# A Framework for Improving Business and Technical Operations within Timber Frame Self-Build Housing Sector by Applying an Integrated VR/AR and BIM Approach

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## Abstract

Timber Frame Self-Build Housing Sector (TFSBS), accounts only to 7-10% of the UK's housing construction market. This figure is significantly higher in some other contexts, e.g. 80% in Austria, 60% in Canada and 50% in the USA. With the government's policies stepping in to encourage self-building, it is essential for the companies to increase their competitiveness providing an efficient workflow and clear communication with the clients by 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 in terms of spatial awareness, ability to visualise technical drawings and understanding the construction process. For many architectural and construction practices in the UK's TFSBS, the primary communication medium with clients is email. This results in an increased number of the iterations per each project lifecycle, leading to difficulties in interoperability among designers, manufacturers and builders. Virtual and Augmented Reality (VR and AR) 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) that would enhance clients' spatial understanding from the solution spaces, simplify architect-client business/marketing communications, provide parametric customisation options, consolidate quantification, support interoperability, and leverage integration across the whole BIM process are still outstanding challenges. Business and technical key performance indicators, as well as conceptual and methodological frameworks, are developed for adopting BIM principles and emerging game-like VR and AR technologies to support TFSBS within the UK housing industry in Business and Technical Operations. This paper concludes with technical recommendations for the development of a proof of concept prototype to support the aim as mentioned above.

**Keywords:** Building Information Modelling, Timber Frame, Self-Build Housing, Interoperability, Virtual Reality

## 1. Background of the study

Majority of residential property buyers in the UK consider self-building route as 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. Clients who undertake a self-build project would typically need to accomplish following tasks: finding a plot, agreeing on house design, cost calculation, attaining planning and building regulations permissions, deciding on finance, project management and others. The Timber Frame Kit Home Manufacturing Companies (TFKHMC) are one of the critical service providers in the sector, who 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 (Banihashemi *et al.*, 2017).

Despite multiple benefits, UK TFSBS is relatively small compared to its European and North American counterparts. The number of self-build projects per year in the UK fluctuates steadily between 10000 to 15000 items and accounts only to 7-10% of the UK's housing construction market, whilst this number reaches 80% in Austria, 60% in Canada and 50% in the USA, with the other countries having similar dispersion (Wilson, 2017). 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. The micro-level of the problem in UK TFSBS, as well as worldwide, is the enabling effective communication process between client and TFKHMC. 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. These results in an increasing number of the iterations per each project lifecycle, having difficulties in keeping all the records in one consistent source and passing accurate information to manufacturers and builders.

With the new governmental incentives directed on raising the profile of the sector, it is essential for TFSBS Companies to reach out for the potential clients, encourage and educate them in several benefits self-build option could offer and simplify the process of self-build for the clients. Virtual and Augmented Reality (VR and AR) 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 (Hackl and Wolfe, 2017; Kandaurova and Lee, 2018).

Therefore, the focus of this study is designing data-rich VREs that would enhance clients' spatial understanding from the solution spaces, simplify architect-client business/marketing communications, provide parametric customisation options, consolidate quantification, support interoperability, and leverage integration across the whole BIM process are still key challenges. Figure 1 explains the focus of this study, which is bringing together of Architecture/Engineering/Construction (AEC) industries with the Computer Science and Electronic&Electrical Engineering (EEE) in order to integrate openBIM, AR/VR/MR, and Gamification for helping and supporting UK TFSBS sector.

