

# Game-like interactive environment using BIM-Based Virtual Reality for Timber Frame Self-Build Housing Sector

## Abstract:

BIM, gamification, and Virtual Reality applications are more often used to serve the interests of DfMA. This paper presents a comprehensive study to exploit these technologies' innovative approaches and capabilities. The study is specifically adopted to implement small and medium-size architectural and construction practices with a limited budget and time dedicated to visualisation creation. The collected evidence proved that a game-like platform combined with BIM could provide simplified data delivery to a client, leading to customer satisfaction, confidence and increased sales. The designed workflow and templates were tested in the case study of a small self-build construction company. The staff was trained to provide BIM data correctly and use supplied game templates. The case study demonstrated that automation of the VR House Configurator creation is achievable. The study's outcome is an integrated solution to regenerate BIM models in the game environment and utilise the house configurator's organised furniture library and costing interface. Furthermore, the usability tests confirmed the applicability, practicability, and validity of the developed framework and tools to deal with the revealed challenges in the self-build sector. Finally, the research provided a fresh approach for the companies in the sector, a step-by-step guide for implementing the innovative changes, and detailed descriptions of the methodologies and workflows.

Keywords:

VR; BIM; Gamification; Integration; design automation; Unreal Engine; parametric design; Collaboration

## 1. Introduction

The Architecture Engineering and Construction (AEC) industry encounters a rising complexity in the design and construction of projects [1] due to the increased number of parties involved in each major venture. It has also been under pressure to improve its productivity, sustainability, and quality. However, the conventional methods and technologies cannot respond to this industry's ever-growing demands. Clients, owners, investors, end-users and facility managers must work efficiently and productively with architects, engineers and contractors to complete a project efficiently and within the estimated time and budget [2]. In various construction scales, the smooth operation of this process necessitates iterative and optimised information exchanges and effective means of communication when trying to convey concepts and principles across various stages of a project life cycle - from financial management through design and spatial planning to operations and maintenance.

In the small and medium enterprises (SME) scale construction sector, bespoke and self-built houses appear to be more popular amongst the clients since they provide an opportunity to save up to 30% on market value and be equipped with high energy efficiency levels and the latest home technologies. Despite this, the Timber Frame Self-

Build Housing (TFSBH) Sector in the UK covers only 7-10% of the market share compared to other housing construction sectors. This number is relatively low compared to other developed countries such as Austria with 80% self-build share, the US with 50% and Canada with 60% self-built share. Although the UK government has recently introduced plans and policies to encourage this type of construction, the problem of complexity of this process awaits resolution on a macro-economic level. Therefore, it is suggested that the kit home manufacturing companies – the core providers in this sector- must considerably contribute to simplifying and popularising the self-build by innovating their workflow.

Therefore, this paper presents a comprehensive study to exploit the potential of digital and emerging technologies in facilitating and optimising the processes of self-built construction in small and medium-size architectural and construction practices with a limited budget and time dedicated to visualisation creation. This study focuses majorly on integrating Building Information Modelling (BIM) and Extended Reality (XR) technologies.

Building Information Modelling (BIM) has quickly gathered momentum for its promise of structure, organisation and efficiency of the work processes and tools. The practicality of documenting and exchanging information, both as metadata and 3D geometry, through unified BIM technologies is superior to the conventional architectural documentation methods in the past, such as orthogonal drawings and specifications. The seminal literature has widely highlighted BIM benefits for architectural, construction, or manufacturing projects [3,4].

While BIM offers great potential to integrate the processes of the entire life cycle of a built asset - from conception through construction and operation, there is an inherent flaw in the structure of this semantically rich modelling technology. The complexity of the technical workflows and processes further limits the possibility of engaging with clients, owners and other non-engineering professionals in the decision-making processes due to the so-called "black-box effect", which refers to a system without transparency.

Despite improvements in orthogonal drawings [5], BIM technologies are primarily designed as management tools or repositories of digital construction documentation, and there are limitations in the 3D information, particularly the visualisation capacities [6]. However, immersive technologies such as Augmented Reality (AR) and VR can offer clients an opportunity to visualise an existing building and walk through it [7]. With such technologies, one can experience design in 3D space, assess indoor factors such as lighting, plan for future maintenance, and decide whether it would meet their needs [8]. However, currently available immersive experience solutions on the market offer only partial opportunities for building design integration; or otherwise require advanced technological skills from the user. As a result, users with no prior advanced training and the necessary hardware are limited in what they can view and achieve with these packages.

This study developed an interface that integrates these two technologies to streamline design processes and provide a comprehensive pared-down BIM system to respond to

and address this functionality gap between BIM and immersive technologies. Furthermore, this interface seeks to be fully agnostic towards the various BIM editing tools that can become a source of input and offer synchronised concurrent user accessibility with low latency to promote active collaboration. Finally, a case study was chosen to validate and indicate the operational principles of a developed Timber Frame Kit Home Manufacturing Companies (TFKHMC) interface. The project is based around offsite manufactured self-build housing, where TFKHMC would present house designs in a virtual environment from their BIM models directly, enabling their clients to walk through a range of customised home features remotely.

The proposed solution can allow small and medium-sized companies to display their new houses during the pre and early construction stages to customers and enable them to interact with the design and propose changes. As such, this can significantly increase the turnover and profit of these companies.

## **2. Conceptual Background**

### **2.1. Self-Build Housing Sector in the UK**

#### **2.1.1. Timber Frame Self-Build Sector Definition and Benefits**

The developer-led private housing sector currently delivers most UK residential homes [9-11]. The final purchaser is typically unknown to the developer throughout the design and construction processes. The developers' short-term relationship with the homes they produce often results in poor quality design and specification decisions. Another continuously reported issue in the UK housing sector is the unmet demand for housing quantity in the UK [12,13] alongside the growing need to address the environmental sustainability of the new homes.

The alternative to the developer-led private housing sector is the self-build housing sector, the form of housing where the first homeowner is involved in its production, either by arranging for its construction or being involved in building it themselves to some degree [14]. Bespoke Offsite Manufactured House Kits in chosen locations also appeal to clients with an opportunity to save up to 30% on market value or optimise budget use[15,16], and equip the house with high energy efficiency levels and the latest home technologies[17]. Clients who undertake a self-build project typically need to accomplish the following tasks: finding a plot, agreeing on house design, cost calculation, attaining planning and building regulations permissions, deciding on finance, project management and others [18]. The Timber Frame Kit Home Manufacturing Companies (TFKHMC) are critical service providers in the sector. They offer a packaged range of services, which frequently include [19,20]: conceptual and technical design, cost optimisation solutions, assistance in attaining relevant planning and building permissions, kit home manufacturing, shipping kit homes to the construction site, customer service and other forms of consultancy. TFKHMC also represents one of the offsite manufacturing providers characterised by manufacturing and assembling building elements, components, and modules in offsite factories and then transporting them to the site for installation [21,22].

The client-defined benefits of Timber Frame Self-Build Sector (TFSBS) that are frequently associated with decision making to self-build fall into various categories: cost-saving; unique/custom design in a chosen location [23]; energy-saving and sustainability [24,25]; opportunities to include the latest homebuilding technology features; relative simplicity for educated clients. The use of prefabricated kits can increase the efficiency of construction activities and the adaptability of buildings [26-28]. Prefabrication is also reported to shorten the overall project schedule, improve product quality, increase onsite safety, and reduce the need for skilled onsite workers, waste, and carbon emissions.

The literature asserts that self-build homes are more environmentally sustainable than homes built by developer-led companies [29,30]. In addition, previous research identified the need to encourage more self-build procurement methods [31,32] as a long-term solution to the low uptake of environmentally sustainable construction practices in the UK housing sector [12,33]. Therefore, developing business models within the construction sector must promote self-build and optimise the house configuration process depending on costing, sustainability, and other factors [34].

Many scholars investigated group self-build projects as a model to transition to zero-carbon homes [12,14,35-39]. While some scholars researched public group opinions, others investigated case studies and key takeaways from the real-time group self-build. All studies have confirmed that the self-build group results in higher energy efficiency, affordability, quality innovation, sustainable communities, and meeting the occupants' needs. The Self-Build Sector (SBS) is less prone to speculation and volatility.

Above all, self-build housing presents a profound opportunity to increase the accessibility of housing to low- and middle-income households. Housing markets in advanced capitalist economies face recurrent crises of supply.

### **2.1.2. TFSBS. Economic and Business Barriers**

Despite the benefits mentioned above, UK TFSBS is relatively small compared to its European and North American counterparts [23]. It is relatively common for people to build their own homes in other countries. The number of self-build projects per year in the UK fluctuates steadily between 10000 to 15000 items [40-42]. The issues in TFSBS in the UK have been thoroughly covered in the literature [18,21,23,40,43-47] and could be classified into two following groups:

- The macro-level of the stagnation factors in the UK is a culture of the supply chain not being customised enough to cater to individual home builder's demands, difficulty in acquiring the land by individuals versus big house developer companies and educating the market about the process of the self-build, attaining mortgage and other governmental policies.
- The micro-level of the problem is thoroughly described in the literature [47], historical perception, entrenched positioning and traditional thinking, lack of supply chain integration, limited availability of bespoke manufacturing plants, skills shortages and, perhaps, most importantly,

171 lack of evidence-based Offsite Construction Manufacturing (OSM) sector  
172 OCMS business models.

