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Article

Assessment of the Impact of Complex Healthcare Features on Construction Waste Generation

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Abstract: Over recent years, the British government has been investing billions of pounds in new and refurbished healthcare building projects. With the rapid growth in investment in healthcare infrastructure throughout the United Kingdom, a number of sustainability issues have been created, including construction waste generation. There is growing consensus in the literature that healthcare buildings are "complex", due to their unique functional and operational features, and are thus more prone to generating larger amounts of construction waste. However, no significant research has been undertaken to identify the relationships between complex features in building projects and construction waste production, which is the focus of this study. Twenty-five semi-structured interviews and a questionnaire survey were conducted among healthcare clients, contractors, and architects. A life cycle approach has been adopted in this study to holistically assess and evaluate the effects of complexities with construction waste causes in healthcare projects. The findings reveal that the complex shapes and sizes of rooms, and mechanical and electrical services, significantly impact waste caused by such things as: incomplete briefing, incorrect drawing details, complex designs, non-standard designs, and inadequate communication and coordination in the pre-design, design, and construction stages.

Keywords: causes of waste; complex buildings; construction waste; healthcare; waste minimisation

1. Introduction

Sustainable development (SD) is not a novel concept, since numerous civilisations in the past recognised the correlation between environment, society, and economy in the local and regional contexts. The last few decades have further emphasised these needs in the contexts of the national and global levels because of rapid growth, especially in the developing world. SD helps to deliver economic, environmental, and social objectives simultaneously [1,2]. It is most commonly defined as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [3]. The construction industry plays a vital role in the development of a country and in most developing and industrialised economies, the construction industry constitutes approximately 8%–12% of Gross Domestic Product (GDP) [4]. In the United Kingdom this accounts for some 7% of GDP [5]. These statistics highlight the significance of the construction industry in a country's economy, where the concept of sustainable construction (SC) reflects an important component in the SD context.

A number of past researchers have revealed a positive correlation between construction waste minimisation and SC, since this allows securing natural resources while obtaining expected economic, social, and environmental benefits [6–8] However, in the past two decades alarming figures have been reported from different parts of the world in regards to the volume of total waste generation in construction. In countries like the United States of America, Australia, Brazil, Hong Kong, and the Netherlands, these figures account for approximately one third of the total waste sent to landfill sites [9–12]. Moreover, recent figures published by the British government revealed that construction, demolition, and excavation (CD&E) activities produce around 120 million tonnes of waste every year [13], which is approximately 32% of the total waste generated in the United Kingdom and is three times the waste produced by all households combined [14]. Furthermore, 10% of all materials delivered to construction sites are wasted due to damage, loss, and over-ordering [15] and approximately 13% of building materials delivered to sites are directly sent to landfills without being used [16]. As such, the "Waste Strategy for England 2007" has identified the construction industry as a major waste generator [14]. Construction waste impacts on economic competitiveness in the construction industry are substantial since this creates many extra costs (*i.e.*, overhead costs, extra work on cleaning, lower productivity, and landfill taxes) for contractors where the ultimate burden of such costs is borne by clients [17,18]. Additionally, construction waste creates a number of environmental problems at both national and global levels, since it consumes a large proportion of landfill volumes, superfluously uses non-renewable natural resources, and contributes to environmental pollution through air and water pollution [17,19–21]. Moreover, construction waste creates a number of social problems due to health and safety issues. These environmental, economic, and social issues put significant pressure onto the construction industry to reduce construction waste generation.

The National Health Service (NHS) is one of the largest public sector clients in the United Kingdom government, having a considerable property portfolio [22]. With the aim of delivering better health outcomes for people in that country, the NHS has started a significant capital investment programme, including modernisations to its existing buildings, whilst also constructing new healthcare buildings. This capital investment accounted for around £5.5 billion in 2007/08, in real terms almost four times the amount for 1997 [23]. This capital investment programme is expected to continue in the future since the NHS plans to spend over £4.4 billion on healthcare buildings from 2010/11 to 2014/15 [24]. With this capital investment programme a number of sustainability issues have arisen, including excessive consumption of energy and water, carbon emission, and large volumes of waste generation [25]. Therefore, healthcare industry stakeholders are placing more emphasis on SC, while delivering healthcare facilities, to reduce overall building impacts [26]. The Department of Health (DH) sets SC targets for operational energy, water consumption, transport, sustainable procurement, and waste minimisation and recycling [27]. In the construction of healthcare buildings, construction companies are required to meet the UK Sustainable Construction Strategy target to reduce CD&E waste to landfill sites by 50% of 2008 figures by 2012, to achieve zero net waste at the construction site level by 2015, and zero waste to landfill sites by 2020 [28].

