, big data and other DTs for smart andsustainable AEC industry by exploring their challenges and future directionswithin the AEC industry. Rane's study advocates for strategic collaboration among industry stakeholders, policymakers, and researchers to address challenges and unlock the full potential of AI, IoT, big data and other DTs for intelligent and sustainable AEC practices. Rane gathered her data through a comprehensive examinationof existing literature. Rane's findings reveal the synergistic relationship between blockchain technology and its integration with AI and IoT for enhancing transparency, security, and efficiency in AEC transactions.Also, the study discovered the transformative potential of advanced technologies in the AEC industry, particularly, in driving sustainability, efficiency, and innovation across various facets of construction processes and practices.

The study of Rane (2023) is related to this present study because, both studies explorethe integration of DTs such as AI, IoT, BD, amongothers for promoting smart and sustainablepractices within AEC industry. Again, both studies gathered their data for the study through the review of existing literature, but this present research additionally collected data through semi-structured interview and multiple case studies. However, both studies differ in their areas of study.Rane's study covers the globe, that is no specific area was mentioned, while the present study was carried

out in the UK. Again, their choiceof research topics are not the same. The present study's research topic is 'application of DTs for promoting sustainable housing in the UK',while Rane's own is on 'integrating leading-edge AI, IoT, BD technologies for smart andsustainable AEC industry focusing on challenges and future directions.'

Furthermore, Shabha, et al. (2023) use interpretivist beneficial technologies to investigatea qualitative assessment of theimpact of smart homes andenvironmentally beneficialtechnologies on the UK 2050net-zero carbon emission target.They gathered their data for the study through a semi-structured survey that was administered to two groups which are professionals knowledgeable about smart home technology and users of smart home systems.Their findings reveal that there is an urgent need for renewable, low-carbon energy sources to address the significant carbon emissions associated with UK households, which currently stand at approximately 5 tons annually per household. They also observed that achieving carbon emission reduction targets requires a multi-faceted approach involving both public and governmental involvement, in addition to the use of smart meters within households. As such, they recommendcollaborative efforts from all stakeholders and policy interventions as measures toaddress environmental sustainability challenges.

Shabha, et al. 'study is related to this present research work as both studies focuson assessing the synergetic effect of DTs and sustainable housing on the UK 2050 net-zero carbon emission target. The two studies are qualitative research work. As well, both studies have the same geographical location - UK. However, their choiceof research topics are not the same. While the present research topic ison the 'application of DTs for promoting sustainable housing in the UK'Shabha et al.'s own is on 'a qualitative assessment of theimpact of smart homes andenvironmentally beneficialtechnologies on the UK 2050net-zero carbon emission target.'

Methodology

This study adopts and adapts Saunders, Lewis, and Thornhill's (2009) concept of the research onion. This study adopts an interpretivism research philosophy. Saunders et al. (2009) identify different types of research strategies, which are experimental, surveys, case studies, action research, grounded theory, ethnography, and archival research. This study adopts qualitative research technique. This study uses both primary and secondary data sources. Semi-structured interview with four AEC experts that specialised in DTs and sustainable housing were employed to serve as the primary data sources for this project, as well as the instrument for data collection. After gathering the data for the study through semi-structured interview and case studies, the researcher confirms facts; the researcher also transcribes, collates, categorises, juxtaposes them, and then, subject them to analysis, using thematic analysis (TA) assumptions.

Case Studies Analysis

Challenges to the Integration of DTs

The Forge projectfaced challenges coming from transitioning to new standards and upskilling the projects teamto meet the requirements of the DTs incorporated into the project.The decision to update the project from Building Research Establishment Environmental Assessment Methodology (BREEAM) 2014 to BREEAM 2018 presented challenges, as certain credits were no longer available under the latest version (UKGBC, 2022).Similarly, implementing novel construction methods and technologies posed challenge as they involvedupskilling for project

teams, subcontractors, and stakeholders, which require additional time and resources for stakeholders to familiarize themselves with new processes, and overcome technical challenges. So, aligning project goals with evolving sustainability standards and technologies and ensuring early compliance with regulatory requirements to optimize credit attainment and project outcomes.

Despite the effective incorporation of DTs for meeting the 80 Charlotte Street project's sustainability goals, the project faced difficulties with their implementation. It is gathered from UKGBC (2022),that the project adoption of DTs such as IoT, BD, cloud, and BIM entailed upfront costs and requiredthe hand of expertise.Thesepose challenges for the project stakeholders. Also, regulatory requirements and logistical complexities put obstacles to seamless integration of these DTs into the project. Thisaligns with the claim made by Rane (2023) disposed under (2.1.4.2). Also, the project substantial application of IoT devices and cloud computing for data collection and analysis raised concerns about data security and privacy.Hence,ensuring thatsensitive data generated from building systems and occupants is appropriately protected against cyber threats and unauthorized access posed difficulty.

