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BIM and Building Resilience: A Hybrid Mechanism to Integrate Measures Against Flooding

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Abstract
For over a decade, there has been a rapid progression in applying the use of Building Information Modelling (BIM) across the whole life cycle in a construction project. Despite many of the benefits that BIM offers, there is limited evidence that portrayed the role that BIM plays in improving the resilience of built assets, especially against unprecedented events such as flooding. To date, many flood resilient measures were introduced, however, a hybrid mechanism that integrates these measures collectively integrating stakeholders' needs and requirements is currently lacking. This research aims to portray the role of BIM in facilitating an integrated mechanism toward improving the resilience of built assets against flooding. Data was attained using secondary data from existing studies in the literature and primary data using semi-structured interviews with six experts from one of the city councils in the UK. The findings show that despite the progressiveness of measures against flooding, it is often targeted at an urban level with limited emphasis at a building level. The analysis supported pointed out the role that BIM can play in improving the resilience of built assets through informing design elements, which can support providing more informed decisions. The paper proposed a hybrid mechanism that supports recognizing BIM's role in integrating resilience measures of the built assets against flooding. Future work will examine the effectiveness of the proposed mechanism in a real-life scenario.

Keywords
BIM, Flooding, Resilience, Design, Risk.

1. Introduction

Across the globe, resilience against flooding has been a major area of interest for both academia and industry, and this can simply be reasoned by the longitudinal impact that flooding imposes on the environment, economy and society [1]. The term 'resilience' refers to the capability of a system, community, society or defence to react and recover quickly and easily from the damaging effect of a realised hazard [2]. Although the concept of flood resilience may be associated with scale (e.g. single building, city scale, or regional scale), the common understanding of flood resilience refers to the ability to withstand flood hazards and recovery after the flood hazard takes place [3]. Over the years, flood resilience has recognizable become one of the key aspects of flood risk management. The complexity of flood risk management is context-dependent where, for instance, it is considered more complex in urban areas when compared to rural areas [4]. There are many studies on Flood risk management, for instance, a study by [5] conceptualised risk management as the result of measuring hazard, exposure and vulnerability. [6] proposed a six-step flood risk management process whereas another study [7] outlined a four-step process. In 2020, the Environment Agency outlined four components of resiliency: placemaking, protecting, recovering and responding [8] where these components require integrating the view of different stakeholders. However, with most of the ongoing efforts on flood resilience, the anticipation is often toward visualizing and simulating the impact at an urban scale, and this can potentially narrow the focus at a building level, and more importantly, do not take into account the view property owners and how they perceive flood resilience measures [9]. Another complexity is the fragmented coordination between property owners, operators and also developers, which often lead to limited hazard considerations [10].

With the advent of information technology in construction, Building Information Modelling (BIM) is recognised as one of the robust mechanisms that support the built environment across different aspects by allowing a technologically collaborative process that integrates different stakeholders [11]. Conceptually, BIM allows for projects to be built virtually before they are constructed physically, which supports a more holistic consideration of many inefficiencies and potential issues that occur during the construction process, and an overlook of the whole life cycle of a building [12]. This plays an important role in informing cost-related aspects ([13][14]), improving risk mitigation, and ultimately supporting improved and robust coordination between stakeholders involved in a project [15]. In the context of unprecedented events including natural disasters, the use of BIM is often for visualizing purposes [16] which supported many aspects including emergency evacuation path planning, indoor localization, and fire emergency simulation. Amongst natural disasters, flooding can be recognised as one of the events that are classified as one of the unprecedented natural events and also accounted for as part of infrastructural-related considerations for buildings. To date, some efforts (e.g. [10][17][18]) have elaborated on BIM's role within the context of flooding, however, there are limitations in terms of the integration of different flood resilient measures as part of the BIM process to provide a hybrid mechanism to support a more tangible recognition of flooding-related aspects. This research aims to portray the role of BIM in facilitating an integrated mechanism toward improving the resilience of built assets against flooding.