Many authors argue that source reduction is the best way of minimising construction waste and eliminating waste disposal problems to landfill sites [29–31]. Additionally, past research studies identified causes and origins of waste, using different classifications, such as project level activities [17,19,32], waste to material types [33,34], and project lifecycle stages [35,36].

There is a consensus in the literature that healthcare buildings are "different" and "complex", due to complexities within functional and operational features [37]. Furthermore, it can be argued that these complexities adversely influence generating construction waste in healthcare projects. However, existing literature fail to establish a clear relationship between healthcare complexities and construction waste generation. Hence, this research aims to explore relationships between construction waste causes and healthcare complex features.

2. Research Methodology

This research followed a three-step process to gather information required for this study. The first step was a thorough literature review to define construction waste, obtain insights into the causes and origins of construction waste in the project life cycle, and identify complexities in healthcare project lifecycles that could affect construction waste generation. The second step was to conduct 25 semi-structured preliminary interviews with key stakeholders involved in the main life cycle phases in a healthcare project, namely client representatives (Estate Managers, General Managers), architects, and contractor representatives (Project/Site Managers, Project Directors) with previous experience in healthcare projects. In addition to healthcare construction experience, interviewees' experience on other building projects was also considered to be an important factor in the selection process, because the preliminary data collection study aimed to compare waste-generation severity levels in healthcare buildings with other building projects. Moreover, as per Yin [38], geographical accessibility was given high priority when selecting the interviewees to increase convenient access. Thus, priority was given to the English Midland region. As a result, six NHS trusts, three Primary Care Trusts, eleven architectural companies, and twelve contracting organisations were contacted by phone to arrange preliminary interviews. The preliminary data collection study focused on a more generalized, but in-depth, investigation into the waste generation issues particular to healthcare construction. The interview template consisted of three sections: background information, complex healthcare features that affect construction waste generation, and causes of waste in a healthcare project life cycle. Two pilot interviews were conducted to enhance the clarity of the questions, assess the time required for each section, test the voice-recording devices, and act as a practice session prior to the actual interview series. The constant comparative method introduced by Glaser and Strauss [39] was followed to analyse the qualitative data gathered during interviews. Firstly, narratives given by the interviewees were divided into the smallest pieces of meaningful information under each interview question, and these were appropriately modified/replaced to increase clarity and to avoid repetition. Subsequently, those units of information that related to the same content were brought together and categorised meaningfully to maintain the internal consistency while creating entirely mutually-exclusive groups.

Thirdly, a postal questionnaire survey was conducted among key stakeholders in the healthcare project life cycle phases to map relationships between healthcare complexities and construction waste causes. The architects and contractors for the questionnaire survey were selected from the United Kingdom's top 100 consultancy and contracting organisations with a good profile in healthcare construction. Additionally, questionnaires were sent out to Estates/Facilities departments in NHS trusts and Primary Care Trusts to obtain views from client representatives. The questionnaire included a combination of rating scales and open-ended questions. Open-ended questions were mainly targeted to capture additional information and respondents' views on healthcare waste generation issues that were not covered in the survey. The questionnaire was tested using a pilot study before being sent to the respondents. The pilot test helped to improve the quality of the questionnaire template by enhancing poorly worded questions and the questionnaire format (*i.e.*, lack of spaces to record answers) [40]. Moreover, pilot testing helped to refine the questionnaire and eliminated problems in understanding and answering questions and improved the validity of the contents of the questionnaire, so improving the reliability of the data. Altogether, 100 questionnaires were sent out and 36 questionnaires were received, representing a response rate of 36%. This includes 10 client representatives, 15 architects, and 11 contractors. A simple and meaningful data representation approach was given priority during the data analysis. Mostly, descriptive statistics, such as counts (numbers or frequency), proportions (percentages), and mean ratings were used as appropriate in analysing data.

3. Literature Review

3.1. Construction Waste Definition

The growing body of literature in the field of construction and demolition waste has produced several definitions for construction waste. However, Osmani *et al.* [41] argued that most of the definitions apply to all waste, irrespective of whether it is destined for disposal or recovery operations. In the sustainable construction context, material wastage is the greater concern, as construction activities generate large volumes of material waste and most of the raw materials from which construction inputs are derived come from non-renewable resources [17]. Therefore, this research focuses on defining the term "construction waste" in relation to "material" in construction projects.

