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Review

A Meta-Integrative Qualitative Study on the Hidden Threats of Smart Buildings/Cities and Their Associated Impacts on Humans and the Environment

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Abstract: Smart buildings deploying 5G and the Internet of Things (IoT) are viewed as the next sustainable solution that can be seamlessly integrated in all sectors of the built environment. The benefits are well advertised and range from inducing wellness and monitoring health, amplifying productivity, to energy savings. Comparatively, potential negative risks are less known and mostly relate to cyber-security threats and radiation effects. This meta-integrative qualitative synthesis research sought to determine the possible underlying demerits from developing smart buildings, and whether they outweigh the possible benefits. The study identified five master themes as threats of smart buildings: a surfeit of data centers, the proliferation of undersea cables, the consternation of cyber-security threats, electromagnetic pollution, and E-waste accumulation. Further, the paper discusses the rebound impacts on humans and the environment as smart buildings' actualization becomes a reality. The study reveals that, although some aspects of smart buildings do have their tangible benefits, the potential repercussions from these not-so-discussed threats could undermine the former when all perspectives and interactions are analyzed collectively rather than in isolation.

Keywords: smart buildings; 5G; internet of things; IoTs; sustainability; climate change; humans; cyber security; electromagnetic radiation; undersea internet cables; datacenters; E-waste

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1. Introduction

Smart buildings are defined as those advanced forms of buildings that utilize Artificial Intelligence (AI) to provide such structures with the leverage to be flexible, adaptive, and responsive while offering real-time control to users [1,2]. These buildings are often seen as an upgraded form of intelligent structures. They deploy several sensors and automation as part of their operations, they process data, and they provide realistic feedback to the users regarding the building's performance [3,4]. As an added advantage over conventional buildings, smart buildings also intend to reduce the operating costs and energy consumption, and can be connected to the smart grid [5–7].

With the advancement of the Internet of Things (IoT) technology, automated buildings have been upgraded to function using IoT and wireless sensors [4,8–10], which have essentially become the expected norm for a sustainable built environment. The Internet of Things, also known as the Fourth Industrial Revolution, is bound to change the concept of industrialization and building construction, as the technology implementation is not limited to smart buildings alone, but also to body-centric wireless devices and even the provision of security and safety surveillance of a nation [11]. To have better system efficiency, throughout, large-bandwidth 5G will be introduced and is expected to connect the world through billions of sensors and artificial intelligence [12].

Smart buildings that deploy IoT primarily operate by physically connecting all the building's devices and leveraging the internet's power, using sensors and actuators. These intelligent devices collect data about their environment and provide other attributes to their decision-making centers. The required changes can be monitored and modified by the user even by remote web access. The devices are connected to a server, mostly cloud-based, that processes, analyses, and produces meaningful interpretations, with real-time data provision [13,14]. Interconnected devices such as Heating Ventilation Air-Conditioning (HVAC), window shutters, motion sensors, and fire sprinklers are made smart to conserve energy and optimize their system performance using data analysis. The system can help analytics make educated decisions concerning the building's operational efficiency, including leaky and faulty detections. Put in a meaningful format, the analyzed data is then sent to the building users to bring awareness to highlighting the energy savings such as Greenhouse Emissions (GHG) produced and Energy Star score, while indicating possible areas of improvement [7]. As buildings constitute important elements of a city, smart buildings are planned to be extended on a large scale, creating smart cities using smart grids, smart vehicles, smart governance, and a smart environment [15–17]. The idea of a smart city using 5G aims to improve the way a city functions—a digital city that has all related information that could even help eradicate poverty and social deprivation [18–20]. These smart cities are also considered sustainable where healthcare to industrial warehouses is connected and runs on energy efficiency principles, thus providing a fundamental focus on users [21].

Predicted positive aspects of smart buildings on people are numerous. They include operational savings and the collaborative working of HVAC with other building systems from a single control point that gives rapid access to all equipment and systems in a building, incidentally increasing the building's market value [1,7]. The energy efficiency of these smart buildings and the integration of IoT using main servers are expected to save a significant amount of electricity [7,22–24]. Apart from these tangible and verifiable benefits, there are intangible benefits that can be induced to change people's lifestyle and behavior by promoting wellness, comfort, productivity, and even creating a virtual world inside their homes to induce amiability [1,25].

Countering these claims, researchers and environmentalists believe that there are also negative aspects of these smart buildings that are important yet not found to be given the same weightage as the benefits. Some of the reported negative aspects include cybersecurity concerns [10,26] and radiation effects. Individually or as a group, countries such as Germany, Netherlands, Australia, and the European Union (EU) have demanded an impartial assessment of human health, especially from radiation, before a widespread retrofitting to smart buildings. These countries have also voiced their opinions about their concern related to data security implementing 5G [27]. However, risks associated with smart buildings still seem to be given less weightage or are considered almost nonexistent as holistic research related to risks associated with smart buildings does not exist currently, though several independent researchers are seeking an understanding of the phenomenon. This meta-integrative qualitative study aimed to determine the possible hidden threats from the realization of smart buildings deploying 5G and IoTs. Thus, it can be considered that the paper presents a dual contribution, one for the meta-integrative methodology and the other for determining the demerits of smart buildings.

2. Meta-Integrative Research Method

Meta-integration, also known as the mixed-meta-synthesis qualitative research approach, is a relatively new way of research synthesis that aggregates from qualitative, quantitative, or mixed studies [28]. The purpose of such study approach is to make unique contributions that were not achieved in the original studies to illuminate a new direction that was absent from isolated disciplinary research findings, which can even lead to the potential formulation of a new theory [29,30]. A meta-integration process is performed qualitatively by blending findings from different methodologies and can be briefly categorized as segregated and integrated [31]. The segregated method is used if the research outcome is to generate topologies or configurations of the primary studies. The integrated method is useful when it is required to assimilate studies regardless of their unique methodology, i.e., whether it is a primarily qualitative or quantitative one [28,32]. Further, this method focuses on identifying key elements and common themes among the studies that are dissected in order to reveal a novel interpretation of the phenomenon under study.