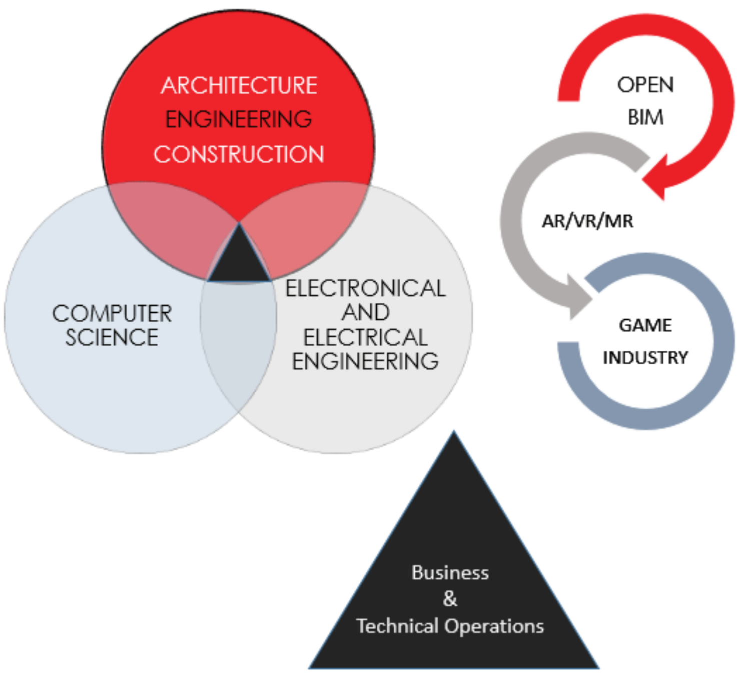


*Figure 1: The Study Focus*

# 2. BIM Principles Implementation with the help of VR/AR/MR Technologies

With the very few existing studies focusing on the application of BIM and Virtual Reality (VR) technologies in TFSBS (Pour Rahimian *et al.*, 2019), this paper has explored the broader subject of BIM and VR (as reported in: Boton, 2018; Chalhoub and Ayer, 2018; de Klerk *et al.*, 2019; Heidari *et al.*, 2014; Sun *et al.*, 2017).

The Idea of Virtual Showroom has been conceptualised for decades and been reported in several studies (Abdelhameed, 2013; Rahimian and Ibrahim, 2011; Yu, 2011), however previously scholars pointed out factors related to the existing hardware and software limitations. In the last couple of years (2017-2018) rapid growth in the application of gaming technologies in the AEC sector, development of BIM interoperability and EEE have enabled a new chain of available capabilities in visualising high fidelity virtual spaces. This progress in technology requires a new sequence in the exploration of the idea of Virtual Showroom.

Several studies focused on the application of VR in BIM to resolve the complexity of dealing with federated models: VR has attracted increasing attention of the AEC and Facility Management (AEC/FM) industry in recent years, as it shows a great potential to improve workflow efficiency through enhanced common understanding (Du *et al.*, 2018). One of the examples of property management using VR technologies focuses on room views influence on apartment prices. To assess such an influence, a virtual experiencing and pricing method for room views based on BIM and oblique photogrammetry was proposed by Sun *et al.* (2017).

Huge progress has been made on ‘Augmented Reality’ (AR) techniques such as registration, tracking, and display hardware. However, a construction AR system should be more convenient and combined with in-use applications to support multi-disciplinary users throughout the construction lifecycle (Solihin *et al.*, 2017). In an industrial environment, where strategic decisions are to be made, to create aesthetically beautiful experiences is unless specific applications such as design or perceived quality (only) a plus. What is needed is to have reliable systems upon which one can rely on a development process. The developers need to make sure that an engineer will be able to work with a digital mock-up with as much performance as needed (Perroud *et al.*, 2017).

Few other researchers emphasised the need for collaborative and multi-user VR experiences in construction and architectural design. Scientists experimented with conceptual prototyping design, the flow of data from an authoring tool to visualisation environment as well as participatory decision making (de Klerk *et al.*, 2019; Du *et al.*, 2018; Sanchez-Sepulveda *et al.*, 2019). This paper has analysed the research mentioned above, and the findings are presented in the Framework.

# 3. Business Operations Implementation with the Help of VR/AR/MR Technologies

The seminal literature has reported on the subject of communicating design intent between an architect and a client and presenting outcomes in the form of a winning bid (Sawczuk, 2013). Large architectural projects are expected to have extended project lifecycles and planning stages; as a large number of stakeholders are involved. Conversely, small scale residential projects require significantly shorter project cycles and faster interoperability workflows reaching out clients often remotely.

To examine the subject of business operations in TFSBS applying VR technologies authors have investigated a broader range of VR applications.

Several scholars addressed the use of immersive virtual reality technologies in virtual simulated stores, museums or archaeological sites and its correlation with enhanced presence and usability compared to conventional desktop technology (Goulding *et al.*, 2012). The studies showed the use of immersive technologies resulted in improved presence and usability; however, admitted the need for further advancement in VR hardware and software capabilities.

Another study conducted by Fang *et al.* (2014) proposed the mechanisms to enable reputation building for e-commerce in VR. They stated that people are becoming more willing to shop online rather than going to traditional shops. However, current e-commerce systems only provide users with a simple browser-based interface to acquire details of products and services. VR experiences allow buyers to model trustworthiness of sellers and distinguish honest sellers from malicious ones. Showroom sales process characterised by creating a specific environment that enhances the sale. The factors that boost showroom sales include lighting, sound and ability to interact with an object to test (de Wijk *et al.*, 2018).