Skoyles [42] defined wastage of building materials as the "remains of the materials delivered on site after being used in the construction work". Skoyles and Skoyles, [18] explained construction waste in a more detailed manner as "material which needs to be transported elsewhere from purpose of project due to damage, excess, or non-use or which cannot be used specifically due to non-compliance with the specifications, or which is a by-product of the construction process". The latter definition gives a better explanation to construction waste, as it explains the reasons for material waste generation on site. Ekanayake and Ofori [17] went further to explain the actions to be taken when construction waste is generated on site (*i.e.*, land filling, incineration, recycling, reusing or composting), while highlighting the reasons for waste generation (*i.e.*, material damage, excess, non-use, or non-compliance with the specifications). Therefore, this research adopted the definition of Ekanayake and Ofori [17] for "construction waste", which is "any material, apart from earth materials, which needs to be transported elsewhere from the construction site or used within the construction site itself for the purpose of land filling, incineration, recycling, reusing or composting, other than the intended specific purpose of the project due to material damage, excess, non-use, or non-compliance with the specifications or being a by-product of the construction process".

3.2. Definition of Construction Waste Minimisation

The waste management hierarchy [14] clearly indicates that waste management must primarily aim to prevent waste generation from the start of the project, since this helps to reduce the costs associated with handling, managing, and eliminating many waste disposal problems [43]. This was further confirmed by several authors, who stated that source reduction is the best way of minimising construction waste [29,30]. Waste minimisation is an in-plant process that reduces, eliminates or avoids the generation of waste [30]. Even though literature defined waste minimisation simply, as the reduction of waste at source, different authors have given different definitions to waste minimisation. For instance, the Environment Agency [44] defined waste minimisation as "the reduction of waste at source, by understanding and changing processes to reduce and prevent waste", indicating the ways in which waste can be minimised. A much different definition to the above was given by the Environment Protection Department (EPD) [45], stating that waste minimisation was "a process or activity that either eliminates or reduces waste generation at the source or allows reuse or recycling of waste for benign purposes". This definition incorporates "reuse and recycling" as also part of waste minimisation, where the former definition considers only "waste reduction at source". However, the former definition is considered more appropriate for current research, since it focuses on construction waste minimisation through the identification of waste sources and suggests process changes to reduce and prevent waste.

3.3. Causes of Construction Waste

The literature reveals a large number of past studies conducted to identify the origins of waste. However, the findings of these studies cannot be compared directly, as these studies used different approaches to classify waste origins from construction projects. For instance, some authors classified waste origins based on project level activities. Gavilan and Bernold [32] classified waste origins under six categories based on different project activities: design, procurement, handling of materials, operation, residual related, and others. A similar approach has been adopted by Bossink and Brouwers [19], who further extended the list of causes of waste related to aforementioned waste origins at site level. Ekanayake and Ofori [17] also categorised waste origins into four clusters: design, operational, material handling, and procurement. Soibeiman *et al.* [34] and Pinto and Agopayan [33] used a different approach to the above and related construction waste to material types such as steel, cement, concrete, sand, mortar, ceramic block, brick, timber, hydrated lime, ceramic wall tiles, and ceramic floor tiles. Moreover, Rounce [46] pointed out that major construction waste origins are related to the design stage, such as design changes, and variability in the numbers of drawings and in the level of design details, whilst Keys *et al.* [47] classified the origins of design and construction waste under the headings of manufacture, supplier, procurement, designer, logistics, client, contractor, and site management. The latter classification indicates that waste origins are associated not only with project activities but also with project stakeholders. Apart from the above, some researchers linked causes and origins of waste to project life-cycle stages. A study by Graham and Smithers [35] found that factors causing construction waste span the project life cycle, including design, procurement, materials delivering/handling, construction/renovation, and demolition. This was further confirmed by Osmani *et al.* [36] who stated that construction waste is effectively generated throughout the project from inception to completion, while categorising design-related waste causes into project life-cycle stages. Since life-cycle categorisation of construction waste causes covered most of the issues related to construction waste generation, a life-cycle approach was considered to be the best method for compiling construction-related waste causes in this research. Some studies define the term "project life cycle" from inception to completion [36], while some studies adopt the concept of cradle-to-grave [35]. However, the former approach of defining the lifecycle from inception to completion well suits the construction waste definition in this research, as demolition waste is not considered. Additionally, a project life cycle was broadly divided into four stages: pre-design, design, tendering and contract agreement, and construction; and compiled causes of waste mentioned in the literature as shown in Table 1.

Table 1. Causes of waste in a project life cycle (Compiled from literature).