It is also imperative to note that a meta-integration method does not provide a summary of the other findings as in a review paper, but conceptualizes again the initial findings to facilitate new insights related to the question addressed [28]. These findings are also explorative and inductive in nature and do not consider the context under which initial studies were carried out, but rather the starting point of the meta-integrative method occurs at the conclusions of the primary studies, not their datasets [28]. A meta-integration differs from other meta-studies such as meta-synthesis and meta-analysis research. The former qualitatively assesses the conclusion from studies of only qualitative studies [32], while the latter generally conducts a statistical analysis of primary conclusions from several quantitative research studies [33]. However, the initialization process of meta-synthesis and meta-analysis also emerges from conclusions of primary findings rather than the route of results.

This paper seeks to contribute to the new methodology of meta-integration by designing and presenting the results of the risks and impacts or, in other words, the demerits associated with smart buildings. There are currently a lot of research papers, both original works and reviews related to many aspects of smart buildings; however, the meta-integration process can facilitate perceptions that might be missing from exclusive qualitative or quantitative studies. Thus, through this meta-integrative method, it is expected that the paper can identify several facets connected to the impact of smart buildings on humans and the environment that may not be fully realized using traditional research review methods such as critical review or narrative review.

3. Methodology

Some researchers have detailed the process of integrating information from mixed methods [34,35]. To determine the selection of studies that need be included, some researchers have used the Mixed Methods Appraisal Tool (MMAT) or have even developed the Meta Quality Appraisal Tool (MetaQAT) [36]. Joanna Briggs Institute's appraisal tool [37] is preferable for meta-synthesis studies; hence, it is used for this meta-integration study. Finally, there was no cap fixed for the number of studies to be selected, to ensure that findings and interpretations were all saturated; moreover, there were only a few studies that directly correlated to the research question.

The meta-synthesis methodology consisted of the following steps:

3.1. Inclusion/Exclusion Criteria for Selection of Studies

Inclusion criteria for selecting the studies to determine smart buildings' demerits were mostly related to the nature and quality of the study. Though the nature of the methodology was not a consideration, a careful evaluation was set to oversee and verify the validity of the method used and the result interpretation mentioned in the primary studies. The time frame was chosen between 2000 and 2020. Studies before 2000 were excluded as they might have used outdated equipment or laboratory measurements. Moreover, the primary studies thus generated could be verified and categorized by the authors thoroughly following the latest trends and developments in smart buildings. Exclusion criteria were set to use the findings of studies that were most focused on the research topic. For example, when the effects of undersea cables on marine life were considered, those studies exploring in more detail the impacts on marine life or on power transmission were excluded as their focus derails from the area under investigation. Hence, all studies that were not directly linked to smart buildings, either directly or indirectly, were excluded.

3.2. Determination of Keywords and Search Database

Databases that were used include science direct, IEEE Xplore Digital Library, Taylor and Francis, Springer, Google Scholar, Pubmed, Scopus, and Web of Science. Several search phases were conducted to obtain the variables and cluster master themes. The intimal search keywords were "smart buildings" and "IoTs" or "benefits" or "challenges." Further search words related to the materialization of smart buildings and IoT were applied such as "5G" and "Problems" or "cloud data." This generated more than 100 articles, and after an initial sorting, specific or emerging specifically related keywords and search term combinations were used such as "under-sea cables" or "E-waste" and "datacenters." Searching for under-sea cables also gave rise to articles that specified the damage they caused to marine life. Radiation effects and cyber security issues applied to smart buildings were already known; therefore, a new combination of search keywords was used such as "Radiation effects" and "Smart buildings/smart cities" or "cyber- security." Search results from radiation effects also revealed new phenomena, such as "electrosmog" or electromagnetic pollution; hence, the connection between "Electromagnetic pollution" or "smart buildings" or 5G was also used as search criteria.

The generated results were shifted to appraise the methodology of the study conducted, the validity of the article, the year of publication, and to ensure that the collected materials were published in peer-reviewed journals. The study did not include any unpublished work/theses. Overall, 879 articles were generated from the databases, including duplicates. Though the search keywords related to what constitutes a smart building from a cradle-to-grave perspective was the main target, raw-materials processing or any related aspects were not included, as the results were highly feeble.

3.3. Selection of Included Studies

The articles collected from search databases were screened using the inclusion/exclusion criteria to find the focused studies. Notably, 68 studies met the inclusion criteria, out of which 12 were found in Google Scholar. The scrutiny of the studies' reference list generated additional screening again based on the inclusion criteria after the abstract analysis. A few articles were not included, as they were not written in English, and some of the studies had inconclusive results or invalid methodologies. Depending on the methodology they used, a segregation of articles was also carried out at this stage, and articles from the narrative or phenomenological perspective were not considered. The time frame also contributed to the non-selection of several articles. A large number of studies were related to several theme clusters but were not included, as they did not meet the timeframe criteria or were only review articles. It is also important to point out that most articles, for example, those related to E-waste, are review-based papers and, among them, only a few were originals. This resulted in the final refined 43 studies that were highly focused, original, detailed with a valid methodology and results, and published in peer-reviewed journals. All included studies with their country of study, research methodology, and summary findings are presented in Table 1.

Table 1. Summary finding of selected articles.

Sl No:	Article	First Authors	Country of Study	Research Methodology	Summary Finding
Master Theme 1: Surfeit in Datacenters					
1	A Methodology to Predict the Power Consumption of Servers in Data Centres	Basmadjian et al., 2011	Germany	Quantitative	The researchers explained that datacenters are the consumers of global electricity along with their complementary power, storage, and cooling requirements, and they developed a methodology to predict it [38].
2	Inside the Social Network's (Datacenter) Network	Roy et al., 2015	California	Quantitative	Highlighted Facebook's network data traffic, while expressing that the operator's network architecture is hardly published; therefore, it is difficult to assess their operability features [39].
3	United States Data Center Energy Usage Report OSTI.GOV	Shehabi et al., 2016	United States	Quantitative	Electricity consumption has increased from nearly 90% in 2000 to 2020 and is still predicted to rise, especially with cloud services [40].
4	The future data centre	Irish Enterprise, 2017	Ireland	White paper, Mixed research method	Operational costs are excessively high compared to regular buildings. The size of data centers has increased tremendously to accommodate higher data traffic and storage, and the actual cost can range from $3000/sq m to $18,000/sq m [41].
5	Beyond 1Tb/s Datacenter Interconnect Technology: Challenges and Solutions	Zhou et al., 2019	United States	Quantitative	Research work provided retrospection on ten years and the need for handling 1 Pbps of bisection bandwidth. They also developed a clos topology and centralized control for Google's datacenter network [42].
6	Practice and experience on deploying green datacentres for cloud computing	Xiao and Liu, 2019	China	Quantitative	Developed a novel technique for energy reduction in a campus-based cloud datacenter [43].
Master Theme 2: Proliferation in Under-Sea Cables					