2. Literature Review

2.1. Flood Resilience: Review of Barriers and Challenges

Flood resilience forms one of the core elements of flood risk management [4], which is seen by many studies [6][7][8] as a complex combination of considerations to ensure that the level of preparedness for flooding is sufficiently efficient. A study by [19] that combined empirical evidence from 22 publications classified flood resilience measures for property into two categories (see table 1): water exclusion ([19][20]) and water entry ([21][22][23][24]). Whilst studies on both water exclusion and water entry were extensive, one of the key challenges with implementing flood resilience measures is the reluctance of homeowners to accept change and responsibility for purchase and installation for flood resilient technologies/measures [26]. Furthermore, a study conducted by [6], in France, Germany, the UK and the Netherlands concluded that participants view flood resilience as a complex and tedious exercise carried out by experts working for local government, combined with other issues such as a lack of guidance, knowledge and capacity. This ultimately has a long-term effect on the property's level of resilience, and research also indicated that even when the key stakeholders were aware of flood resilient technologies/measures, there was not enough information or experience [27] to confidently decide on the type of flood resistance technology to purchase [3][26]. In addition to this, it is imperative to state that, with the recent technological developments, many stakeholders highlighted their lack of confidence in the application of innovative flood resistance measures/technologies such as mobile flood barriers, levees and sustainable urban drainage systems [28]. Imperatively, this highlights the complex issue associated with implementing flood resilience measures and the need to have an integrated approach toward flooding [8][27]. Despite the wide range of resilience measures against flooding, the complexity of improving resilience against flooding can be captured through the need for a hybrid approach to integrate these different measures, and the need to incorporate the views of different parties involved from designers, developers and property owners, and more importantly provide incorporate inputs that improve the design aspects of a building [10][29]. This rationalizes the need for a hybrid mechanism that integrates flood resilience measures while integrating stakeholders' needs and requirements. This can perhaps support an improved optimization of appropriate resilience measures to provide a more informed decision and manage cost implications associated with flooding [27][30].

Table 34. Flood Resilient Measures based on Existing Literature

Resilience Measure	Type of Measures	
Water Exclusion Measures	Wave return wall, rock armor, beach nourishment and coastal cliff stabilization, Planting trees and hedges, covering the ground with plants to reduce water pollution, diverting high water flows, creating leaky barriers to slow water flow and restoring salt marshes.	[19] [20] [21]
Water Entry Measures	Aperture and closing systems, building skins and wall sealants, barriers, automatic flood doors, non-return valves, air bricks and pumps, tiled floors, raised sockets, wall-mounted TV, Closed-cell insulation, plasterboard laid horizontally.	[22] [23] [24] [25]

2.2. BIM role for Flooding

In the context of flooding, research indicates that BIM uses the first two phases to identify a primary BIM data set for flood risk management solution selection and early cost estimation before the installation phase [31]. One of the research studies illustrated that BIM can be used for flood risk management by providing timely information for informed decision making [32]. For refurbishment options for properties, BIM can be used for refurbishment option selection and early cost modelling [31][33]. Once a basic BIM model is built in the BIM system, the flood risk strategy design process is followed to develop and plan a flood protection scheme [17][32]. To make an informed decision about the type of floodproofing design to be deployed, detailed project information is essential during the assessment process in conjunction with physical assessment data. This includes customer design requirements, construction material specification, expected project duration and risk management [31]. Moreover, BIM has also been implemented in Fukuoka, Japan, alongside GIS it was used to simulate underground flooding [34][35] and measure the impact climate change would have on coastal and riverine flooding [36]. The implementation of BIM for infrastructure is nearly 3 years behind its use on buildings, however recent studies have indicated its use on infrastructure projects is increasing [37]. A study conducted by [38] suggested that the use of BIM on infrastructure has brought about financial as well as technical benefits for stakeholders, BIM has enabled accurate cost estimations to be formed which aid in better planning and coordination. In addition to this, BIM supports capturing and storing data which reduces time-consuming tasks [39]. Furthermore, BIM has also helped in bridge infrastructure projects by identifying uncertainties. The use of BIM has enhanced productivity by reducing trial and error within the construction phase, BIM tools have enabled the visualisation of potential risks. Bridges are at risk from flooding, other natural hazards and scouring, these are all risks that can result in collapse; with BIM these risks can be identified before they occur [37]. Research constructed by [40] demonstrated that the use of BIM on infrastructure can reduce risks by increasing collaboration in the construction phase which supports reducing costs for stakeholders. Collaboration can be seen as a major key in informing decisions, especially in complex situations, for instance, a recent study by [10] illustrated the value of incorporating different stakeholders by integrating their requirements within BIM-GIS to improve the resilience of drainage infrastructural systems for hospitals when flooding occurs. Another study by [16] illustrated the value of incorporating the views of different stakeholders to develop a resilient system for hospitals.