Lifecycle stages	Construction waste causes
Pre-Design Phase	**Briefing** • Lack of identification of client's needs • Lack of planning of project requirements • Incomplete design briefs • Improper detailing of documents
Design Phase	**Drawings-related** • Last minute design changes due to client's requirements during construction period • Errors in drawing details/lack of information in the drawings/Design complexities • Delays in drawings /Slow drawing revision and distribution
	Materials selection and specification-related • Selection of non-standardised materials for the design /Not working to standard dimensions • Designers lack of knowledge on alternative products • Selection of low quality materials and products/unclear/unsuitable specifications
	Other • Lack of attention paid to dimensional coordination of products/Lack of communication and coordination • Inadequate experience of the designer with construction sequences • Long project duration

Table 1. *Cont.*

Lifecycle stages	Construction waste causes
Contract Agreement Phase	**Tender/contract document-related** • Errors in contract /tender documents • Incomplete contract documents at the commencement of construction
	Other • Type of contract varying responsibility towards waste minimisation • Method of tendering (allocation of waste allowance during tendering)
Construction Phase	**Material procurement** • Materials ordering errors (over/wrong ordering) • Supplier errors • Shipping errors
	Material storage • Inappropriate material storage facilities on site leading to damage or deterioration • Improper storage methods • Materials stored far away from point of application
	Material handling • Material supplied in loose form • On site transportation methods from storage to the point of application • Inadequate material handling
	On site management and planning • Lack of on site management plans • Improper planning for required quantities • Delays in passing on information on types and sizes of materials and components to be used • Lack of on-site material control • Lack of supervision
	Site operation • Accidents due to negligence • Unused materials and products • Equipment malfunction • Poor workmanship causing rework • Use of wrong materials resulting in their disposal • Time pressure • Poor work ethics between project team and labourers • Poor communication between project partners • Damage caused by subsequent trades
	Transportation • Damage during transportation • Difficulties for delivery vehicles accessing construction sites • Insufficient protection during unloading • Inefficient methods of unloading
	Residual • Off-cuts from materials to uneconomical length and shapes • Waste from application process (*i.e.*, over preparation of mortar) • Packaging

As shown in Table 1, the current literature provides clear evidence that the causes of waste have either a direct or indirect impact on generating construction waste, and this could arise at any stage of a construction process, from inception to completion. The impacts of these waste causes could vary due to the nature, complexity, size, and stakeholder relationships in a project. To identify the most appropriate waste minimisation approach, it is important to customise the causes and origins of waste particular to each project. There is a general consensus in the literature that healthcare buildings are different and more complex than other buildings [37]. However, existing research findings are not enough to determine the impact of each waste cause on generating construction waste due to those complexities. The next section explores complexities in healthcare buildings which could impact adversely on construction waste generation.

3.4. Complexities in Healthcare Project Life Cycles

Even though many studies claimed healthcare buildings were “complex”, none of the above studies stated a clear definition for “complex buildings” or any basis for categorising healthcare buildings as “complex”. Baccarini [48] defined a complex project as “consisting of many varied interrelated parts that can be operationalized in terms of differentiation and interdependency”. This study identified organisational and technological complexities as the most commonly observable complexities in construction projects. While introducing a more comprehensive definition to “complex buildings”, the New Zealand Registered Architects Board (online) [49] highlighted the characteristics that could be seen in complex buildings, such as: complicated structural requirements, multiple occupancy or special purpose user requirements, complicated spatial articulation, complex planning and coordination of complex construction systems, materials, building services, fittings, challenging site configuration, and existing features. In the literature, a number of studies specified issues relating to complex characteristics in healthcare project life cycle.

3.4.1. Pre-Design Phase

The main objective of the pre-design phase is to produce a project brief that defines the project requirements, to assist the facility-design, construction, and maintenance processes throughout the building life cycle. A precise definition for the scope of the project maximises project outcomes throughout the life cycle of the facility, while enhancing the satisfaction of the project stakeholders. A study by Lima and Augenbroe [50] mentioned that ineffective communication, poor scope definition, the unique technical background of stakeholders, and complex decision environments are the major problems in the pre-design phase of a healthcare project. Also, Sengonzi *et al*. [51] highlighted that the number of project stakeholders involved in the project requirements identification phase in a healthcare project is particularly large as it includes end users (*i.e.*, patients, staff), boards (*i.e.*, NHS, Trust, PCT), construction providers, funders, community and pressure groups, and government and regulatory authorities representing the client organisation. Therefore, it can be argued that the large number of users involved during the project-requirements identification phase increases the complexity of identifying all the project requirements Moreover, Gibson *et al.* [52] stated that inadequate or poor scope definition in a construction project tends to increase the final project cost due to having to rework and interrupt project activities. Rework is commonly known in the literature as a major cause of waste in construction projects. Moreover, Lima and Augenbroe [50] reported inherent complexities within the decision environment in healthcare projects through the diverse and unique technical background of stakeholders with different priorities and expectations of the final facility, the desire to achieve multiple objectives at once, the management of multiple criteria and alternatives, the need to justify decisions, and difficulties in understanding the problems. Thus, the possibility of efficient communication among project stakeholders during the pre-design phase in a healthcare project is arguable. However, the aforementioned studies have not extended their findings to identify the relationship between healthcare pre-design-phase complexities and construction-waste generation.