7	The environmental effects of the installation and functioning of the submarine SwePol Link HVDC transmission line: a case study of the Polish Marine Area of the Baltic Sea	Andrulewicz et al., 2003	Poland	Case-study, Quantitative	No significant impact on macrofauna or biomass after installation, and magnetic field effect did not exceed a natural variability of 20 m [44].
8	Whale entanglements with submarine telecommunication cables	Wood & Carter, 2008	New Zealand	Quantitative, secondary data aggregation	Whale entanglement with undersea cables reduced as telegraphic cables were replaced with optic fibers [45].
9	Effects Of Emfs From Undersea Power Cables On Elasmobranchs And Other Marine Species	Tricas & Gill, 2011	United States	Quantitative	Electrosensitive species are at risk from undersea direct current (DC) and alternating current (AC) cables, such as Elasmobranch, sea turtles, and other sea mammals [46].
10	Of Cables, Connections and Control: Africa's Double Dependency in the Information Age	Surborg & Carmudy, 2014	Africa	Qualitative	Discussed the doubling of undersea cables in Africa for the information age and explained the constraints against the opportunities [47].
11	Effects of submarine power transmission cables on a glass sponge reef and associated megafaunal community	Dunham et al., 2015	Canada	Quantitative	100% of glass sponge mortality along direct path of under-sea cables. Damage to mega-fauna [48].
12	The thermal regime around buried submarine high-voltage cables. Geophysical Journal International	Emeanea et al., 2016	England	Mixed research methods	The heat release from these cables can be as high as 18 °C more than the ambient temperature, which can prove hazardous to micro- and macro-fauna [49].
13	Electromagnetic Field (EMF) Impacts on Elasmobranch (shark, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables	Hutchison et al., 2018	United States	Quantitative	Both behavioral and physiological effects on marine species (sharks, lobsters, skates, and rays) were conclusive from laboratory and field studies of buried under-sea cables [50].
14	How the internet spans the globe	Kugler, 2020	United States	Qualitative	Briefly gave an insightful explanation of the current under-sea cables usage around the world [51].
			Master Theme 3: Consternation from Cyber-Security Threats		

15	Cyber Security Threats to IoT Applications and Service Domains	Koduah et al., 2017	New York	Qualitative	Experiments based on smart-metering to understand the threats, and results revealed that a critical attack on hardware, software, and firmware is possible and potentially dangerous [52].
16	Using virtual environments for the assessment of cybersecurity issues in IoT scenarios	Furfaro et al., 2017	Italy	Qualitative	Addressed smart homes, and IoTs can increase cybercriminal activities. Simulated smart world virtual environment, created a scenario of IoT attack occurring inside the smart home, and suggested a possible approach to mitigate it [53].
17	Security threats taxonomy: Smart-home perspective	Anwar et al., 2017	India	Qualitative	Designed a taxonomy for security threats in a smart home [54].
18	Cybersecurity-IoT	Naik & Maral, 2017	India	Quantitative, algorithms	Evaluated the need to mitigate the cloning of devices and exposure of sensitive data through an algorithm [55].
19	Cybersecurity and its discontents: Artificial intelligence, the Internet of Things, and digital misinformation	Wilner, 2018	Canada	Qualitative	Highlighted the concerns related to digital misinformation at strategic and policy levels. Evidence-based policy brief of nexus of IoT and AI [56].
20	Security Considerations for Internet of Things: A Survey	Jurcut et al., 2020	Singapore	Qualitative	Through an extensive survey, they identified the significant risks concerned with IoT implementation such as data identify theft and distributed denial of service [57].
21	IoT cyber risk: a holistic analysis of cyber risk assessment frameworks, risk vectors, and risk ranking process	Kandaswamy et al., 2020	India	Qualitative	Developed a computational approach with risks and impact factors, especially for IoT [58].
			Master Theme 4: Electromagnetic Pollution		
22	Temperature rises in the human eye exposed to EM waves in the frequency range 0.6–6 GHz IEEE	Hirata et al., 2000	Japan	Quantitative	Using finite-difference time-domain (FDTD), the temperature rise in the human eye exposed to millimeter waves was studied, and they reported that the value is crucial with regard to cataract formation [59].
23	Human Electrophysiological Signal Responses to ELF Schumann Resonance and Artificial Electromagnetic Fields	Cosic et al.,2006	Australia	Quantitative	Experimentally found a correlation between human EEG and Schumann's resonance in the ionosphere. Further, they demonstrated that artificial EMF could have an altering effect on the human brain [60].

24	Natural and man-made terrestrial electromagnetic noise: an outlook	Bianchi & Meloni, 2007	Italy	Qualitative	Explained different man-made radio noises existing in the atmosphere and their association with cosmic radio waves [61].
25	Methods for Monitoring Electromagnetic Pollution in the Western Balkan Environment	Getsov et al., 2007	Bulgaria	Quantitative	Monitoring of EMP using advanced techniques (GIS), conducting of pilot measurements, and comparison with preliminary experimental results [62].
26	A Possible Effect of Electromagnetic Radiation from Mobile Phone Base Stations on the Number of Breeding House Sparrows (Passer domesticus)	Everaert & Bauwens, 2009	Belgium	Quantitative	Through their study, the researchers established that fewer house sparrows are present in areas with high EM radiation [63].
27	The Electromagnetic Pollution of Wireless Electronic Equipment in Areas with High Human Accumulation	Skountzos et al., 2014	Greece	Quantitative	Researchers carried out field measurements in the campus to measure the electric field intensity developed and found that the peak measurement happened in the airport entrance with the least human presence [64].
28	Tumor promotion by exposure to radiofrequency electromagnetic fields below exposure limits for humans	Lerchl et al., 2015	Germany	Quantitative	Lymphomas were found to be increased with the number of heavy-phone users. Further tumor-promoting effects may arise due to metabolic changes induced by radiation [65].
29	KELEA, Cosmic Rays, Cloud Formation and Electromagnetic Radiation: Electropollution as a Possible Explanation for Climate Change	Martin, 2016	United States	Qualitative	EMF disrupts kinetic energy-limiting electrostatic attraction (KELEA) from cosmic rays, contributing to global warming and climate change [66].
30	When theory and observation collide: Can non-ionizing radiation cause cancer?	Hava, 2017	Canada	Qualitative	Nonionizing radiation causes the production of more free radicals, and this radiation interferes with oxidative repair mechanisms, thereby causing damage to DNA and leading to cancer [67].
31	Statistical Investigation of the User Effects on Mobile Terminal Antennas for 5G Applications	Syrytsin et al., 2017	Denmark	Quantitative	It is found that a significant amount of power can propagate into the shadow of the user by creeping waves and diffractions, providing power absorption into the human body [68].
32	To protect ecological system from electromagnetic radiation of Mobile communication	Das & Kundu, 2019	India	Quantitative	Unlimited WiFi access and sensor deployment cause ecological problems, creating an undesirable environment for plants and living organisms such as bees, ants, and insects [69].