173 The research studies conducted with community groups [12] identified common  
174 opinions about the disadvantages of self-build: the difficulty of financing, requirement  
175 for commitment, and difficulty obtaining sites. Scholars also recorded some perceptions  
176 that the 'zero carbon' housing (ZCH) standard was too complex for construction  
177 professionals and, thus, potentially, to a greater extent, for self-builders. The United  
178 Kingdom has been a slow adopter of energy efficiency measures in domestic buildings  
179 [33]. Policymakers have expressed ambitions to ensure that new homes are built to ZCH  
180 standards, but subsequent targets have been abandoned [48]. In the UK housing sector,  
181 the high land costs, the stagnating delivery of affordable new-build homes, and market  
182 dominance by many high-volume housebuilders limit progress towards lower carbon  
183 new-build homes [49,50]. Framed as a socially innovative means of opening up the  
184 demand for technological progress [51], local interventions into market practices,  
185 operating in the shadow of the ZCH policy failure, have actively cultivated this  
186 relationship more intimately, connecting the benefits to be derived from energy-efficient  
187 housing to the people who can enjoy them [36].

188 It can be argued that despite the promising advantages TFSBS can bring to the market  
189 (e.g., cost and timesaving, client-focused design approach), the adoption of TBSBS in the  
190 UK is still reported to be considerably low. The proposed research will narrow the gap in  
191 the sector by conducting a detailed study in numerous BIM Principles, Business and  
192 Sales, Software and Hardware technologies to identify optimal adoption pathways and  
193 the framework that would ultimately raise the sector's profile. The studies have yielded  
194 some important insights on potential self-builders perceived difficulties and  
195 commitment challenges towards the project's initiation. A substantial amount of the  
196 research has focused on identifying the benefits and barriers of self-build housing.  
197 Nevertheless, the only handful of focused studies in the sector harnessed the power of  
198 BIM/Game technologies to breach the gap between potential self-builders and TFKHMC  
199 as the guides, consultants and supply chain representatives for effective self-build  
200 projects.

## 201 2.2. BIM Configuration Variables in Self-Build Sector

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203 The impact of BIM on design can mostly be detected in the conceptual phase [52] of a  
204 project as it supports greater integration and better feedback for early design decisions:  
205 embedding energy efficiency parameters during the design[44,53]; assessing a wide  
206 range of construction options and their embodied environmental impact[54,55]. It  
207 involves the construction level modelling, including detailing, specifications and cost  
208 estimation, then the integration of engineering services and supporting new information  
209 workflows, and last but not least collaborative design-construction integration [56,57].  
210 The research findings identify methods for simplifying the geometry module and  
211 transliterating it from an architectural or structural modelling paradigm into an idiomatic  
212 thermal analysis model[58]. The findings also establish a BIM-based database capable of  
213 handling BIM-based data from multiple design tools [59]. Integrating disciplines and  
214 stages in design and construction activities is a key aim of major projects and an  
215 underlying theme of integrated approaches to project delivery [60-62]. The vital

challenge of today for BIM impact is striking a balance between zero-carbon goals and the demand for new houses [63-65].

Accurate and timely cost feedback is critical for design decision-making on building construction projects. This is a significant challenge for estimators in the early design phases as they must create detailed and accurate cost estimates [66,67]. Unlike broad public and commercial architectural projects, small residential projects have a limited timescale and budget for the visualisation of each project. However, repetition and similarity in each cycle are excellent for generative design and developing a framework for collaborative design knowledge [57].

### **2.3. Applications of XR technologies for BIM**

The number of studies applying the XR technologies for BIM has increased in recent years due to technological growth and increased interoperability of the BIM software with game engines. Many studies focused on the application of XR technologies in the conceptual stages of the project; others were mostly focused on construction workspace planning. One of the novelty studies incorporated VR technologies into energy analysis studies. The literature review findings adjacent to TFSBS are laid out below.

Researchers emphasised the need for collaborative and multiuser VR experiences in construction and architectural design [68,69]. Instead, scientists experimented with conceptual prototyping design, the flow of data from an authoring tool to a visualisation environment, and participatory decision-making [68,70,71]. This paper has analysed the research mentioned above, and the findings are presented in the framework.

Effective workspace planning is crucial in site planning and construction activity scheduling, particularly in the TFSBS area. Therefore, research was conducted to enhance the usual manual workspace planning process by simulating a construction activity using VR and BIM technologies [35].

With the government's policies stepping in to encourage self-building, the companies need to increase their competitiveness by providing efficient workflow and clear communication with clients using the latest digital technologies. End-users, who make buying decisions to self-build, often have little or no knowledge of the construction industry. Therefore, they face significant challenges in communication with professionals regarding spatial awareness, visualising technical drawings and understanding the construction process. For many architectural and construction practices in the UK's TFSBS, email's the primary communication medium with clients. This results in an increased number of iterations per project lifecycle, leading to difficulties in interoperability among designers, manufacturers, and builders. XR technologies are widely acknowledged as aids for clients and professionals in a more productive interaction. Game technologies have also been recognised to be effective in resolving problems in science and business. However, designing data-rich Virtual Reality Environments (VREs) to enhance clients' spatial understanding of the solution spaces and leverage integration across the BIM process are still unique challenges. Business and technical key performance indicators and conceptual and methodological frameworks are developed for adopting BIM principles and emerging game-like XR technologies to

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263 Operations.

264 Davila Delgado *et al.* [72] suggest that the application of MR technologies in design  
265 processes is beneficial mainly for the following four reasons; Improving companies'  
266 image; Improving overall performance in projects, and enhancing companies' corporate  
267 performance by bolstering research and development. This is mainly due to the ability  
268 of this technology to improve interoperability and standardisation of design and delivery  
269 processes by facilitating coordination and collaboration among teams [73], facilitating  
270 the monitoring and controlling of processes [74], and supporting information and data  
271 visualisation, and supporting the various design and building simulations [75].

272 Using such technologies during design processes leads to enhanced decision making,  
273 increased efficient and effective problem-solving actions, improved design alterations,  
274 and enhanced quality of visual presentations. This, in turn, results in a more efficient  
275 resource allocation, enhanced planning and building resources, processes and materials,  
276 and hence reduces the overall time and cost of the project's life cycle. Furthermore, the  
277 application of XR reduces the inefficiencies of data and information overload, which  
278 results in improved information absorption and better comprehension of the project.  
279 This will reduce labour cost and overall project time by reducing errors and rework and  
280 improving time management [72,76-81].

281 During building and construction processes, XR technologies can be extremely helpful by  
282 reducing workers' cognitive workload during various building and assembly tasks. It also  
283 reduces the time spent on building component selection and assembly processes and  
284 operations by augmenting images and the ambient environment illustrated in the  
285 relevant devices [80,82-86]. As suggested by Hou *et al.* [82], using XR during building and  
286 assembly tasks can “lend credence to dimension comparison and position  
287 determination, [and therefore] the time of component selection and assembly can be  
288 significantly shortened, and assembly errors can be effectively decreased” (p. 05014007-  
289 3). Similar to the design stage, using this technology in the building stages can enhance  
290 collaboration and improve information retrieval and interoperation between various  
291 technologies and human and guiding mediums. Integrating virtual objects into a real  
292 environment and virtually simulating prototypes into real scenes allows workers to  
293 access practical information. This, in turn, results in increased workers' perception of  
294 their surrounding environment and the task to be completed. More precisely, the  
295 application of XR in building tasks and processes increases the overall projects  
296 productivity/efficiency by decreasing search and reading times, the time needed for task  
297 completion, reducing the number of errors and therefore reworks, decreasing physical  
298 demands such as head and eye movements and mental transformation required in  
299 building and assembly tasks. Decreasing workers' cognitive workload could be  
300 underlined as the main advantage of XR application in building processes, which reduces  
301 time and budget spent on a project and reduces the overall waste of resources and  
302 embodied energy [79,80,83,87,88].

Therefore, MR technology can offer a step-change in the design and construction sector productivity by reducing the project's overall cost and time spent on a project lifecycle. But, more importantly, they increase project sustainability By reducing work, rework, and energy and resources used in a project, decreasing the carbon footprint and pollution [72,89,90].

#### 2.4. Research gap and motivation

Table 1 lists key published papers implementing VR technologies in real estate. It can be seen that most of the applications and existing research focused on using commercial packages to employ VR and AR in real estate. However, there are no specific and deep applications for the Self-Build Housing Sector and clients in this sector do not have extensive experience to provide clear requirements. As such, advanced BIM and VR research is highly needed to foster the adoption of VR with BIM in the Self-Build Housing Sector.