3.4.2. Design Phase

Healthcare designs are considered complex and unique, since they comprise functionally- and operationally-interconnected, built and technical elements that interact with several management systems. Therefore, unlike other buildings where a poorly designed environment may cause dissatisfaction and annoyance, inhibit effective communication, or contribute to relatively minor health problems, in a healthcare environment the consequences of getting the design wrong can be far more serious, including causing loss of life [53]. Furthermore, patient satisfaction is an important factor in the process, because it has been associated with commitment to return to and recommend the hospital to others [54]. Therefore, the design of healthcare buildings needs to increase the likelihood of producing a facility that functions well for patients, staff, hospital administrators, and facility planners. Well-designed buildings with features such as natural light, good ventilation, and access to green spaces can result in quicker patient recovery. However, Lawson [55] mentioned that maintaining the balance between quicker patient recovery features and critical adjacencies within the departments in a healthcare facility is a very stressful process for the designers, indicating the level of complexity in a healthcare design. The requirement to follow Healthcare Technical Memoranda (HTMs) and Healthcare Building Notes (HBNs) introduced by the NHS further increases complexities in healthcare designs. Moreover, healthcare designs require integration of a large number of mechanical and electrical (M&E) services, which accounts for nearly 50% of the total project cost [56], increasing design-associated complexities. In terms of functional considerations, Thomson *et al.* [57] suggested that healthcare building designs need to be flexible to facilitate future changes (*i.e.*, climate, new ways of working, new technology, changing healthcare demands, advances in science and medicine and changing patterns of disease), without significant structural or fabric alteration. Although the published literature demonstrates the design-stage complexities in healthcare buildings due to healthcare building regulations, adaptability and flexibility needs, and M&E services requirements [56,58–60] no clear evidence can be found in the literature to recognise the effect of these complexities on causes and origins of waste.

3.4.3. Contract Agreement Phase

The data published by the British government and the NHS clearly indicates that current and future healthcare construction projects use non-traditional procurement systems such as: Private Finance Initiative (PFI), Procure 21 (P21), and the Local Improvement Finance Trust (LIFT); the latter two were especially introduced by the NHS for healthcare projects. These procurement systems comprise multi-disciplinary teams working from the start of the project to its completion. In the literature, several authors [12,61,62] highlighted that construction waste causes could be influenced by the selected procurement system. For instance, the effect of some causes of waste (*i.e.*, type of contract varying the responsibility towards waste minimisation, method of tendering) could vary greatly, according to the relationship and understanding among project team members. Moreover, McDonald and Smithers [31] emphasised the need for a future study to identify the ways in which different construction procurement systems affect the generation of on-site waste as a result of the different interrelationships involved in alternative procurement processes. This was further confirmed by Gamage *et al.* [63], who particularly focused on enhanced design-and-build projects and the customised causes of waste particular to enhanced design-and-build projects. Akintoye and Chinyio [37] mentioned that the use of healthcare specific procurement systems enables project participants to work collaboratively in speeding-up and finalising a design. Also, in terms of waste generation, the use of highly integrated procurement systems could be advantageous. Since no clear evidence can be found in the literature relating to construction waste causes particular to the use of procurement systems, it is worth exploring the causes of waste particular to healthcare projects, since healthcare projects use specific partnering procurement systems such as P21, P21+, and LIFT.

3.4.4. Construction Phase

Healthcare facilities need to operate continuously throughout the facility life cycle, and therefore construction and renovation activities often take place on live hospital sites, which could increase complexities in site operations, materials handling and storage facilities, transportation inside the site, and site waste management activities. A study conducted by the Waste & Resources Action Programme (WRAP) [64] revealed that, on large and congested healthcare sites, segregation of different waste streams is challenging, especially when sub-contractors are not allocated waste minimisation responsibilities. Also, healthcare buildings require a large number of M&E services. By their very nature, building services cannot be designed and installed independently, as these vital elements have to be fully integrated with other building components and require a high level of coordination. Lam [56] revealed that the lack of integration and coordination of building services into the main construction work is detrimental to the success of a project, as they could delay other construction activities, create major monetary claims, unsightly services, and potentially difficult maintenance. Due to the aforementioned complexities, it can be argued that waste generation from healthcare projects is significant in the construction phase. On the other hand, the use of non-traditional procurement methods for healthcare construction might reduce construction waste generation as a result of early project team formation that allows communication and coordination enhancements from the start of the project. However, there are not enough findings in the literature to clearly identify such effects on waste generation due to embedded complexities in the healthcare construction process.

The results from preliminary interviews and the questionnaire survey that aims to map the relationship between causes and origins of construction waste with healthcare complexities are presented in the next section.