33	Electromagnetic Pollution: Case Study of Energy Transmission Lines and Radio Transmission Equipment	Przystupa et al., 2020	Ukraine	Quantitative	Researchers proved that there exists a strong dependence on electromagnetic waves on humans and ecology through field-measurements of radio transmitters [70].
34	Absorption of 5G radiation in brain tissue as a function of frequency, power and time	Gultekin et al., 2020	United States	Quantitative	Analyzed the bovine brain as a function of frequency, power absorption density, and depth. They noted that even modest incident power causes result in considerable temperature rises and power densities [71].
35	Electromagnetic Radiation Reduction in 5G Networks and Beyond Using Thermal Radiation Mode	Kour et al., 2020	India	Quantitative	Proposed a system called "Thermal mode" for consideration along with mobile communication systems to reduce radiation effects for 5G and the forthcoming 6G [72].
36	Smart Glasses Radiation Effects on a Human Head Model at Wi-Fi and 5G Cellular Frequencies	Kaburcuk & Elsherbeni, 2019	Turkey, US	Quantitative	Calculated temperature distributions in the human brain by the FTDT method [73].
			Master Theme 5: E-Waste Pollution		
37	Designing for the End of Life of IoT Objects	Lechelt et al., 2020	Netherlands	Qualitative	Shorter lifespan of IoT devices worsens the situation of E-waste. Addressed the need to increase the lifespan of these devices by new design strategy [74].
38	Recycling of WEEEs: An economic assessment of present and future E-waste streams	Cucchiella et al., 2015	Italy, United Kingdom	Quantitative	Encouraged the development of collaboration between manufacturers and recovery centers. Performed sensitivity analysis to evaluate the recovered revenues from E-waste [75].
39	Barriers to electronics reuse of transboundary E-waste shipment regulations: An evaluation based on industry experiences	Milovantseva & Fitzpatrick, 2015	US, Ireland	Qualitative	Identified barriers to reuse of electronic products through interview and survey. The researchers also facilitated policy recommendations for legislative amendments [76].
40	Toxicity trends in E-waste: A comparative analysis of metals in discarded mobile phones	Singh et al., 2019	China	Quantitative	Their analysis reported that smartphone usage of toxic compounds increased significantly from 2006, nickel being the largest contributor, which has carcinogenic potential, followed by lead and beryllium [77].

41	Informal E-waste recycling: environmental risk assessment of heavy metal contamination in Mandoli industrial area, Delhi, India	Pradhan & Kumar, 2014	India	Quantitative	After risk assessment, the authors revealed that, apart from toxic compounds released from informal recycling, this process also led to the groundwater contamination in their study area [78].
42	Where next on E-waste in Australia?	Golev et al., 2016	Australia	Quantitative	Discussed the potential possibility of the recovery of metals from E-waste [79].
43	An empirical survey on the obsolescence of appliances in German households	Hennies & Stamminger, 2016	Germany	Quantitative	Analysis highlights that the repairing of electronic products does not last long, and consumer behavior is also a factor for the obsolesce [80].

3.4. Summary Tabulation of Results

The most critical findings from the articles review or articles findings were segmented into thematic clusters and compiled in the summary Table 2. The derivation of themes or variables was made after reviewing the Results and Discussion section of the original articles. This exercise led to the extraction of the themes identified by the authors. Special care was taken to extract original themes mentioned through these papers rather than creating new constructs. Nonetheless, whenever original constructs lacked depth, new theme variables were produced, as proposed by Duggleby et al. (2012) [81] and Lindahl and Lindblad (2011) [82].

Table 2. Summary table of results generating master themes.

		Master Themes				
	Theme Clusters	**Surfeit of Data Centers**	**Proliferation of Undersea Cables**	**Consternation from Cyber Security Threats**	**Electromagnetic Pollution**	**E-Waste Pollution**
1	Direct impacts on humans	[40,41]		[52–54,57]	[59,64,70]	[80]
2	Direct impacts on environment	[38,40,41,43]	[45,46,48–50]		[61–63,66]	[78,79]
3	Cost	[40,41]	[47,51]	[52,55]		[79,80]
4	Security		[47,51]	[52,54,55]		
5	Opaque supply chain	[38,39]	[47,51]	[56,58]		[78]
6	Short-term health effects				[59,65,68,71,73]	[77]
7	Long-term health effects				[65,67]	[77,78]
8	Policies and regulations			[56]	[72]	[74–76]
9	Unrecognized rebound effects	[38–42]	[44,46,47,49–51]	[52,53,56]	[60,69]	[78,79]
10	CO_2 emissions	[38,40,41]				
11	Toxic compounds		[46,49]			[77,78]

3.5. Result Interpretation and Analysis

As an important step in the analysis, the themes procured in the above step were then assigned to different thematic clusters. The initiation point of cluster-naming was generated from the original author's interpretation. However, where other authors mentioned different labels, or expressed similar meanings, it was collapsed into a single cluster representing the same meaning. This interpretative process resulted in cluster themes expressed as variables that were again rechecked in the form of comparative analysis and verified against the interpretation of primary studies. The last step in the summary table involved reviewing the 11 theme clusters and their interrelationships with one another and the research problem to extract the master theme as categories, thereby crystallizing the layered interpretations it held. This exercise led to the formulation of five master themes, namely (1) electromagnetic pollution, (2) cyber-security concerns, (3) surfeit of datacenters, (4) proliferation of undersea cables, and (5) E-waste, altogether identifying the main parameters that exist with the actualization of smart buildings and mapping out the demerits of smart buildings that deploy 5G and IoTs. The master themes were assigned to higher-order categories as they resonated closely with the underlying parameters that they expressed [83].