Regarding the above efforts, current literature demonstrates the limited role that BIM plays towards flooding as the key benefits highlighted are better collaboration and communication, model-based cost estimation, preconstruction project visualization, improved coordination and clash detection, reduced cost mitigated risk, improved sequencing/scheduling increased productivity and prefabrication, safer construction sites, better build and stronger facilities management and building handover. Such benefits of BIM implementation have been well documented. Existing literature does not identify data/information requirements that support better design decisions for buildings and infrastructure. The type of data/information collected to enhance the value BIM can offer to infrastructure and building projects, and infrastructure and building flood resilience has not been identified. It can be argued that due to this BIM currently plays a limited role in identifying more resilient materials that can be used to make informed design decisions. Current literature demonstrates that the research on flood resilience for buildings and infrastructure has mainly focused on preventive measures such as coastal defences and that other measures proposed by the risk assessment against flooding and BIM research on its role towards flooding is limited and does not identify data/information requirements that support more informed decisions with relation to flood resilience measures. This research will focus on what is required within the BIM environment to allow for the design and construction of more resilient buildings and infrastructure to help protect the UK against flooding.

3. Research Methodology

This research aims to portray the role of BIM in facilitating an integrated mechanism toward improving the resilience of built assets against flooding. This research adopts an inductive approach through using qualitative data to provide a more holistic and exploratory view of the complex phenomenon in this research. Data was attained using secondary data from the literature, and primary data using semi-structured interviews with six experts from one of the city councils in the UK. The secondary data was used to derive the benefits of BIM for buildings, and how it supports facilitating a collaborative process between different stakeholders [41]. The secondary data supported rationalizing the need for a more collaborative mechanism that engages the view of different stakeholders and how this support provides more informed decisions about flood resilience measures. Despite the many benefits for improving different aspects across the whole life cycle, improvements are still required to unlock the full potential BIM can offer to infrastructure and building resilience. As for the primary data, the use of semi-structured interviews was rationalized by the need to gain an in-depth understanding of the needs and requirements of stakeholders. In this study, the views of stakeholders involved were property developers (4 participants), a city planner (1 participant) and a BIM Manager (1 participant) who work at one of the city councils in the UK. Property developers were selected as this would support gaining perceptions on flood measures incorporated for new properties, city planners for their view on risk management and accountancy against flooding, and a BIM Manager to gain a practical insight into how BIM can support incorporating flood-related measures within the BIM process. In this study, the sample size was determined by the accessibility to data, the fact that in the UK city councils heavily inform flood measures [26] and finally that this research does not seek saturation point, hence gaining and interpreting perceptions to gain an understanding of the phenomenon have superseded the need to interview a large sample. Thematic analysis using open coding was used to code the responses from participants in this study, and this would support drawing meaningful outcomes for the research. To illustrate the thematic analysis process followed in this paper, the below figure (figure 1) explains the process of data analysis.