Table 1. Research gap and motivation

Author	Focus of study	Limitation
Brenner [91]	Conducting several experiments to employ virtual reality to enable home buyers to decide whether to visit the house or not.	The scope of the research only focused on residential real estate, specifically on staging
Pleyers and Poncin [92]	Employing Non-immersive virtual reality technologies in real estate	The outcome of the properties focused on visual information, and there was an issue with displaying the type of factual information that is included in real estate advertisements.
[93]	Presents a case study to implement Virtual Reality for Real Estate (VR4RE)	The Advanced BIM model should enable decision-makers to buy or sell before construction.
Lang and Sittler [94]	Employing different Augmented Reality (AR) applications in the real estate field	The solution was not developed to cover specific types of buildings, and there was no specific developed AR environment.



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<b>Mahpour and Akabri [95]</b>	Exploring the impact of virtual reality on Consumer Behavioral Intention in the Real Estate Industry	The outcome should be implemented in a real-life case study
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### 3. Research methods

To achieve the objectives of this study, the current state of TFSBS within the UK housing industry was investigated, and the key potentials and barriers of adopting BIM principles to support TFSBS within the UK housing industry were identified using various methods including literature review, workshops, and ethnographic study.

Exploratory theoretical research was a primary method for achieving the literature review, including the following directions:

- TFSBS process and issues slowing down the industry;
- BIM principles applicable to TFSBS VR technology as a sales tool in architecture and construction;
- review of significant hardware and software technology enablers for future VR software.

The industry research entailed identifying the structure of the companies in the sector and analysing product catalogues and detailed product libraries. Furthermore, by reviewing the literature, a BIM-based VR solution is needed to facilitate better communication between professionals and clients and leverage the integration of their work procedures to optimise the design and contribute to saving labour, cost, and time. Finally, comprising the results achieved, the author estimated the target Key Performance Indicators (KPIs) of a future project lifecycle length and the ratio of closing the deal per number of client cases.

The qualitative data was collected through discussion with industry partners and academic professionals aiming at:

- capturing current business systems and staff capabilities relevant to the project;
- identifying and exploring existing design platforms and visualisation tools currently used in the sector as the baseline situation that can be referred to in the future business cases to help map out infrastructure, compatibility, and cost issues involved in future developments;
- developing an initial product database and matrix and acquiring an understanding of the common parameters of each product and detail and Service Order Records;
- working with the detailed drawings and technical aspects of TFSBS's products;
- Investigating the potentials and barriers of adopting immersive technologies to support TFSBS within the UK housing industry.

The results were then used to develop a framework for improving marketing and technical operations within the TFSBS housing sector by applying integrated XR and BIM technologies. In developing such a framework, it is essential to develop relations precisely, data and follow

models (using Unified Modelling Language UML) to present an overview of the system in machine vision. All objects, users, system behaviour and their relations are defined in these models in a diagrammatic way. Using UML models with an iterative software development approach in each step (prototype and final version development) will accelerate the development process by enabling amendments to the models' interfaces, algorithms and codes in an interactive manner. Moreover, dealing with a large data set of BIM models and noting that the final software application targets the mobile platforms, it is crucial to carefully design the mobile/server process models to prevent latency, lag and high load in devices. The author assessed the hardware related issues (e.g. accuracy and accessibility, the interaction of users with VR/Mobile interfaces) as another challenge that must be considered in designing the user interface of final virtual showrooms. Special attention was also given to identifying what drawings, project data, sales information, and design documents were needed to access the project and gain a brief overview of potential application algorithms.

The software design process is iterative [96]. However, the author followed a structured design methodology to develop design alternatives and employed a design rationale model to meet the specification requirements. This study designed a developmental framework and integration strategy for a Game-Like VR Showroom environment using the latest hardware and software technologies and enabling multi-criteria optimisation. This process includes data representation, object classification and hierarchy (behaviour/structure/relationship), Unified Modelling Language (UML) methodology, BIM compliance and metadata rubrics (See figure 1).

In the first stage of the application development lifecycle, the project establishes the requirements and priorities represented in an ontological structure. This activity thoroughly discusses experiment participants' scope, constraints, and system requirements.

The next step is designing a prototype, which allows users to interact with systems and develop models representing processes, inputs and outputs. This step includes architectural design, preliminary user interface and application behaviour design, code development, verification and validation, including developing the environment through an optimised everyday data environment matched to the archiving strategy. This stage will include the development of entity relation, data flow and object models using UML. The generic structure and content for the VR objects are then formulated.

The next step is designing a prototype, allowing users to interact with systems and develop models representing processes, inputs and outputs. This step includes architectural design, preliminary user interface and application behaviour design, code development, verification and validation, including developing the environment through an optimised everyday data environment matched to the archiving strategy. This stage will include the development of entity relation, data flow and object models using UML. The generic structure and content for the VR objects are then formulated. After that, Software Usability KPI will measure the overall performance of the software. The product improvements KPIs will measure the Timber Frame Kit Home (TFKH) improvements achieved due to VR software interaction. Finally, the prototype is tested in different stages, the first stage after developing 'Virtual Showhome' and after accomplishing the development of the prototype. The usability tests will measure these KPIs by asking participants to evaluate the proposed solutions against these KPIs. Although the literature review covered a number of the KPIs in this section, only three of them were

selected, which are most relevant to the project. The third group of the KPIs, Business Benefits, will demonstrate values achieved for business due to VR Software. The detail of these KPIs is presented in Table 2.

**Table 2. Collected Study KPIs and Their Categories, Adopted from [97,98]**

Software Usability KPIs		Product Improvement KPIs [99,100]		Business Value KPIs [101]	
<b>AVC</b>	Audial and Visual Cues [102]	<b>MO</b>	Materials Optimisation	<b>CO</b>	Cost Optimisation
<b>FR</b>	Frame Rate [103]	<b>SO</b>	Spatial Optimisation	<b>LO</b>	Labour Optimisation
<b>FOV</b>	Field of View [104]	<b>ZCH</b>	Zero Carbon Housing	<b>SLI</b>	Sales Increase
<b>LOD</b>	Level of Detail [105]			<b>TO</b>	Time Optimisation
<b>OLL</b>	Optimisation and Low Latency [106]				
<b>SP</b>	Sense of Presence [107]				
<b>SU</b>	Spatial Understanding [108]				
<b>UX</b>	User Experience, Ease of User Experience [109]				
<b>VF</b>	Visual Fidelity [110]				
<b>VI</b>	Viewer Immersion [110]				

Applying agile software development methodology, the first group of prototyping stages focuses on client-designer/salesperson interactions, providing optimal interface and visual perception. The second consequent group of prototypes focuses on OpenBIM Principles

integration. Finally, software development cycles examine the fastest routes possible at current technology development for in-House VR software tools and reach out to geographically remote clientele via mobile devices and necessary VR hardware.

In this stage, BIM compatibility is added to the developed application. The Interface module between the mobile application and Industry Foundation Classes (IFC) is developed, and interoperability is assured. Afterwards, the interface is enhanced to integrate information representation and reporting capabilities with the VR model. The final application will be capable of inserting IFC models into the VR environment and provide users with full integration of semantically rich building information with VR models. Users can:

- navigate the VR environment easily with mobile devices and in-house software;
- integrate them with the physical environment and existing objects (as well as manipulate interior design options to measure the room sizes);
- see how they would fit their prospective house, as well as customising layout, building components, and materials and see results in real-time;
- This also includes how space will look and perform and the other consequences of changes, such as changes in the project budget, energy performance, and completion time.

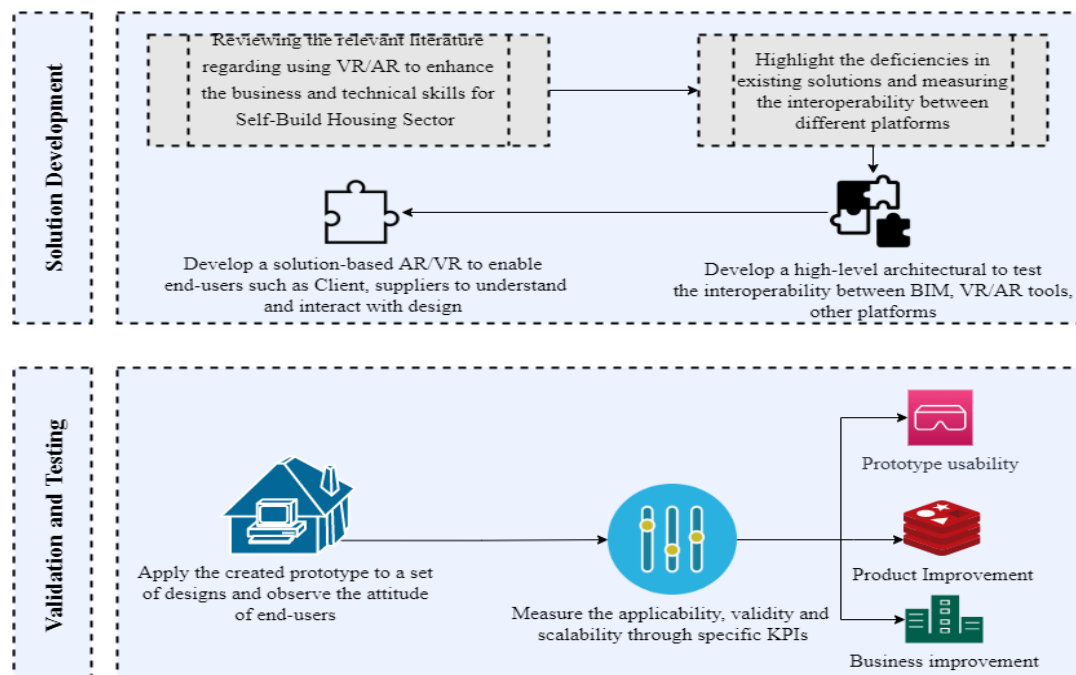


Figure 1. Research methods and logic.