4. Results

The meta-integrative result work was based on the 43 selected studies from worldwide publications. This work was conducted in an interdisciplinary mode but was mapped in concordance with the actualization of smart buildings, including the supply chain, to determine their potential demerits. This was due to the transdisciplinary analysis of the master themes rather than treating them from an isolated perspective. The meta-integrative generated 11 overall theme clusters which in turn led to the construction of five master themes (Figure 1). Each master theme captured unique repercussions from the deployment of smart buildings. Together, they represent the entire spectrum of problems starting with cloud access or a massive increase in the datacenters that is indirect but visible, and to the invisible yet direct radiation effects. The number of themes clusters contributing to the creation of each of the master themes varied. Thus, the master themes put in conjunction brought out all the demerits—direct and indirect, visible, and invisible—associated with the deployment of smart buildings.

The selection of labels for master themes was an interpretative action generated mainly from analyzing the themes clusters they represented. All master themes are presented below separately before analyzing their interrelationships with one another, which is explained in the following sub-sections. The result section describes each master theme in contextual analysis with the smart buildings. This first-tier discussion of the master themes also includes other theoretical or review-based studies that have contributed to theme clusters or master themes. This approach allows the execution of the meta-integration process right at this stage.

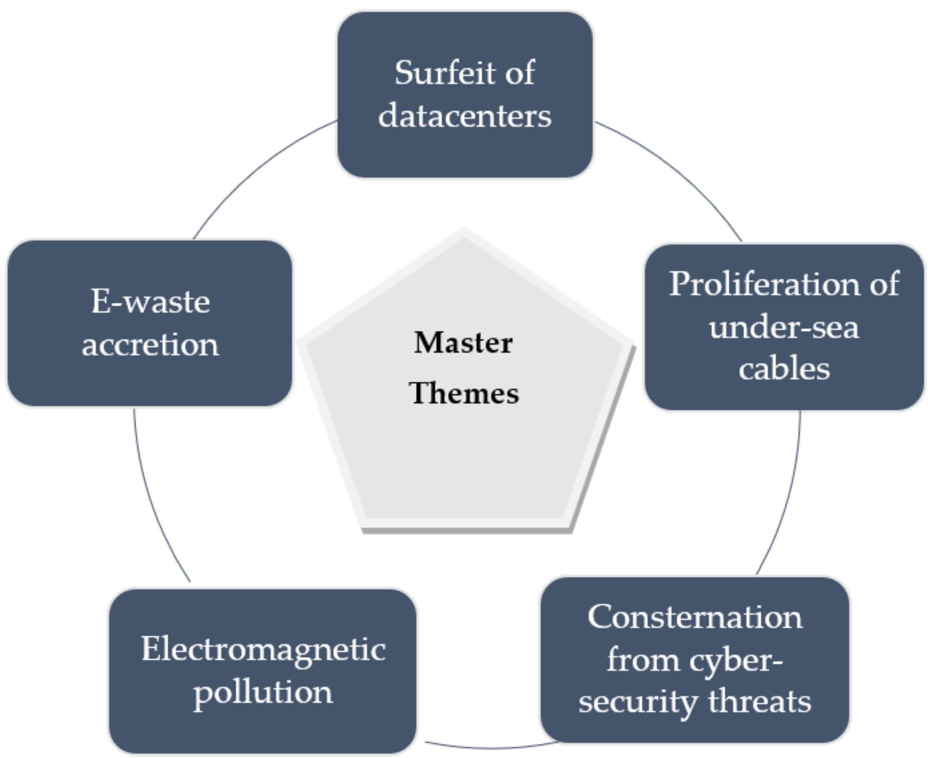

Figure 1. Five master themes generated from meta-integration process.

4.1. Master Theme 1: Surfeit of Data Centers Electromagnetic Pollution

This master theme labelling was used to directly decipher the increase in the number of data centers and cloud processing that would be utilized by IoTs. Data centers are the physical spaces where multiple servers are stacked to store data related to various services and applications, including web services such as social platforms like Facebook and others [39]. The size of the data centers could be just a rack for a small office to large buildings of up to a million square feet in size such as Google and Amazon facilities [40,42]. Unlike other large buildings, these structures require a large cooling demand and powerful HVAC systems to keep the equipment safe [38]. Due to a tremendous increase in the bandwidth and internet traffic, data traffic to these data centers, their number has also increased tremendously. Moreover, cloud computing has become the norm for general application purposes, such as editing documents by multi-users simultaneously, in which case fiber optic technologies are used to run the smooth functioning of the data centers networks [84].

On the downside, there are a lot of environmental concerns related to data centers such as high energy consumption [85], E-waste, emissions of CO_2, and GHGs [41]. Uddin et al. (2012) explained in their paper that an average data center uses 70% for work, while the rest consumes power and produces GHGs [86]. Rivoire et al. (2007) emphasized that many servers in these data centers are often underutilized. In 2007, the contribution of data centers to the emissions of global CO_2 was estimated to be 23%; the value increased by threefold in 2020 [86].

Smart buildings are generally designed to function with the integration of smart devices connected to each other and requiring local and/or cloud data processing and storage. Smart buildings with Building Management Systems (BMS) and cloud processing would mean that the data are stored in a data center for access [87]. As most data may not be useful, for example, in the case of a motion sensor that captures data every few seconds, the user needs to be alerted only when an intruder is near the door; hence, cloud processing ends in high cost and space as physical space in some servers is lost due to the storage of unnecessary and redundant data. In order to avoid this shortcoming, local computing and processing are sometimes performed primarily before transferring the data to the cloud service, also known as a cloud data center [87].

5G systems would increase the density of fiber connections than the standard wired ones as they work with a higher bandwidth that uses plastic or glass (plastics is a source of E-waste) and ultimately more data centers [88]. In a scenario where all buildings are smart, the amount of unnecessary data will exponentially increase, leading to an increase in servers and the emergence of a constant need to build and operate massive data centers. It is only imperative to highlight that the data stored in these servers, whether the updating of an application or horizontal scalability or an improvement in the material storage of devices, would eventually collapse to the shredding of hard disks [89], culminating in an alarming amount of E-waste production.