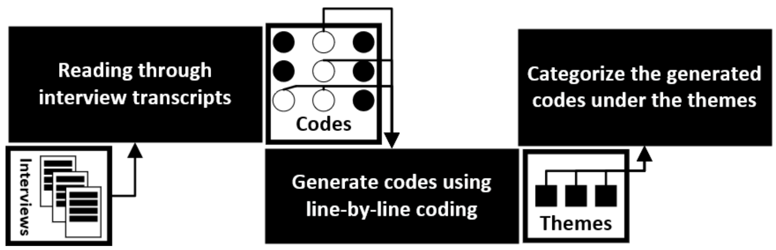

Fig. 36. The Thematic Analysis process followed in this research

4. Results and Analysis

4.1. Perspectives on Flood Resilience Measures

This theme aims to demonstrate and interpret the various perspectives of flood resilience. On flood measures, most property developers had similar perspectives on flood resilience technologies, for instance, participant 1 quoted *"**so in terms of resilience it involves identifying the source of flooding and then tackling the mechanisms that allow flooding get there…..say for instance a local authority trying to protect the town would look at upstream flood storage or conveyance and things like that to try and prevent flooding**"* Another participant quoted "***flooding you look at different kinds of defences, to that whether it be flooding on the coast and it's sea walls or you're looking at trying to stop flash flooding in mountain areas; some of that has happened because of deforestation***". The responses demonstrate that flood resilience/technologies are implemented as mitigation measures in response to the potential source of flooding (e.g. upstream flood storage & conveyance) at a level away from the built asset to prevent floodwater from penetrating the built asset altogether. As for the city planner, it was quoted as "***resilience being you're allowing it in or accepting that it's going to come in and making the recovery quicker***". The city planner's viewpointindicated that a key part in flood resilience measures/technology is stakeholders accepting that floodwater is going topenetrate the built asset, and flood resilience is about creating an environment in which the built asset can return to normal functionality as quickly as possible. The property developers' perceptions highlighted certain measures that are taken into account, for instance, one of the participants quoted "***include things like raising your electrics to above water level, maybe thinking about replacing more expensively perhaps hollow floors and for maybe some more solid floors***". As for the BIM Manager, he mentioned that "***for flood measures, I think it's about materials and services integrated into the design of the building, and their resiliency in the event of flooding, which certainly is an element that must be adhered to***" this shows that flood resilient technologies/measures should proactively take into account the level of resiliency of building systems when flooding occurs so that risks can be reduced once the building has been affected by a flood event.

3.2 BIM Potential for Flood Risk Management

This theme aims to investigate the role BIM currently undertakes in flood risk management of built assets. According to most property developers, they had limited awareness of BIM, however, some had limited knowledge where one of the participants stated **"*I think our interaction with BIM is limited because we're not specifically in that design space, we're not doing design, we're often at the planning stage - that's where our involvement is most often and there's an element of design in there but it's not you know we're not getting into often not getting drawn into that detailed design which in my view is where BIM seems to be most useful*…"**. The quote above demonstrates that role of property developers is mostly during the planning phase with limited involvement during the design stage, hence their awareness of BIM capabilities is considerably limited. As for the city planner's perspective, it was quoted "***It has, in this domain it has some clear potential I think the idea that we are integrating the different stakeholders involved in that design process through the BIM platform is going to save a lot of wasted effort sharing of information**…**and this can support informing many aspects about a building especially if information about nearby developments are retrievable***", the response further highlights that BIM currently plays a limited role in flood risk management, and this is considered vital when digital information. As for the BIM Manager's perception, "***so I think that data is already available and we don't need more data we just need to be able to use the data that already exists better, that's people understanding, not just what data does exist but how it can be used to inform the design and provide more informed decisions***". The response given by the BIM Manager demonstrated that there is a lack of understanding of how to make use of data available within the BIM environment; the data required for them to work within the BIM environment is available, however as they lack an understanding of how to access, interpret and then make use of that data they cannot gain the full suite of benefits.