The empirical evidence confirms a literature review on the superior quality of the Oculus VR (Rift, Quest) and HTC Vive/Vive Pro headsets compared to other VR Headsets. As a result, it was established that future VR software would be developed for the above-selected platforms. Robust interoperability workflows are essential to support the fast-pasted decision-making process and efficient estimations. Therefore, as a part of the prototyping stage, various workflows were tested to identify the best solution and software to support small and medium-sized companies.

After detailed consideration and study of various software features including Revit, Bentley, Vectorworks, IFC, and game engines including Unreal Engine 4 and Unity, Autodesk Revit and Unreal Engine 4 were selected as the primary tools for this study. This was predominantly due to the wide range of available scripts and packages for Unreal and the progressive popularity of this engine within the gaming industry. Moreover, Autodesk Revit is a widely employed application within the BIM industry. Besides, all model houses used here as study cases were thoroughly modelled in Revit previously. Finally, several libraries are available to support input and output between Revit and Unreal engine.

The comprehensive literature review stage has established the associations between Mass customisation (MC), product configurators, BIM and the latest software and hardware capabilities intending to investigate the effective deployment of the adaptive customisation approach in the Self-Build Sector.

The Agile Software Development Methodology (ASDM) is significantly more flexible than the traditional linear waterfall workflow. It is characterised by multiple iterations and empirical studies cycles to test the ideas and solutions. Figure 2 demonstrates the common ASDM cycle and prototyping stages. ASDM works well when the outcome vision or features are not fully defined. ASDM allows software development management to adjust requirements and priorities to take advantage of opportunities and ultimately deliver a better product to all the project stakeholders. The prototyping stages were focused on client-salesperson interactions and VF, SP, OLL, SU and other KPIs of the kit homes virtual space. The collected usability tests helped analyse feedback on improving the interface and suggesting additional functionality for the next stages. The final prototype was developed during the final stage, which presented a proof of concept house configurator using BIM variables and validated test results.

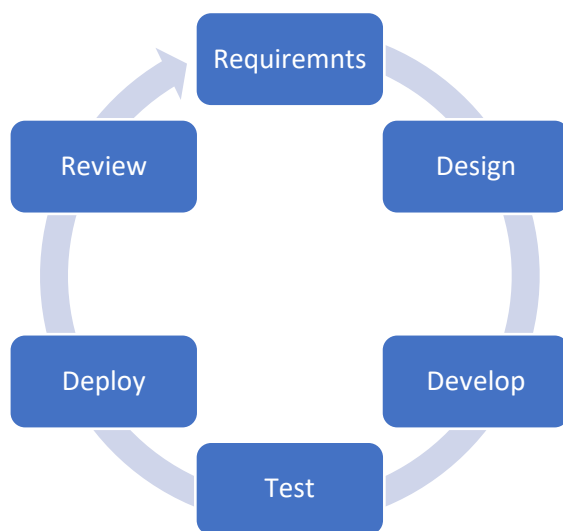


Figure 2. The common ASDM cycle and prototyping stages.

The wide spectrum of the KPIs could be classified into three groups, namely, Software Usability, Product Improvements, Business Benefits.

## 4. Solution development

In this study each prototyping stage was divided into three steps: (1) requirements, (2) design/develop, (3) test/deploy/review => new requirements. The process is described below.

### 4.1. Prototyping Stage 1 "Virtual Showhome"

#### 4.1.1. Requirements.

The author used one of the smallest and most commonly used TFKH to enable fast prototyping for prototype one. The chosen two-bedroom design is widely used for holiday homes or two-person households and has various options for extension ( see Figure 3). The primary objectives for this prototyping stage were to test some of the available BIM interoperability formants with the game engine software have VR walkthrough functionality and interactive objects.

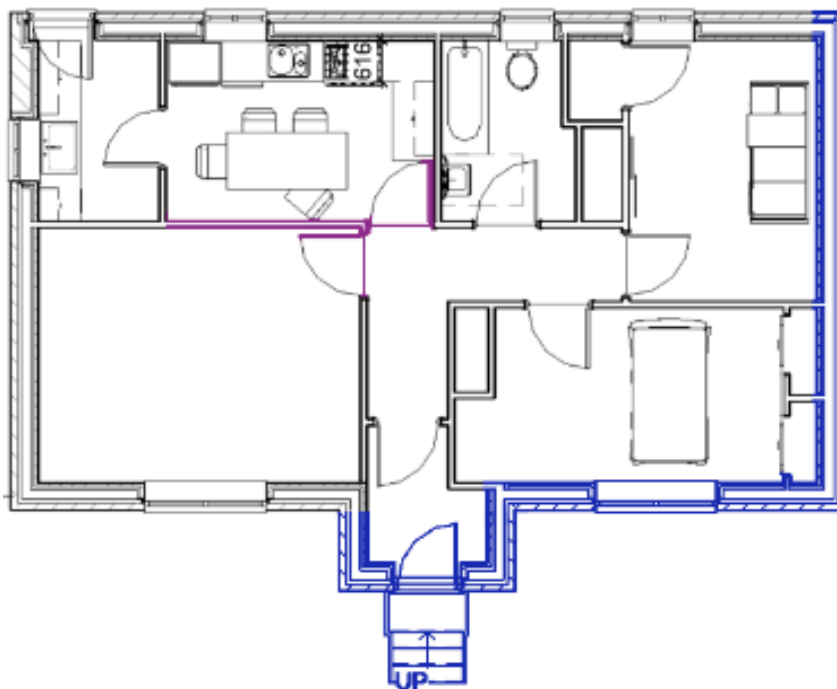


Figure 3. Virtual Showhome Floor Plan

#### 4.1.2. Design/Develop.

The original BIM model was remodelled in Autodesk Revit using linked Autodesk AutoCAD files. The tested interoperability workflows included: Revit(.fbx) =>game engine; Revit(.ifc) =>game engine; Revit (linked file import) => 3DS Max(.fbx) =>game engine. Each of the described

workflows has demonstrated some form of data loss, the need for manual object placement into correct positions, and some forms of 3D object distortion due to tessellation and triangulation. As a result, manual model adjustments using 3DS Max were required to improve the visual perception of the models. Lastly, the prototype was developed using the HTC Vive VR headset. The experience included a teleportation interface, picking up and moving furniture, opening and closing doors, and reflective mirrors. Figure 4 shows the virtual Showhome of the floor plan.

#### 4.1.3. Test/Deploy/Review.

Initially, 75 usability tests were conducted. As a result, 32% of the participants were classified as frequent game players, the other 35% were classified as potential clients, and construction industry professionals represented the remaining 33%. The test BIM model was a frequently purchased house template for a holiday home design. The typical house customisations highlighted by previous clients were removing the wall between the living room and the kitchen (highlighted in the image in purple), bedroom extensions, and the entrance space's size (highlighted in the image in blue). In addition, the users suggested the capability of viewing the common design extension variations.

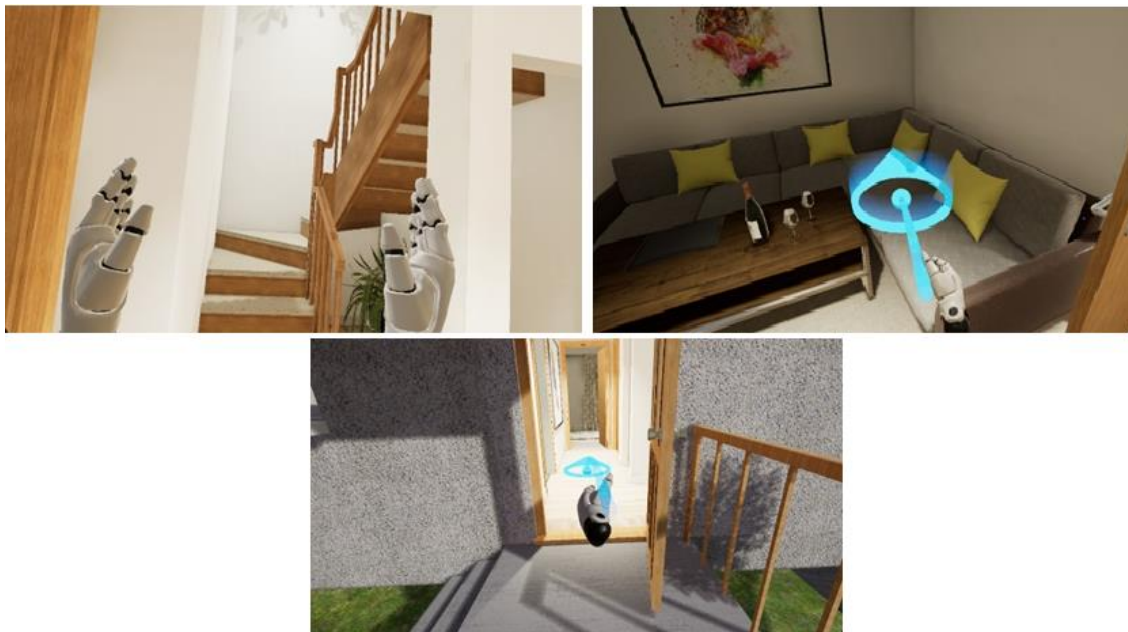


Figure 4. The virtual Showhome.