4.2. Master Theme 2: Proliferation of Undersea Cables

Earlier forms of undersea telecommunication used coaxial cabling, which was replaced by the more efficient optic fiber in the late 1980s, designed theoretically to carry data at the speed of light [90]. These cables' diameters range from 20 to 50 mm and use either DC or AC for power transmission [91]. The deployment of these cables generally involves the process of burying them to a depth of 1200 m, and they are sometimes even laid in the seabed, where legally allowed, by specially equipped cable-laying ships [90]. Undersea fiber optic cabling forms the backbone of the internet, accounting for handling about 99% of internet data, and it is mostly owned by companies such as Google, Facebook, and Amazon, currently covering a total distance of 1.2 million kilometers [51,92]. Between 2014 and 2019, the cabling's fiber investment witnessed an overall increase of

USD 144.2 billion, particularly for 5G networks [34]. Figure 2 illustrates the cable connections around the world as it stands today.

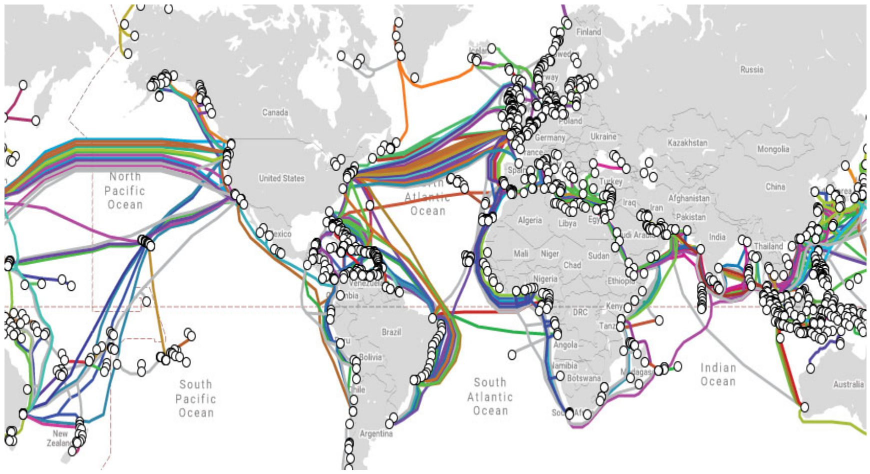

Figure 2. Current status of undersea cables around the world. Reprinted from ref. [51].

However, several negative impacts of these undersea cables are present in all three phases of cable life, such as installation, operation, and de-commissioning [44]. Research has shown that these cables cause destruction and disruption of the marine environment by being a hazard to fish and water quality [45,48,49]. Data leakage and security are other concerns raised by research [90]. Electromagnetic fields (EMF) effects from the cables could cause much damage to marine species, including their reproduction as many species are sensitive to either electric or magnetic fields. The contamination of toxic chemicals such as arsenic, zinc, and mercury can also occur during repair works, cable deterioration, and the de-commissioning of cables [50,90,93]. 5G and IoT are expected to create exponential growth in the undersea cables as they are developed to handle more data speed and volume [94], which can worsen the already severe environmental issues caused by these cable networks [47].

Generally, there is a belief that wireless connections decrease CO_2 emissions. However, the wireless transfer of data can take place only for a short distance (distance being dependent on the frequency of operation of the smart devices), for example, for 4G, the wireless data transmission is around 1000 miles, while, for 5G, it is only 10 miles. As a result, additional relay cell towers and antennas are required for the operation of 5G devices [95]. As a result, the generic notion that wireless data transfer is energy-conserving or can act as a CO_2 eliminator can be challenged. Therefore, the data from any sensor device would have to take a wired path for almost 99% of its travel time to reach back to the user's mobile phone [96]. Thus, smart buildings that function with multiple smart devices that are connected to a network culminate with the installation of more undersea cables.

4.3. Master Theme 3: Consternation from Cyber Security Threats

The master theme consternation from cybersecurity threats refers to the protection of servers, networks, and online applications from malicious activities through malware [57]. Malware software may include phishing, viruses, Trojan, and spyware. The main reason for breaching data is to acquire financial or other sensitive data of an organization or an individual [52,97,98]. Risk-Based Security, an organization that looks into the breaching of data and risk ratings, has mentioned that in the quarter of 2019, around 7.9 billion records were breached, which was more than double the record of 2018 [99]. Several countries have developed a protocol for dealing with cybersecurity concerns such as the National Institute of Standards and Technology (NIST) in the US [100], and the Australian Cyber Security Centre (ACSC) [101]. In the case of a smart building, being part of

Big Data, hackers can modify the settings of the appliances via the web and steal assets or even cause life-threatening situations [59,102]. Technological companies, including Facebook, Google, and Amazon, were alleged to be sharing user data information to third parties, raising concerns about their data privacy breach. Rocha and Correia (2011) argued that with cloud computing and data processing, as is the case with IoTs, data stealing could intensify and be maliciously used against them by any third-party users supplemented by these same cloud service providers [103].

Smart buildings and a city's security breach are significant concerns [53,54]; hackers can use vital information about a city such as military data and exploit it [55]. Moreover, there are cybersecurity concerns and data loss possible from undersea cables and even data centers. There are reported cases by many environmental agencies that damages to undersea cables carrying data in several parts of the world were criminal in nature and led to multiple losses, including the grounding of flights, and other communication flows [104]. Hence, there is a pertinent need to understand the transparency behind data sharing and the processing of information from these smart buildings.

4.4. Master Theme 4: Electromagnetic Pollution

This is generally an identified problem with the deployment of smart buildings using 5G and IoT devices. Many countries have called to ban 5G in general until impartial research data can be made available, and several researchers around the globe have submitted a "5G appeal" [105]. The radiation effects could range from causing headaches, insomnia, to DNA alteration, along with the possibility of creating other biological damages such as hormonal imbalances, reproductive issues, tumors, nerve damage, and eye damage [65,106]. Belpomme (2015) concluded from a comprehensive study that the EMF effect could worsen health conditions related to oxidative stress, a deficit in melatonin metabolism, and is more reflected among electro-sensitive people [107]. Several studies by biochemical and medical researchers found that high frequencies can significantly change the heart rate, chromatin (DNA complex and proteins), and melatonin, as well as other hormonal changes [59,71,108]. Kojima et al. (2018) revealed that though most of the effects were thermally related as millimeter frequencies are quickly absorbed by water, it can induce damaging effects without the heating of the tissues, i.e., nonthermal effects that are more dangerous [109].