Findings and Discussion

The results of this study show thatthough, DTs have the potential forimprovingthe sustainability of housing in the UK and worldwide, there are challenges hindering their broad implementation and integration in the building industry. These challenges include, among others, technical, practical, ethical, and social aspects. Technical challenges, such as data integration, interoperability, security, and scalability, arise from the diverse and voluminous nature of data generated by DT-enabled sustainable housing projects.Practical challenges, on the other hand, revolve around interdisciplinary collaboration, cost considerations, and change management within AEC organizations,whereasethical and social challenges include concernabout job displacement, biases in algorithms, and the lack of standardized regulatory frameworks.

Similarly, the Forge project and the 80 Charlotte Street case studiesfacetechnical, practical, ethical,and social barriers related to transitioning to new standards, upskilling project teams, data security concerns, resistance to change, regulatory compliance, managing upfront costs and logistical complexitiesassociated with DTs implementation. Notably, the UKGBC (2022) stated that the incorporation of IoT devices and cloud computing in both case studies raised concerns about data security and privacy, pointing out the importance of safeguarding sensitive data generated from building systems and occupants against cyber threats and unauthorized access.

The findings of this study’s interviewsalign with the above outlined challengesof implementing DTs for promoting sustainable housing in the UK and beyond by various scholars. P1 says that:

> *…the main challenges include the human element, particularly human error and ethical considerations. Human error can lead to unintended inefficiencies in the use of DTs, while ethical concerns arise regarding biases and inclusivity in technology development...*

P2 also asserts that:

> *…the major challenge for me is the high cost of software and other DTs, particularly with the shift to subscription-based models like Autodesk's, which can be prohibitively expensive for smaller subcontractors and businesses in the supply chain…*

However, P3and P4 respectivelystate that:

> *…the main barriers, in my opinion is the high costs associated with adopting these technologies, and then the drive for it is often coming from clients rather than the industry itself. Additionally, there is a lack of clear policies to guide the implementation of these DTs, leading to a sense of freedom that can sometimes result in resistance or skepticism among professionals...(P3).*

> *…regulations are not pushing to prioritize simplicity and sustainability in new and existing buildings, as well as tax policies that incentivize new construction over retrofitting. Budget constraint is also a problem, as achieving high levels of sustainability often requires additional investment in installation and additional workmanship, despite decreasing costs of renewable technologies. Also, limited research and development efforts within the industry hinder the identification and adoption of innovative sustainable solutions (P4).*

So, the foregoing viewpointsreveal that the main challenges of implementing DTs for promoting sustainable housing in the UK and globally comprisehigh cost of these DTs, ethical considerations, resistance to change, lack of clear policies, regulatory constraints favouring only new construction, budget limitations, inadequate training, and limited research and development efforts. However, the result of the findings of this study is in line with Rane's (2023) claim that to achieve more favourable sustainable housing outcomes, using DTs, there is need to fully understand these challenges and then come up with measures that will help mitigate them.

Conclusion

DTs may aggravate the current global climate crisis if not carefully regulated through governance and guiding principles. Hence, the need to use them thoughtfully and strategically, since they will contribute to the reduction of global Greenhouse Gas emissions. Discussed also in the study are the challenges and problems associated with the implementation of DTs for advancing sustainable housing in UK, and the enablers and strategies for effective integration of DTs for promoting sustainable housing practices in the UK.

Recommendations

This researchwork has proved that the application of DTs for promotion of sustainable housing practices is an active means of advancing housing sustainability in the UK. Therefore, it is important for the industry to have an in-depth understanding of the use of DTs as that will help in promoting sustainable housing development in the UK. Besides, a sound knowledge of DTs and their usage will help students of BuildingTechnology appreciate the effect of DTs in advancing sustainable housing development fully. However, having acknowledged that this work cannot exhaustively cover all the issues surrounding DTs processes involved in promoting housing sustainability practices in the UK, it is pertinent to make some recommendations here for further studies. We, therefore, suggest that future researchers should focus their investigations on addressing key barriers to the implementation of DTs for raising sustainable housing across the world, since the present study focuses on the application of DTs for promoting sustainable housing in UK, using the same or different theoretical assumptions, during future studies in this area.

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