#### 4.2. Prototyping Stage 2: Virtual Showhome and design variables, metadata demonstration

#### 4.2.1. Requirements

"The exhibition template" VR experience was proposed for development to respond to the gamification of the interaction of the first point of contact with the client and application of 'B2B'(conversion browser to the buyer) techniques in VR. Other requirements included testing the various options of teleport menu UI to support the user's orientation and navigation in virtual space; testing various options of internal design representation to support the user's spatial perception; selecting one of the BIM variables, and testing as a proof-of-concept prototype for future house configurator; demonstration of the metadata from Autodesk Revit model at software runtime.

#### 4.2.2. Design/Develop

Three new BIM models were placed in the interactive game environment for this stage. As a result, each virtual show home had a different teleport menu system, as presented in Figure 5. Before the development, several VR architectural walkthroughs and gaming experiences [111,112] were tested to propose various teleport menu styles (see figure 6 for the script). Figure 5 shows the following points:

1. Motion controller attached floor plan. When clicked on the grip button, the left motion controller had the teleport menu enabled and other variables in the house. By clicking with the right hand (right motion controller) on the red targets on the floor plan, the user was teleported to the corresponding location in the house.
2. Image-based teleport menu. The Teleport location UI was placed around the house in images of the next location options. For example, to teleport upstairs, the user would need to click the image with an upstairs landing. Users were also provided with a button to return to support those who started feeling disoriented in virtual space. This method has given the user opportunity to follow a narrative path created by the developer.
3. The third teleport system was automatically assembled in the UI by placing in the model scene bookmark actors(scripts) and giving each actor a location name. The users could then select each name from the UI list to teleport to the desired location.
4. For the users, who preferred to be guided by the sequence of locations guided by a consultant (designer; salesperson), the teleport keyboard shortcuts were created, so the person who supervises the user in a VR experience could override her teleports by using the keyboard. For example, to teleport to the kitchen, a consultant would need to click k; bedroom 1 – 1; back yard – b; u – utility and others.



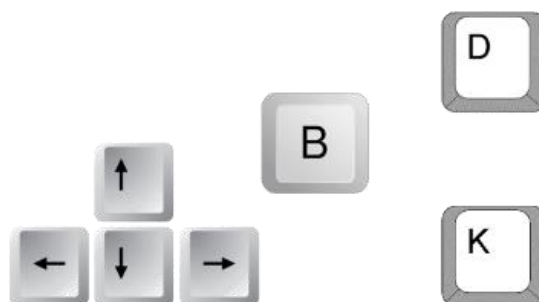


Figure 5. Teleport menu systems left to right: (1) motion-controller-attached 2D floor plan with teleport locations, (2) location-based menus with images of teleport options and return to start button, (3) scroll menu with room names and teleport destinations. In addition, (4) keyboard shortcuts for teleport locations were created to be used by sales consultants outside VR experience to assist participants teleportation in VR.

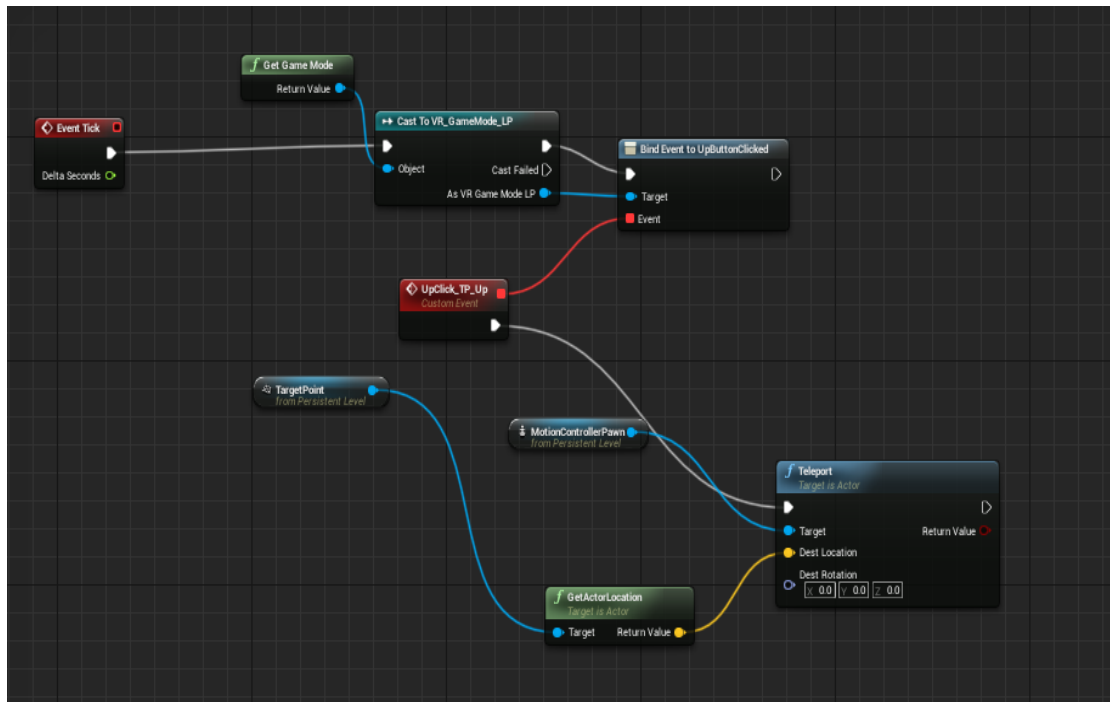


Figure 6. Menu Setup for Left Controller. Setting up teleport locations in Level Blueprint.

Due to the KPIs results from the collected data during the workshops in the previous prototype, the users found that moving each piece was cumbersome. Therefore, the new method is developed to include: firstly, the size of the bed was chosen as a variable. Then, the bed size was controlled by UI, which helped users to decide if further extensions of the house were needed by placing the desired size of the bed in the room and estimating the remaining void (see figure 7).

The evidence suggests that each room in the BIM model could be used for various purposes (study; bedroom; snug). Therefore, interior UI various furniture sets were created for each room, and context-based 3D widgets were used to switch from one interior option to another and an empty room. Also, the size-changing bed UI was proposed for each bedroom to determine which bed size would fit in a room in correlation with a remaining void and if further room extensions were required. The UI script is presented in figure 8.

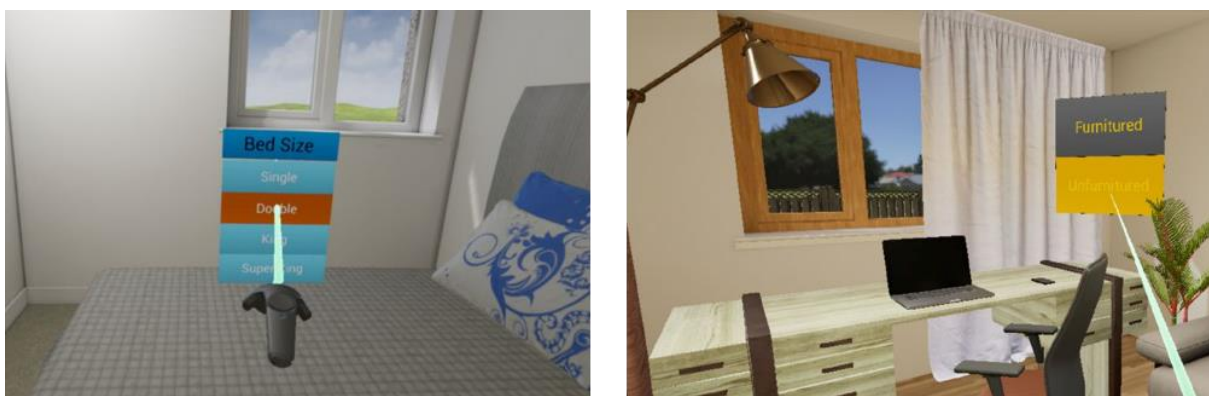


Figure 7. Interior UI prototyping. Left to right: (1) Changing size bed UI; (2) UI for adding and removing a room furniture.