4. Results and Discussion

4.1. Preliminary Interview Results

4.1.1. Healthcare Complexities and Construction Waste Generation

In-depth discussions were held during the interviews to identify the complex features which lead to high waste generation in healthcare projects. As discussed in Section 2, interview transcripts were carefully analysed to identify complex features in healthcare projects affecting construction waste generation. These complexities were broadly categorised into two: functional complexities and operational complexities. Functional complexities can be simply defined as complex quality requirements to consider during the facility construction to serve the purpose/functionalities well. Operational complexities are related to healthcare operational stage complexities. Respondents' views regarding the impact of each healthcare complexity on construction waste generation were also analysed and they were divided into three categories: significant, moderate, and mild/no impact, as shown in Table 2. Aforementioned analysis considered key words used by respondents to explain the impact of construction waste generation severity by healthcare complex features.

Table 2. Impact on healthcare complexities of waste generation.

Complex Healthcare Features	Number of Respondents (of 25)	Level of Impact on Waste Generation (Code)
Functional Features		
Complex building requirements for different shapes and sizes of rooms.	22	Significant
Complex mechanical and electrical services of the building.	20	Significant
Requirement for a large number of materials to satisfy quality standards.	15	Moderate
Complex nature of identifying all the functional requirements of the building at an early stage.	14	Moderate
Requirement for high density of materials per m^2 of the building.	11	Moderate
Operational Features		
Adaptable and flexible building-needs to fulfil future requirements.	10	Moderate
Continuous operation of hospital buildings in construction sites.	18	Significant
High wear and tear of the building throughout the lifetime.	5	Mild/no

Functional Features

In most healthcare buildings, each room has to perform a different function. Unlike other buildings, to perform these functions, each room is required to maintain certain standards specified in healthcare building notes (HBNs) and healthcare technical memorandums (HTMs). Hence, most of the interviewees argued that the complex nature of functions in adjacent rooms requiring different shapes, different sizes, different materials, different medical equipment, and stringent environmental controls significantly increases the quantities of waste during the facility construction.

Another very important feature highlighted by the interviewees related to waste generation in healthcare projects was the complexities in mechanical and electrical services. Almost all the respondents confirmed this, declaring that waste generation was a result of the high density of materials used, reworking, off-cuts, *etc.*, due to extensive services use.

Moreover, some interviewees mentioned that the number of materials used and density of materials per m^2 of the building is high in healthcare projects as they require complying with healthcare building regulations. Hence, respondents argued that this increases waste composition in healthcare projects compared with other buildings of similar size. Additionally, some respondents stated that the use of different types of material to meet special quality standards to perform special functions (*i.e.*, X-ray rooms) and psychological needs of patients (*i.e.*, use of multi-colour paintings in children's wards), as specified in healthcare guidance notes, further reduces the capacity to design-out waste.

Apart from the above, some interviewees stated that the identification of all the complex functions in a healthcare project is very difficult and challenging at the start of the project, as multiple users with different priorities are engaged in the process. Therefore, interviewees have revealed the above as a reason for increased waste generation in healthcare projects, due to late changes to the client's requirements resulting in late design changes.

Operational Features

As well as functional features, the interviewees revealed that continuous operation of healthcare facilities creates a number of issues relating to construction waste minimisation in healthcare projects. The majority of the respondents (18 of 25) confirmed that constructing/renovating a healthcare building on a live hospital site creates enormous complexities in site activities. They highlighted the requirements of emergency access roads, temporary accommodation for patients and staff, and high-quality partitioning to avoid disturbances due to noise and dust, *etc.*, as grounds for generating waste in live healthcare. Highlighting the above, they established the view that construction activities in a live hospital site produce more waste. Further, respondents mentioned that waste removal and segregation is also a challenge on a live hospital site due to space limitations and reducing disturbances to the adjacent live buildings.

Moreover, some interviewees declared that healthcare buildings need to be adaptable and flexible for future changes to accommodate future management and user requirements. Since healthcare requirements change rapidly with improvements in medical technology, interviewees stated that healthcare buildings are difficult to future-proof and generate high quantities of waste throughout the building's life cycle due to frequent modifications. However, some interviewees believe that making changes to healthcare projects with minimum wastage is more practical than planning and designing for adaptable and flexible buildings.

Since most healthcare buildings operate continuously throughout their lifetime and are subjected to constant high wear and tear, some interviewees stated that healthcare buildings generate a lot of waste throughout the lifetime of the facility due to unexpected maintenance and replacements, unless good quality materials have been used initially and maintained appropriately throughout the building lifetime. However, they emphasised that this is a common issue with most public buildings, although the severity of its effect on healthcare buildings is higher due to the hygiene and quality standards required, according to healthcare guidance notes.