As a guideline, the Federal Communication Commission (FCC) adopted the SAR (specific absorption rate) limit value of 1.6 W/Kg for 1 g of tissue approved by ANSI and IEEE [110]. However, current FCC regulations check only the SAR value, which is only a measure of the thermal effects; on the contrary, several studies have concluded that evaluations other than SAR are necessary to fully understand the impact of biological effects other than the thermal effect [111,112]. Scientific evidence suggests that even radiation limits well below the regulatory standards cause severe damage to health even from 2G and 3G [67,105]. Hardell (2017) pointed out that the World Health Organization (WHO) and International Agency for Research on Cancer (IARC) have only classified the risk from wireless cellphones as carcinogenic 2B (for instance, potentially cancerous).

Buildings are generally subjected to electromagnetic radiation (EMR) pollution from two sources: extremely-low-frequency (ELF) and high-frequency wireless devices. Leukemia in children, immunization loss, genes and DNA alteration, cancers, and tumors have been associated with increased exposure from these indoor sources since the 1960s [112]. A smart building that is operated wirelessly with very high frequencies (up to 300 GHz) can put the occupants at risk, particularly the most vulnerable. Moreover, humans have natural bio-electromagnetism [113] in them, and cells, tissues, and skin regeneration, including the sleep process, rely on natural frequencies from 0 to 30 Hz [114–116]. It has been reported that, regardless of the frequency level, being exposed to artificial frequencies is detrimental to human health [112].

Furthermore, 5G cellular networks deploy many small cells placed at shorter distances on poles and buildings [117], which can easily aggravate, to a greater extent, the biological effects [68,72]. Hence, many scientists, health professionals, and environmentalists have enquired about the potential problems of continually being in a smart building with numerous IoT devices emitting radiation at high frequencies, including bio-wearable devices [73,94].

Electropollution radiation can also be a hazard to the living organisms of the ecosystem [61,66,69,70]. This problem is specifically crucial for organisms (living on land and in water) that depend strongly on Earth's natural electromagnetic field for their nutrition and survival [63,112]. The most significant example of such phenomena is the collapse of bee colonies as their navigation is affected by wireless radiation, making them unable to return to their hives or even find food [62,118]. A study spanning almost a decade by Selsam et al. (2016) found out that trees are significantly damaged by radiation, particularly those situated near cellular base stations, and the damage intensifies with aging [119].

4.5. Master Theme 5: E-Waste Pollution

E-waste consists of all electronic products that are discarded and are at or near expiration [120]. After the lifetime of the electronic products expires, which is relatively small (2 to 3 years), it becomes a heap of complex toxic chemicals consisting of heavy metal and non-degradable plastic [74,121]. The E-waste disposal cycle consists of either landfill, dissolution in acid, or incineration; all these methods are proven to be correlated with a cyclic form of toxic generation [79,122]. Almost all E-waste from developed countries is sent to China (around 70%), India, and Africa for E-waste handling [75,123,124]. The discarded electronic products produce carcinogenic smoke that can cause lung cancer, skin cancer, and other respiratory problems [77,78]. Phthalates (from cables) and chlorinated compounds (from fluids such as printing ink and plasticizers) cause kidney failure and affect the central nervous system [125,126]. The Environmental News, Analysis and Reference (ENDS) report of Europe has mentioned a built-in state of obsolescence for electronic products in the companies' present-day market, as evidenced by the increase in replacement appliances from 3.5% in 2008 to 8.3% in 2012 [127].

Moreover, technology companies and software developers regularly update and release newer versions of existing applications or software admissible only with the latest models, thus ensuring consumers' discard of their old appliances. For instance, global companies such as Samsung and Apple often publicize that specific older versions of smartphones cannot access certain newer features or applications, forcing the purchase of the upgraded device [128]. Such reasons prompt consumers to purchase new smartphones or computers. This has been substantiated by a number of researchers explaining that this planned device obsolescence is more dangerous because of the ecological problem associated with E-waste [80,129,130]. The UN Environmental Program waste crime reports that nearly 50 million tons of E-waste were discarded in 2017 alone [131].

A smart city is estimated to have billions of electronic products. By 2030, the number of IoTs connecting smartphones to kitchen appliances is projected to reach 50 billion with an average life expectancy of 2 to 3 years [132]. The 5G technology will increase the additional load of small cells obsoleting most current devices that use 3G or 4G technology. The problem of E-waste when transposed on 5G and IoTs is multi-linked, as, apart from trillions of connected devices that have a very short lifespan, the batteries in these IoT devices, such as wearable or water-resistant devices, are designed to last only 1 to 2 years [133]. These palpable issues, which can erupt globally in the future, call for a transformational and transparent E-waste management plan that can address the situation from material extraction to the end of the lifecycle of these devices—thus allowing the possibility of E-devices to have a longer life span [76].

5. Discussion of Findings on Humans and Environment

The five master themes derived from the theme clusters that are the variables for this study together explain the various risks that will be present with the implementation of smart buildings and cities. The master themes' interrelationships are quite complex and dialectic in nature, yet they are strongly reciprocal. This discussion section explores the interworking and relationship among the master themes and how that eventually affects humans and the environment.

Smart buildings' development follows the cyclic loop from the setting up of cloud service networks or data centers to the final step of information provided to end-users via IoT devices. Thus, and in retrospection, the summation of master themes explains the cradle–grave cycle starting with datacenters (master theme 1); more undersea cables (master theme 2); cyber-security concerns (master theme 3); the electropollution-radiation effect on humans and the environment, and also the reactive influence with Earth's natural electromagnetic frequency (master theme 4); and, finally, the E-waste accumulation (master theme 5).

The master themes inform that the impact of smart buildings on humans is multidimensional and affects directly as well as indirectly. The direct impacts on humans, as informed by master themes, include radiation and cyber-security problems. On the other hand, indirect impacts may stem from the fact that cyber-security threats can affect an individual mentally. A generic building is subjected to radiation exposure that extremely-low-frequency (ELF) household appliances such as television sets, hairdryers, and electric ovens typically use, and wireless devices. Since the 1960s, both types of radiation have been reported to cause health issues [112]. However, with constructing smart homes and smart buildings that use higher frequencies up to 300 GHz, radiation exposure and ill-effects may increase further.