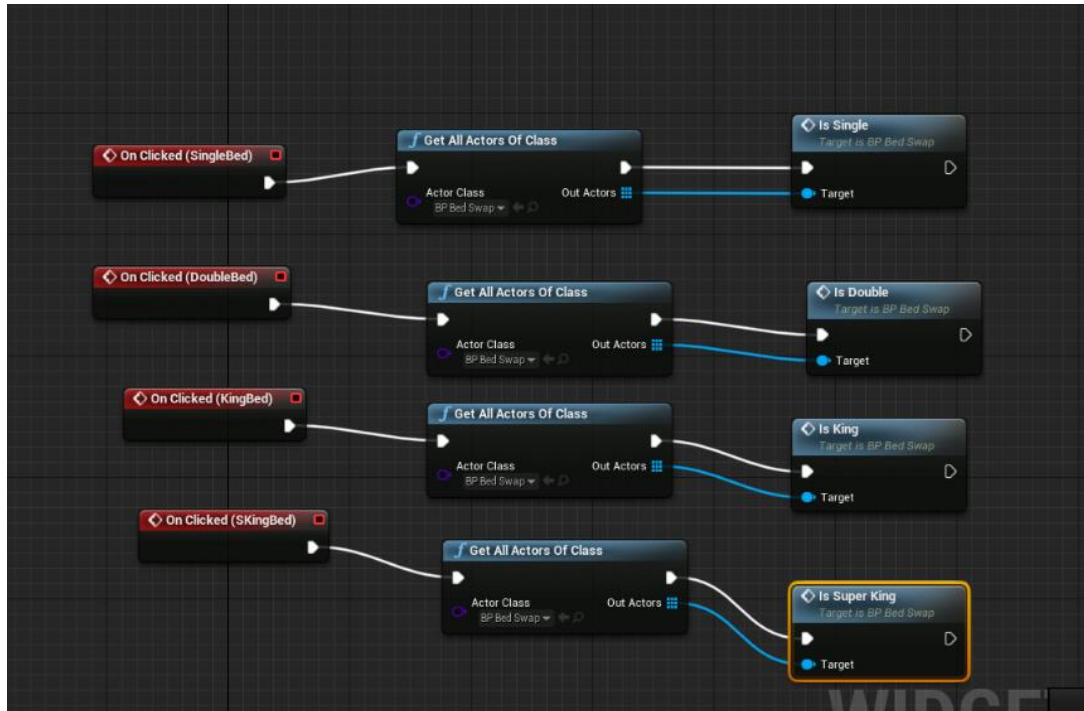


Figure 8. The UI Script for Bed Sizes

650 For the proof-of-concept BIM variable, Norscot interior door designs selection was used.  
 651 The sales algorithm for door selection was examined. The door changing variables  
 652 included style, material, and matching glass door design. The door metadata was  
 653 carefully studied, and the pathways of utilising metadata for quantification filtering were  
 654 suggested (see figures 9, 10 and 11)

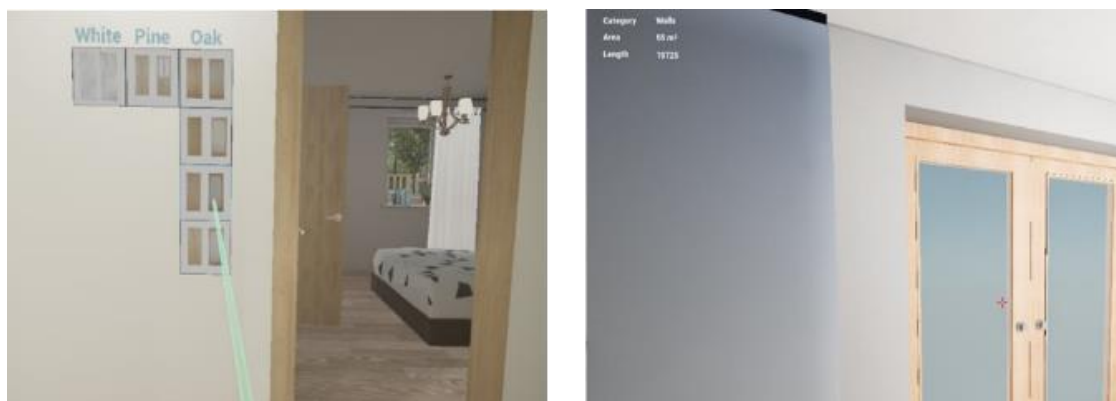
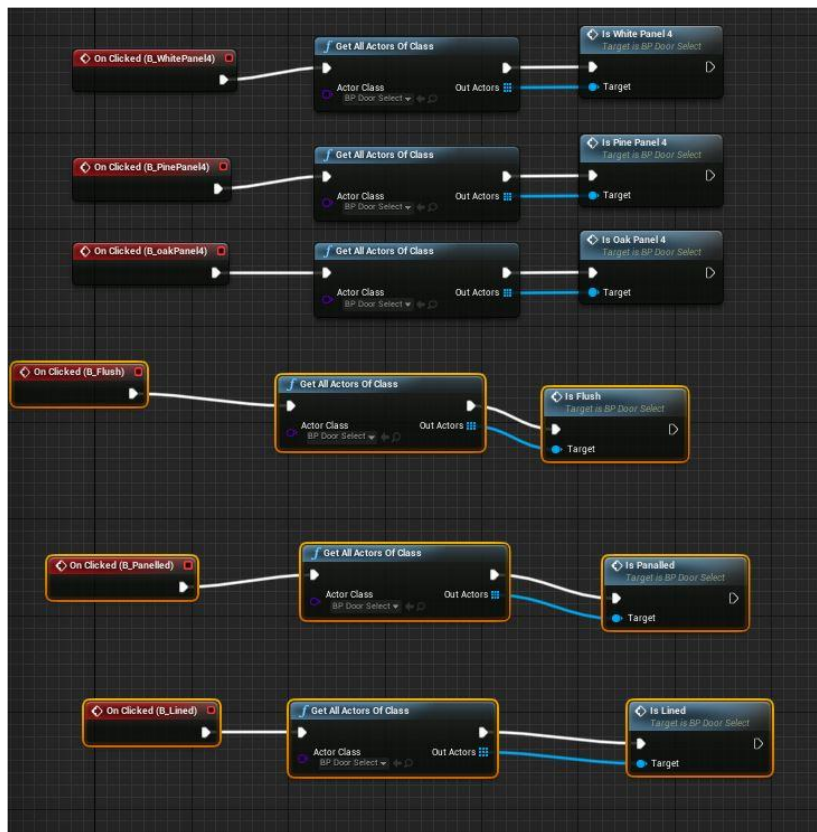
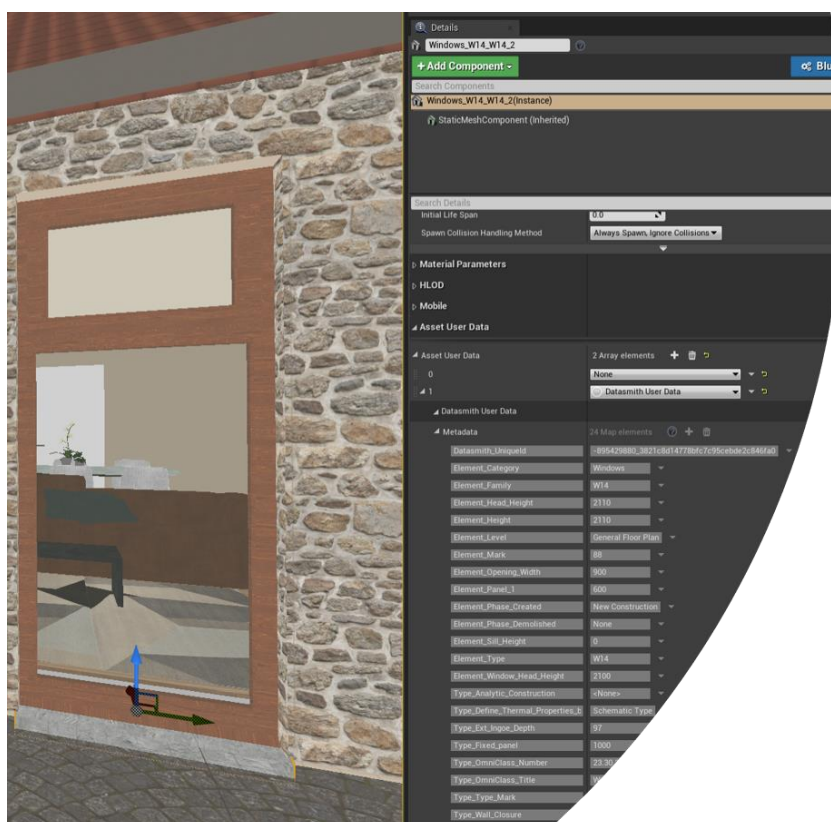


Figure 9. Door Interface (2) Metadata Extraction Example

668 Image one demonstrates the first version of the door changing script that allows users to  
 669 choose a preferred style for all the doors in the house and select matching glass doors for the  
 670 kitchen and living room. Image two demonstrates exposing metadata at run time when right-  
 671 clicking on each BIM Object chosen. Figure 10 demonstrates core scripting logic for setting up  
 672 door configurations, while Figure 11 presented example metadata for a window received from  
 673 Revit in Unreal Engine via Datasmith plugin.



675  
676 Figure 10. UI Logic for Door Swap Script.