4.2. Questionnaire Survey Results

4.2.1. Impact of Healthcare Complexities on Construction Waste Causes and Origins

Preliminary interview results clearly indicate that some complex features in healthcare facilities significantly impact on construction waste generation. It is important to establish clear links between healthcare complexities and construction waste causes to implement waste minimisation strategies effectively in healthcare projects. However, to date, no significant study has been conducted to identify the relationship between healthcare complexities and construction waste causes and origins. The questionnaire gave each respondent an opportunity to rate 25 construction waste causes and origins identified from literature and preliminary interviews on a scale from 1 (no impact) to 5 (very significant impact); the findings are shown in Table 3.

According to these results, it is interesting to note that healthcare functional complexities impact more on construction waste causes throughout the project life cycle than healthcare operational features do. Out of which, results clearly reveal that functional features A and B impact significantly on construction waste causes throughout the project lifecycle. The aforementioned findings of the survey went a step ahead of the studies by Lam [56], FHN [59], and Gaiser and Barlow [60], by confirming the impact on construction waste generation due to healthcare complexities in building regulations (HTMs and HBNs) and M&E services requirements. As shown in Table 2, the above findings are also in line with the preliminary interview results. The majority of the respondents were of the opinion that the A, B, C, and F functional features complicated the project briefing process and thus lead to incomplete briefing more often in healthcare projects. These results undoubtedly confirmed the issues raised by Lima and Augenbroe [50] about the high risk of getting poor scope definition in the pre-design phase in healthcare projects due to the inherent complexities of healthcare projects. This study went a further step by confirming that healthcare complexities impact significantly on poor scope definition (incomplete briefing) and thus have high potential to generate construction waste in the latter stages (*i.e.*, construction).

The findings of Bossink and Brouwers [19], Ekanayake and Ofori [17], Kulathunga *et al.* [65], and Osmani *et al.* [36], argued that inconsistencies (*i.e.*, errors, incomplete documents) in contract documents are a cause of waste. The literature review findings reflected the view that healthcare projects have a greater propensity for inconsistencies in project documents because of the substantial number of project documents that need to be shared among a large number of project stakeholders. However, the questionnaire results show that healthcare complexities do not make a significant impact on the waste cause "inconsistencies in contract documents". The above was also confirmed by the preliminary interviewees stating that the use of more integrated procurements systems (*i.e.*, P21, PFI) in delivering healthcare projects reduce inconsistencies in project documents, since project stakeholders are able to share project documents effectively. This further confirms the arguments raised by McDonald and Smithers [62], Greenwood [61], and Tam *et al.* [66] about the potential impacts from selected procurement methods on construction waste generation. This study confirms that collaborative procurement methods have the potential to reduce overall construction waste generation through better communication and coordination.

Table 3. Impact of healthcare complexities on construction waste causes and origin. (Shadow part shows highly impacted waste causes due to healthcare complexities).

Waste Causes	**Mean Ratings**								
	Functional Features						**Operational Features**		
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Pre-Design and Contract Agreement Phase									
Incomplete briefing	4.3	3.5	3.5	1.7	1.2	3.7	1.0	1.2	1.0
Clients' lack of awareness of the construction process	3.5	3.8	2.1	1.2	1.2	3.0	1.1	1.1	1.0
Inefficiencies in communication and coordination	3.6	2.3	2.1	1.3	1.0	1.4	1.0	1.0	1.0
Lack of concentration on adaptability and flexibility by clients	3.4	3.2	1.4	1.4	1.1	3.2	1.0	3.4	1.0
Clients' are not willing to change their requirements to standard sizes	4.0	2.1	1.9	1.9	1.4	2.2	1.0	1.7	1.0
Clients' lack of knowledge about the materials available	2.6	1.7	1.5	2.1	1.9	2.3	1.0	1.2	1.0
Type of contract varying the responsibility for waste generation	1.4	1.7	1.5	1.1	1.1	1.1	1.0	1.4	1.3
Inconsistencies in the contract documents	2.4	1.1	2.5	1.3	1.1	1.1	1.0	1.0	1.0
Design Phase									
Lack of knowledge of alternative materials	2.4	1.9	2.7	3.3	2.4	2.4	1.0	1.1	1.4
Incorrect drawing details	4.1	3.4	2.2	2.4	2.3	2.3	1.0	1.0	1.0
Complex designs generating a lot of off-cuts	4.3	3.7	1.8	3.1	3.7	1.7	1.0	1.3	1.0
Over-/under-specification	3.4	2.4	2.5	2.4	3.2	3.2	1.0	1.1	1.9
Inefficiencies in communication and coordination	3.5	2.5	1.8	1.2	1.2	1.4	1.1	1.0	1.1
Design changes	4.0	3.4	3.4	3.2	2.4	3.3	1.2	1.4	1.0
Delays in drawings causing time pressure during construction	2.4	1.6	2.8	1.3	1.3	1.3	1.0	1.0	1.0
Wrong selection of material in the lifecycle	1.7	1.9	1.8	2.3	2.3	3.0	1.3	2.3	2.3
Not thinking about the best ways to design	3.3	2.2	3.2	2.3	2.3	3.1	1.0	3.1	1.9
Non-standardisation of designs	3.5	3.6	2.2	1.9	1.5	1.5	1.0	1.7	1.0
Lack of awareness about waste generation in the construction process	3.3	1.2	1.2	1.1	1.6	2.2	1.4	1.4	1.4
Construction Phase									
Poor workmanship causing rework	4.0	3.4	1.4	3.6	3.9	3.0	3.4	1.0	1.1
Inadequate communication and coordination among parties	3.6	3.6	1.3	2.8	3.3	1.4	1.6	1.1	1.0
Lack of planning & organisation	3.5	1.8	2.7	1.3	1.3	3.1	4.2	1.3	1.0
Care and quality of trades used	1.9	1.7	1.1	2.0	2.8	1.4	3.3	1.4	3.5
Material handling and storage facilities on site	1.8	1.2	1.0	2.0	2.6	1.1	4.6	1.0	1.0