Only a few studies have made a direct association between the environment and smart buildings, though indirect correlations have been made between global warming and the usage of radiation technology such as military equipment, medical scanners [134], Wi-Fi, microwave ovens, and the associated acceleration in CO_2 emissions. The indirect impacts derived from master themes such as electromagnetic pollution, under-sea cables, and datacenters have been discussed regarding the potential influence on ecology. For instance, water, soil, and vegetation have been found to absorb and react to external radiation.

Though research performed to mitigate all the threats mentioned in this paper is very limited, solutions have been initiated for problems such as radiation pollution and E-waste. One of the plausible recommendations for reducing radiation inside smart buildings is to make the building "wired" instead of wireless. Researchers have also suggested that heavy-internet-usage places such as schools and offices are designed in a way to provide a hybrid internet service [135]. Some studies have reported that shielding buildings by using appropriate building materials that are opaque to radiation transmission may be used [136–139]. Likewise, one-way E-waste can be reduced to improve the life-expectancy of all smart and IoT devices and encourage the recycling and reduction in their consumption [74]. Similarly, there lies a pertinent reason to conduct more research related to undersea cables and data centers, their contribution to CO_2 emissions, and climate change to help develop suitable strategies.

The above discussion is only from the negative risk aspect that coherently presents all that has been identified from the previous section and related to the scope of the research problem. Nonetheless, this does not mitigate or undermine the benefits smart buildings and IoT devices can foster on human wellbeing. Figure 3 depicts the benefits and threats from smart buildings.

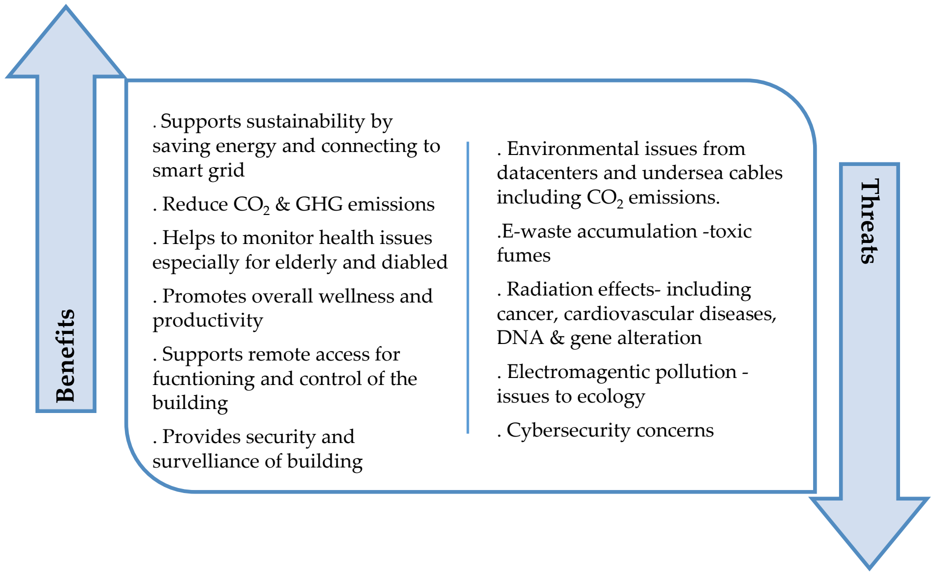

Figure 3. Benefits versus threats of smart buildings.

6. Reflections on Using Meta-integrative Research Methodology and Further Research Directions

While some studies were particularly related to the topic, they had to be discarded due to year of publication or lack of methodology. The preparation of the synthesis of the 43 research findings enabled the determination of demerits that were otherwise hidden and revealed the coherent associations among the interrelated parameters thought to be behind the implementation of smart buildings. The meta-integrative research method facilitated the development of master themes and a better understanding of the cradle-to-grave cycle of smart buildings from analyzing both quantitative and qualitative research findings that would otherwise not have yielded better results.

The meta-integrative work also helped the researchers to integrate the findings across various disciplines and methodologies. Grouping the theme clusters, identifying variables and finally generating five master themes required the researchers to contribute meta-meaning rather than lay in the original studies without changing their essence. There were some limitations to the search strategy, as only research works available in the electronic databases were used, and no manual search was conducted. This means that those articles that did not use the standardized keywords or languages other than English were missed. Similarly, unpublished dissertations and books were excluded while categorizing the theme clusters. However, some important works were cited in the master-theme result analysis and interpretation section.

Nonetheless, this qualitative research aggregates valuable findings that are often underestimated and neglected regarding smart buildings. Further research directions can evaluate all the master themes that were determined by this study and carry out field measurements and more experiments/simulations to produce improved results. Currently, radiation and cyber-security threats are the only two main problems that are directly correlated with smart buildings. Hence, a holistic assessment of all the risks and a comparison with the intended benefits will provide all stakeholders with the real picture, which can be utilized for government policymaking or creating worldwide individual awareness.

7. Conclusions

Smart buildings are seen as the futuristic change in the built environment. Along with smart vehicles, they are deemed to reduce carbon and GHGs emissions by incorporating smart appliances that can communicate with each other and generate live information for data analytics to prescribe the solution to problems ranging from energy efficiency to health are. While technological companies advertise the benefits of smart buildings and smart cities, there is an equal need to understand the demerits behind developing these smart cities/smart buildings. This meta-integrative qualitative research paper tried to understand and correlate the multilevel problems that could arise from the implementation of these structures, especially with 5G and IoT devices. Apart from cybersecurity threats to radiation effects, especially from 5G cells that can directly affect the individual, biologically and mentally, a thorough analysis of the indirect effects such as the carbon emissions from massive data centers and undersea optic cabling is highly recommended to counteract the carbon emission reduction that these buildings claim to make through efficient appliances. The study also considered the potential electromagnetic radiation pollution that could arise from electronics waste disposal and its potential negative contribution to the environment. Finally, this study cautions that more research is needed to quantify both benefits and threats on a comparative scale to verify whether there is any chance that threats could be more detrimental than the benefits. The underlying objective is that impacts on human health, environment, and climate change must be regarded as a top priority prior to the deployment of such a technology on a global scale.

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