677  
678 Figure 11. Example Metadata for Selected Window.

### 4.2.3. Usability Test

The usability tests for this stage included two kit home design cases with clients; 7 Norscot design and sales professionals and 95 industry professionals and peers. In summary, teleport location menus significantly improved the sense of direction in VR space. The scroll menu enabled an alphabetical search of the locations. The floor plan menu helped life project clients establish a connection between the floor plan and actual space. Additional images with the locations helped clients navigate to previous locations and the start point. The keyboard shortcuts were effectively used to aid the users in the VR experience. Ideally, all four teleport menu types should be included in the VR experience. Hypothetically, due to the limited time scale and workforce available in the experiment, adding all four elements to each new design would be challenging. Using furniture as a space measurement tool has proven useful in life projects.

The clients were able to judge effectively if extension or downsizing was required. The proof-of-concept door interface was useful in presenting the company door range; however, further, development was required and connection with costing data and metadata filtering. The construction specialists suggested exposing only metadata for the BIM objects that would directly influence the price of the final kit home. One of the common repetitive workflows included interior objects and decorations in the scene, garden creation and lighting scenarios. A pre-made optimised sublevels library should be suggested. Further effort was required to create a universal and dynamic UI with less customisation for each new design.

## 4.3. Prototyping stage 3. House Configurator

### 4.3.1. Requirements.

The house configurator utilised knowledge and experience developed in previous prototyping stages and was focused on automating repetitive workflows and utilising quantification and costing data. The sub-level library was required to minimise repetition.

### 4.3.2. Design/Develop.

The house configurator was developed using Unreal Engine 4 Collaboration Viewer Template[113] with extended functionality added to meet previous research requirements, as shown in figure 12.

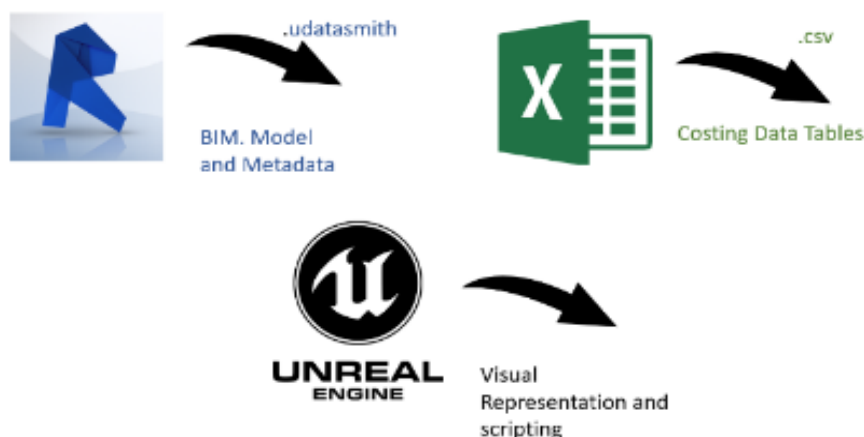


Figure 12. House Configurator Data Flow Elements





The first row demonstrates variables for the façade of the Nisbet house template. These were scripted using Unreal Variant Manager. The second row demonstrates the lighting scenario change from day to evening. Two lighting scenarios were created at different levels and added using the level streaming manager. The UI widget switched controls from one lighting scenario to another. Row three demonstrates the exterior garden setup; similar to lighting scenarios, the exterior setups were brought into persistent level via level streaming and switching controlled using developed UI. The first two images in the row consist of 3D models and landscapes. The third example in the row presents 360 images that enveloped the house. These present a proof of concept, where 360 images from the construction site are brought into a virtual environment to make decisions on house rotation and window views. This solution presents a basic solution and a rough estimate. The complex and precise solution would entail bringing the topographical 3D model into virtual space, modifying the house template to adjust it to the real-life landscape, and adding the scene's views using point cloud data. All these tasks are currently supported inside of Unreal Engine 4. However, this would be a lengthy and cost-ineffective solution compared to the cost of an average project.

Furthermore, the precise model creation could be produced on request for a client at an additional price. However, as a rule, the majority of the clients would agree that a rough estimate was sufficient. For example, rows four and five of the image above correspond to window and roof material swap scripted using Unreal Variant Manager.

In addition, the script was created for interior and exterior doors configuration. The doors were swapped using the automated recipe, and a scripted door interface was automatically added to the 3D view and user interface. The script utilised a data table with the company's door pricing figures (see figure 15).



Figure 15. (Row 1) Bedroom Furniture Swap; (Row2) Snug Furniture Swap.

#### 4.1.1. Solution performance

After checking The usability of the proposed solution by involving seven staff members from the design and sales team and 95 industry professionals and peers and receiving their feedback. The prototype is improved, as shown in sections 4.3.1 and 4.3.2. Another round of testing the solution was conducted to study the staff members' ease of modification of the template. Ten days of training were presented to 5 staff members with the previous skillset in

architecture and drafting. After training was completed, the staff members could customise the template independently, and each house configurator took, on average, 4 hours to complete. The review by peers and staff members has shown users are more comfortable navigating in desktop mode and switching to VR once changes are implemented. In addition, exploring different BIM quantification variables was suggested, such as window materials and house extensions (see Figure 16). Table 3 shows the Software Performance KPIs summary based on the usability two-stages test.

Table 3: Summary of the Software Performance KPIs

KPIs groups	Abbreviation	Full-Form	Outcome
<b>Design and construction optimisation indicators</b>	CO	Cost Optimisation	The prototype has been tested on 15 BIM models created for real-life cases. Each BIM model placed in VR enabled the design team to identify other errors and clashes and change requests by clients. As a result, average cost optimisation improvements due to error detection amounted to 6%.
	ZCH	Zero Carbon Housing	To summarise, the KPIs mentioned above contributed to improvements in ZCH due to increased SO, SU, CO and others.
	MO	Materials Optimisation	The UI delivered method for configuring exterior roof, façade and window materials. The clients and design team could browse various combinations to optimise the choice. 100% of tested BIM professionals and clients had found this feature useful for making design decisions.
	SO	Spatial Optimisation	70% of users tested could make more detailed changes(room size change, windows and doors positions) in the BIM model after interaction with a digital model.
	TO	Time Optimisation	This KPI will be tested in the case study
<b>Enhancing visualisation and decision-</b>	FOV	Field of View	The field of view remained the same across all prototypes as all of them were tested using the same HTC Vive



making for end-users indicators	FR	Frame Rate	The average framerate in VR was 130 frame rates per second, while the standard 60 frames per second in the first-person mode. All users have found the VR experience comfortable and did not experience delays.
	LOD	Level of Detail	All parts of the BIM model were presented at the original level of detail. The visualisation models (interior and exterior) utilised Unreal Engine LOD scripts that render different detail-level models depending on user proximity to the object. This was one of the provided methods to optimise the frame rate.
	SP	Sense of Presence	100% of testers demonstrated an increased sense of presence while interacting with a digital model
	SU	Spatial Understanding	100% of testers reported significant improvement in spatial understanding of the BIM model after interaction with the digital model.
	VF	Visual Fidelity	80% of the BIM professionals confirmed the high level of model visual fidelity; others suggested some improvements due to the lighting quality of the model.
	VI	Viewer Immersion	The prototypes released in the two previous stages were more immersive due to engaging gravity and physics. However, the level of immersion was not the priority at this stage due to the different stages of the sales process in which this prototype would be used.
	UX	User Experience, Ease of User Experience	the users have found earlier prototypes easier, 50%, and more user-friendly as the variety of the new UI variables made it more complex for them to interact with.
	AVC	Audial and Visual Cues-	The prototype provided visual cues by presenting floor plan UI and a list of teleport locations.

<u>Income indicator</u>	<u>SLI</u>	Sales Increase	The case study will further investigate this KPI and its implications for practice.
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Figure 16. End-User Testing Results.

## 5. Discussions

A broad range of literature was reviewed, focusing on the British market of TFSBS. The statistical information was used for England on the number of SBS projects per year and the industry's digitalisation level. The literature review additionally covered TFSBS economic and business barriers in the region. It also briefly stipulated ZCH practices and the potential to improve these aspects depending on the application of XR technologies. The reviewed literature suggested that the significant barrier to application XR in TFSBS has been interoperability in various vendor software packages and game engines. The above-described gap in the literature and the need to develop practical frameworks and empirical studies to narrow this gap were highlighted in this study.

Furthermore, the literature examined BIM variables actively participating in the product-house kit configurations. To instigate the results, the authors researched the adjacent literature on mass customisation of various products and the possibility of adopting collaborative and adaptive approaches to customisation. Integrating BIM, gaming and immersive technologies create an interactive user experience allowing them to interrogate their home design, picture it on their site, and initiate changes whilst understanding their impact on manufacturing, construction and assembly, lifecycle maintenance, and running costs. On the other hand, integrating VR, WebVR, and 360 CGI and making them work together can enhance the user experience and increase the opportunity to comprehend the design.

This study developed a framework to interoperate XR and BIM technologies. The underlying theory stated that applying the XR+BIM technologies in TFSBS would simplify data delivery to the client, increase customer satisfaction, and increase sales. The methodology chapter describes the methods for proving underlining theories and agile prototyping methods to iteratively adapt the framework to the technological growth and development proposals from peer and client reviews.