3.3 BIM for future of Building Resilience

This theme aims to demonstrate how the implementation of BIM can potentially lead to the design and construction of resilient built assets against flooding. In addition to the previous themes, this theme is recognized as one of the key findings to support understanding the phenomenon investigated in this research. From the responses provided by property developers, two participants indicated that BIM has a role to play in the future design and construction of resilient buildings and infrastructure. They added "***Most flooding-related considerations often require simulating at an urban scale, but if you aligned the data to the BIM models it can lead to more consistency to work with, within the BIM environment, so essentially if data outside the BIM environment can be aligned with the BIM model, it could lead to a better accountancy of more resilient infrastructure & buildings***". The above statement demonstrates that there are obstacles currently preventing flood risk specialists importing data into the BIM environment; however, one of the property developers stated, "***In most cases, especially that majority of property development projects data are not produced within a BIM compatible drawings and layers***". This indicates that aligning data to the BIM model is proving to be difficult once property developers can produce data that can be BIM compatible. As for the city planner, the response was "***we are rapidly growing into an era where technology seems to be very domineering, so I think that BIM will be useful, but coordination between BIM data and data outside BIM remains an obstacle …. When we have a development project, there are so many layers of data/information that come from different parties, so we must have a common environment to support better coordination***". This illustrates that managing data/information is complex in a common data environment but seeing how BIM can be a central system remains an obstacle. As from the BIM Manager's perspective, "***Amongst latest technologies, digital twin enables you to simulate different scenarios about whether that be infrastructure or building and you create a digital twin, during the design stage so you will be using predictive analytics to predict how that asset is going to perform in different scenarios and that helps…." and "If you get to a point where you have all the data sorted, you then enable yourself to use machine learning and artificial intelligence…***". The BIM Manager added, "***BIM on its own cannot be enough to mitigate the risk of flooding, so BIM can be the case where information layers can be used to be aligned with a digital twin which then can provide real-time data on change of weather, change of circumstances and this can support provide more informed decisions***". The responses provided by participant 4 demonstrate BIM has a major role in designing and constructing resilient built assets in the future, and to achieve this, the concept of machine learning, artificial intelligence and digital twinning needs to be optimized to ensure the full suite of benefits available are made use of.

Based on the three themes, the first themes showed perceptions on flood often focus on taking mitigation/preventative measures but what lacks is coordination between different perceptions. The second theme showed that BIM currently has a very limited role in flood risk management, but it was also mentioned that data can support informing decisions that will enable the construction of resilient built assets. The final theme showed that for BIM to support resiliency, there is a need to integrate data progressively to support more informed decisions.

5. Discussion

It can be argued that the main flood resilience measures are preventive measures (water exclusion) that focus on either diverting or preventing water from entering the property, for example, participants stated "***so in terms of resilience it involves identifying the source of flooding and then tackling the mechanisms that allow flooding get there…..say***

for instance a local authority trying to protect the town would look at upstream flood storage or conveyance and things like that to try and prevent flooding". When referring to literature, many water exclusion measures were identified such as wave return wall, rock armour, and nature-based resilience measures [19][20][21]. Thus, one of the first complexity identified from the primary data is that majority of the focuses are often upon resistance measures whereas resilience measures at a building level are often focused on avoiding and/or reducing damages to different parts of the property. This can portray the need for collaboration [8][9][10] between property developers, designers, city planners and even building owners so that a more holistic approach is taken toward flood resilience. The second complexity highlighted by participants, is that majority of residential properties are not designed using BIM, which can be reasoned by the limited awareness of many stakeholders, especially property developers. For instance, it was stated, "***I think our interaction with BIM is limited because we're not specifically in that design space, we're not doing design, we're often at the planning stage***". This shows the lack of a hybrid mechanism that can support the integration of different data/information needs, which can limit making an informed decision about resilience measures. The third complexity is the fact that there are many layers of data/information that need to be incorporated when designing new properties, which require effective coordination, and more importantly, how it can be accommodated within the BIM environment. On this, the BIM Manager stated, "***so I think that data is already available and we don't need more data we just need to be able to use the data that already exists better, that's people understanding, not just what data does exist but how it can be used to inform the design and provide more informed decisions***". Recent studies (e.g. [10][16]) highlighted the value of collaboration in the context of infrastructure projects, as this supports capturing requirements of different stakeholders, hence it is vital to apply the same principle in the context of flooding. The final complexity is the need to consider how effectively BIM can support a more hybrid mechanism to capture appropriate resilience measures of buildings against flooding. In that respect, it was found that incorporating resilient measures require the use of multiple layers of data/information so that more accurate predictions can be achieved. To support this, one of the responses was "***BIM on its own cannot be enough to mitigate the risk of flooding, so BIM can be the case where information layers can be used to be aligned with a digital twin which then can provide real-time data on change of weather, change of circumstances and this can support provide more informed decisions***". Although former efforts (e.g. [17][18][32]) have proposed BIM-based mechanisms toward flood resiliency, many limitations were highlighted such as generalizing results and lack of contextualizing. Therefore, this research proposes a hybrid mechanism (see figure 2) to support integrating the appropriate floor resilience measures for buildings.