Notes: A: Complex nature of the building due to different shapes and sizes of rooms; B: Complex nature of mechanical and electrical services of the building; C: Complex nature of identifying all the functional requirements of the building; D: Requirement for high density of materials per m^2 of the building; E: Requirement for a large number of materials to satisfy quality standards; F: Changing nature of functional requirements between projects; G: Continuous operation of hospital buildings in construction sites; H: Adaptable and flexible building needs to fulfil future requirements; I: High wear and tear of the building throughout its lifetime.

According to these results, the complex nature of healthcare buildings, due to different shapes and sizes of rooms, significantly influences the design phase waste causes, such as incorrect drawing details, complex designs generating off-cuts, and design changes. Additionally, it is interesting to note that these three waste causes were highlighted by the preliminary interviewees as significantly influencing waste causes in the design phase of a healthcare project. Nevertheless, results indicate that, while functional feature B does not influence design phase waste causes in comparison with functional feature A, its influence on design phase waste causes, such as incorrect drawing details, complex designs, design changes and lack of design coordination, is noteworthy. Moreover, the results shown in Table 3 imply that healthcare operational complexities (G, H, and I) have less impact on both pre-design and design phase causes of waste compared with functional complexities.

Interestingly, both functional and operational complexities in a healthcare project influence construction-phase causes of waste. Out of these, poor workmanship causing rework can be identified as the highest-impact waste cause, according to the mean ratings as shown in Table 3. The continuous operation of hospital buildings (24 × 7) greatly influences construction waste causes such as lack of planning and organising, and materials handling and storage facilities on site.

It is also worth noting that all the significantly-impacted waste causes due to healthcare complexities throughout the project lifecycle were identified by previous researchers [17,36,67] as the most critical waste causes in construction projects. Therefore, the findings of this study provide reasonable grounds to argue that the potential to generate construction waste in healthcare projects is higher than other projects of similar size.

5. Conclusions

The aim of this paper was to identify complexities in healthcare projects and their level of impact on construction waste causes throughout the project lifecycle. Findings revealed the complex nature of healthcare buildings, due to different shapes and sizes of rooms and complex mechanical and electrical services, significantly impacts a number of construction waste causes throughout the project life cycle. Healthcare functional complexities impact more on pre-design-and design-phase waste causes, while healthcare operational features have a greater impact on construction-phase waste causes. Most previous studies focused either on the design phase or the construction phase, rather than focusing on the whole project life cycle. In particular, lack of consideration was given to pre-design-phase waste causes. However, the findings of this research reviewed cause of waste from a more holistic life cycle perspective. Furthermore, the results emphasised that healthcare complexities adversely impact on pre-design-phase waste causes, such as incomplete briefing and a client's lack of awareness and interest in waste minimization. It can be concluded that healthcare complexities significantly impact on construction waste causes throughout a project life cycle, and the most significantly impacted waste causes are inefficiencies in project documents (*i.e.*, incomplete briefing, complex designs, non-standardised design), inefficiencies in communication and coordination, lack of stakeholder waste awareness (especially clients and designers), and buildability issues (*i.e.*, poor workmanship). However, results indicate that the use of collaborative procurement methods (PFI, P21) in British healthcare projects has the potential to reduce the overall impact from the aforementioned complexities on construction waste causes. Even though this research specifically attempted to identify healthcare-project-related complexities that tend to increase construction waste generation, there are clear grounds from the literature to claim that most of the aforementioned complexities (*i.e.*, complex project requirements, large number of drawings, long project duration, *etc.*) are also common to other construction projects. Hence, these findings could be used as the basis for future research studies to identify other project-related complexities and their associated construction waste causes, to plan and implement appropriate waste management strategies.

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Conflicts of Interest

The author declares no conflict of interest.

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