The prototyping of the proposed solution was divided into different agile development stages to fulfil the aim of the study. The developed software and automation scripts were presented to the design team in the selected case study. The case study focused on the adoption of existing software to the company's needs. Adopted automated workflow was tested with staff

members. During the described period, they received training on using automated templates in their workflow, and 6 Interactive kit homes BIM models were built with the supervision and instructions from the author. The proposed conceptual solution was validated by putting it to a real-world test. The Interactive BIM Model with House Kit "Nisbet" was demonstrated to the client in VR. The floor plan drawing seemed to be completed, in the client's opinion. However, when the model was placed in the VR in a simplified data delivery format, several more changes appeared to be needed in the model: repositioning the windows and reducing the size of the living room. This ultimately helped the customer save more money and agree to the final purchase.

The solution provided in this paper enables TFKHMC to develop a better understanding of the emerging digital technologies to increase efficiency and improve services to clients. The TFKHMC was challenged to create a fully immersive and photorealistic Virtual Showhome for Company clients. Due to the varying customer types, there is also a need for a mobile platform that could easily be used at the early stages of the sales process. The final need of the TFKHMC was to be able to create these different virtual and immersive methods of viewing the house designs in a way that would both speed up and make the design process more efficient, giving the customers substantially improved service and ensuring they had a fuller understanding of the finished product to ensure fuller satisfaction of the product. The added benefit of the research project is the improvement in their methodologies and understanding of how this applies to their business, allowing them to create a strategy for further developments and how to make these more efficient. The provided framework is also valid for remote communication and training using relevant source control methods, which became actual for the COVID-19 lockdown period and the subsequent regulations.

The dissemination of the research project to a wider audience has been important in its success. The AEC professionals and the colleagues in the case study have now been fully empowered to adopt digital technologies, especially 360 Virtual Tours, BIM, Gamification and VR, in their design and marketing processes. These are all new skills to the industry. This significant development has created a more acceptable price point for the potential clients and increased possible margins.

Besides all measurable benefits for all parties, the project achieved all initial objectives stated in the above section. In addition, it also achieved a different objective that was proposed as part of reaching out to users through web and application of 360 Images Web VR solutions compared to the stand-alone mobile app development. The research triangulated with other research works on applications of VR for BIM and Data configuration. The credibility could be validated by comparing results with the theoretical framework.

#### 4. Novelty and Originality

Despite improvements in orthogonal drawings [5], BIM technologies are primarily designed as management tools or repositories of interrelated descriptive and 3D information [6] are limitations in their visualisation capacities. However, immersive technologies can potentially offer clients an opportunity to visualise a built asset and walk through it [7]. With the aid of virtual and augmented reality (VR and AR), one can experience design in 3D space, assess indoor factors such as lighting, plan for future maintenance and decide for themselves whether it

would meet their needs [8]. However, currently available immersive experience solutions on the market offer only partial opportunities for building design integration; or otherwise require advanced technological skills from the user. As a result, users with no prior advanced training and the necessary hardware are limited in what they can view and achieve with these packages. Additionally, the existing software solutions offer no integration of BIM; hence, no data on the construction materials, services or costs are available for interaction. As a response to this functionality gap between BIM and immersive technologies, this study proposes an interface that integrates the two to streamline design processes and provide a comprehensive pared-down BIM system. Additionally, this interface aspires to be fully agnostic towards the diverse BIM editing tools, which can become a source of input and offer synchronised concurrent user accessibility with low latency to promote active collaboration. Finally, to illustrate the operational principles of this system, the project is based around offsite manufactured self-build housing, where TFKHMC would present house designs in a virtual environment directly from their BIM models, allowing their clients to walk through and customise a range of home features remotely.

The proposed solution dealt with the issue of the cumbersome exchange procedure of large files, the complex methods for achieving interoperability due to The frequent and timely interdisciplinary collaboration, or the high latency of the interfaces [2]. Moreover, the proposed VR solution for The Timber Frame houses deals with the complexity of the technical workflows and processes that limits the possibility of engaging with clients, owners and other non-engineering professionals in the decision-making processes due to the so-called "black-box effect", which refers to a system without transparency. The validity, workability and suitability of proposed solution has been tested by a wide range of professionals to ensure its usability to enable Timber Frame Self-Build companies to make the decision in terms of design before the construction processes begins.

The majority of residential property buyers in the UK consider the self-build route an alternative to mass production development options. Bespoke houses in chosen locations also appeal to clients with an opportunity to save up to 30% on market value or optimise budget use, equip the house with high energy efficiency level and latest home technologies [114]. Clients who undertake a self-build project typically need to accomplish the following tasks: finding a plot, agreeing on house design, cost calculation, attaining planning and building regulations permissions, deciding on finance, project management and others. TFKHMC are critical service providers in the sector. They offer a packaged range of services, which frequently include: conceptual and technical design, cost optimisation solutions, assistance in attaining relevant planning and building permissions, kit home manufacturing, shipping kit homes to the construction site, customer service and other forms of consultancy [15].

Technical drawings and 2D images are frequently insufficient for clients with no construction background to visualise their future builds, decide on details and extensions needed. In addition, an increasing number of iterations per project lifecycle, having difficulties in keeping all the records in one consistent source and passing accurate information to manufacturers and builders. As such, this study provided a user-friendly solution to enable clients to make a decision based on realistic information, which can foster the adoption of self-build route to fill the housing gap in the worldwide market.

928  
929

## 6. Conclusions

930 The main body of scholars has identified macroeconomic factors of the stagnation in the  
931 sector, rarely elaborating on microeconomic supplier issues of TFSBS KHMC. The current  
932 research contributes knowledge by identifying issues in the sector that could be resolved via  
933 technological innovation. The multidisciplinary findings of the research in business and  
934 innovation of other sectors draw foundations for building trust, confidence in product and  
935 rapport by applying XR technologies to TFSBS. The proposed solution in this study provides a  
936 practical and tailored solution for TFSBS, which can foster XR's implementation in such a sector.  
937 Moreover, research elaborates how classic business and sales principles could be adopted in  
938 XR for AEC in general and TFSBS.

939

940 Applying XR technologies for TFKHMC can offer an advantage over its competitors in appearing  
941 to be more sophisticated and efficient in our methods. As their marketing improves, this will  
942 increase their ability to secure additional leads and sales percentages. The created solution  
943 combines and fosters new technologies for the construction market, such as (1) Using  
944 advanced ICT to reach out to new markets; (2) Using XR technologies to offer a more efficient  
945 service and add value to the clients; (3) Improve interoperability and standardisation of  
946 product design and delivery processes to decrease the length of the average project cycle and  
947 offer more competitive prices.

948

949 The dissemination of the research project to a wider audience has been important in its  
950 success. The proposed solution was presented to a wide range of AEC professionals, and a  
951 usability test was conducted to ensure that the solution is user-friendly in terms of  
952 prectioners' receptivity to adopt it in their companies. This could enable buyers of houses to  
953 interact with designs and proposes changes to meet their requirements before the  
954 construction stage. In addition, it enhanced the company's turnover, profit, and customer  
955 satisfaction.

956

957 Regarding the future recommendations, the proposed solution covered the only examples and  
958 tested BIM variables for doors, windows, and materials pricing. The pricing for the components  
959 was imported to Unreal Engine from the company pricing data table. Future works could be  
960 dedicated to developing a complete set of BIM variables to assemble a full sales quote for the  
961 client. Then, the quote could be printed out for the client for future reference with a  
962 comprehensive description of all items and their prices. The future workflow will include the  
963 following steps: (1 ) the BIM model of a house kit will be autogenerated in Revit using Dynamo  
964 table, which will output coordinates of each component; (2) after imported to Unreal Engine;  
965 and (3) the collaborative discussion between the design team and the client will result in  
966 further changes to the BIM model; (4) the Unreal Engine will update the new coordinates for  
967 the house kit components in the same table the model was created from in step 1; (5) – this  
968 will result in updating the model coordinates in Revit. (6) – the updated version interactive BIM  
969 model will be fed back to Unreal Engine.

970

971 Working with small projects in TFSBS was the “perfect playground” for testing automation  
972 concepts. The concepts discussed in this thesis could be adopted in the future for larger AEC  
973 and Infrastructure projects. The upcoming research will focus on the digital twin development

for the UK and European road infrastructure software. The traditional software used to control road equipment(traffic lights, cameras, road signs) commonly utilises only GIS(geographical information system) data in geographical and schematic maps. Adding BIM data to the equation will equip traffic operator/ traffic controllers with an additional layer of spatial information. Interactive experiences for road networks will enable them to take faster and more precise spatial decisions. The scripts used in this thesis to configure BIM variables will be reused for configuring the road equipment states and enabling equipment controlling from a data table. The road networks and tunnel systems BIM models are significantly more complex than building models in export/import relationships with game engines. The workflows developed in this research will need further detailed and expanded to subdivide the BIM model into gaming sub-levels to reduce optimisation challenges and latency drawbacks.

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