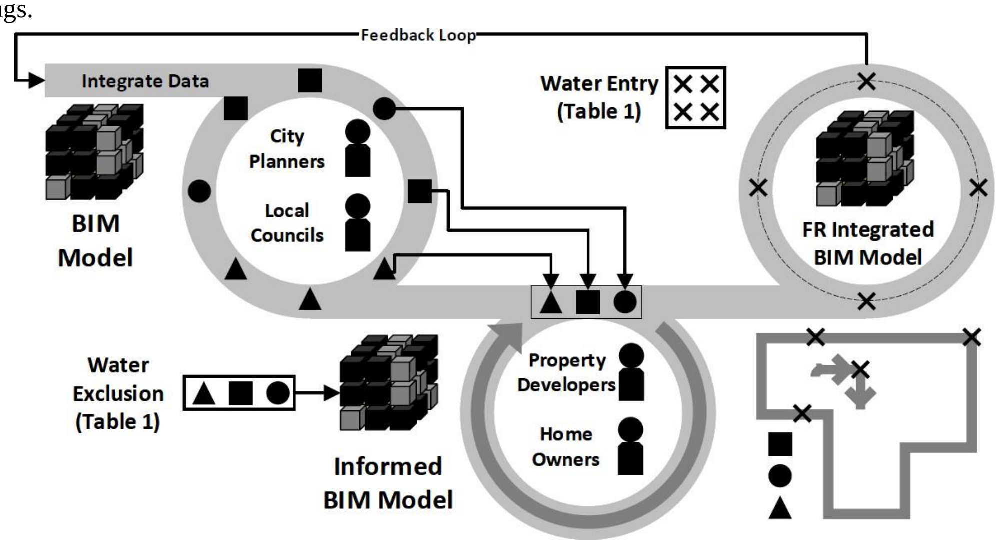

Fig. 2. Proposed BIM-based hybrid mechanism to integrate flood resilience measures.

The proposed framework (figure 2) illustrates the proposed hybrid mechanism toward building resilience against flooding using BIM. The mechanism allows informing water entry measures using in-place water exclusion measures, and this will support informing the appropriate aspects within the property, which supports reducing additional costs, and achieving Flood Risk (FR) integrated BIM Model. The proposed mechanism engages different stakeholders, and support a proactive approach to alert different design parameters (e.g. wall thickness, mechanical services, etc.).

6. Conclusions

To sum up, this research aimed to portray the role of BIM in facilitating an integrated and hybrid mechanism toward improving the resilience of built assets against flooding. The literature showed that there are vastly many ongoing efforts with relation to flood resilience and flood risk management. Although there are many measures including those for water exclusion and water entry, limited efforts illustrated how these measures can support providing an informed decision toward resilience and how it considers different stakeholders' needs and requirements. Literature also highlighted that some complications such as costs can also act as a barrier for implementing resilience measures for properties. Although there are some efforts on BIM for flooding resilience, these efforts are limited, could not be generalised, and more importantly, do not incorporate the views of different stakeholders. To contextualise the research, primary data was attained using one of the city councils in the UK where semi-structured interviews were conducted with property developers, city planners and a BIM Manager. The analysis and discussion identified many complexities that must be acknowledged so that BIM can support the resiliency of properties against flooding, and consequently, the research suggested a BIM-based hybrid mechanism that supports providing informed decisions on resilient measures, especially at water entry-level, so that additional costs can be reduced. This research contributes to knowledge in terms of providing a hybrid mechanism that can facilitate a more informed decision-making system,and more importantly, engage different stakeholders. The research suggests a more robust utilization of parametric data that can be embedded in BIM. Future research will look into validating the proposed approach and identify its practicality in a real-life scenario.

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