Haller (2017) examined underlying universal colour patterns in interior design that everyone responds and a combination of colour evoking certain emotions. The study conducted by Sherman and Craig (2018) emphasises the equal necessity for a comprehensive exploration of the VR subject area as well as the VR medium. Wide range of VR applications subjects in the research conducted, includes military training, education and design. Authors draw attention to the fact that adoption of VR in each area must be driven by deliberate design, design to engage the audience, social interaction consideration, understanding user objective, start, process and end of the game scripts and need for tradeoffs.

Lin *et al.* (2017) conducted on clients' feedback on VR product configurator use. The empirical evidence appears to confirm the notion that the VR system of product configurator enables a better understanding of the future product and hence reduces indecision/objection handling stage during the sales process. Kandaurova and Lee (2018) studied VR effects on empathy and the level of donation for charitable giving. Scientists have found evidence VR experiences boosts the level of empathy and social responsibility, which manifests in a high level of monetary donations and intention to volunteer.

In-person sales are one of the most effective sales tools as it engages all channels of communication: verbal, the intonation of the voice, opportunity to use sales visuals, expressive body language and demonstrations. Various publications and authors have focused on identifying critical stages of successful sales. Immersive VR software as a sales tool should adopt the principles of the essential buyer-seller steps in the in-person sales process.

# 4. Game Technologies

The quality of VR experience is often recognised via two characteristics: a sense of presence and sense of immersion (Jarald, 2014). Whilst immersion is about the characteristics of technology, presence is an internal psychological, and physiological state of the user. There is a large number of factors that contribute to the quality of virtual experiences (Jarald, 2014; Paes *et al.*, 2017). Although a substantial number of studies focused on improving the effectiveness of operational processes in the construction industry, there also a pool of studies in storytelling in Virtual worlds for marketing and sales. However, the few researchers focused on the integration of both areas of knowledge.

The exponential growth of VR in applications across various platforms has been depicted in multiple statistic sources and events. Nevertheless, mainstream customers appear to be relatively uninformed of existing VR/AR channels as a medium for sales. To narrow the gap in experiencing VR as sales channel, the current generation of VR developers should consider the needs of first-time VR users, evaluating needs for introduction videos, lighter interface versions and also multi-user VR experiences, where one of the participants would act as a guide through virtual environment as well as the possibility of voice-controlled interface. Further studies should be implemented to examine the effectiveness of each interface component to aid first time VR Users;

Multiple researchers and developers have emphasised optimal hardware requirements for comfortable VR experiences, including Graphics Card and GPU ranges, which would be facilitating high frame rate; as well as specific headset brands and new market trends for wireless VR hardware. With the hardware market steadily improving, larger volumes of high fidelity data could be visualised in VREs. For the current study, all elements of a VREs could be subdivided into four main groups: (1) Essential AEC data that has been predefined in a vendor software and exported into VE; (2) Visual objects that have been added by various sources to set the scene, e.g. example interior design; (3) Existing VR interface and programmed sales logic; (4) Effects and others, including lighting, particles, render and audio effects.

The essential part of this research included empirical studies of existing VR interfaces. This study has interacted and analysed a number of existing VR experiences, among them:

- AEC focused interfaces;
- Creative art and sculpturing experiences;

- Guided virtual tours experiences;
- Scientific visualisations;
- Virtual stores;
- VR Games.

The advantages and drawbacks of applicability to the study have been classified in discussed in the Framework section.

# 5. Framework

The available functionality needs to be examined for serving sales purpose and not deriving client from it. It is a general game purpose to entertain. However, the scope of the research is to identify only functionality that would sell the product at the end of the iteration. VR software should be considered as a part of the company sales process and fit seamlessly into company workflow.

Understanding the stage of the client's journey is paramount in determining the required functionality. Three forms of client interactions were identified in this study: (1) First point of contact, (2) Option Selection, (3) Final Inspections. The exclusive approach was offered for each form of interaction.

The first point of a company communication with a client is characterised with building the rapport, establishing company credibility and familiarisation with the multitude of the product range. Therefore for the clients, who just considering the self-build option, are recommended to use a lighter version of the VR experience. 360 images and videos, WebVR experiences are now fairly easy to be accessed through brand mobile apps and company websites. HTML frameworks like A-Frame and Roundme provide easy deployment of Interactive WebVR experiences on any website. Branded cardboard headsets could be posted to a client location for further encouragement. The 360 scenes with gaze interaction interface enabling the transition from one image to another are sufficient to fulfil the first point of contact communication stage with the client: high fidelity spatial perception demonstration, reputation building, quick access to a multitude of the product demo scenes. At the current level of hardware and software capability, lightweight 360 scenes have proven to be more efficient, compare to heavyweight 3D scenes, which would need to incur significant optimisation or loss of the level of the detail and visual quality to be adapted for WebVR.

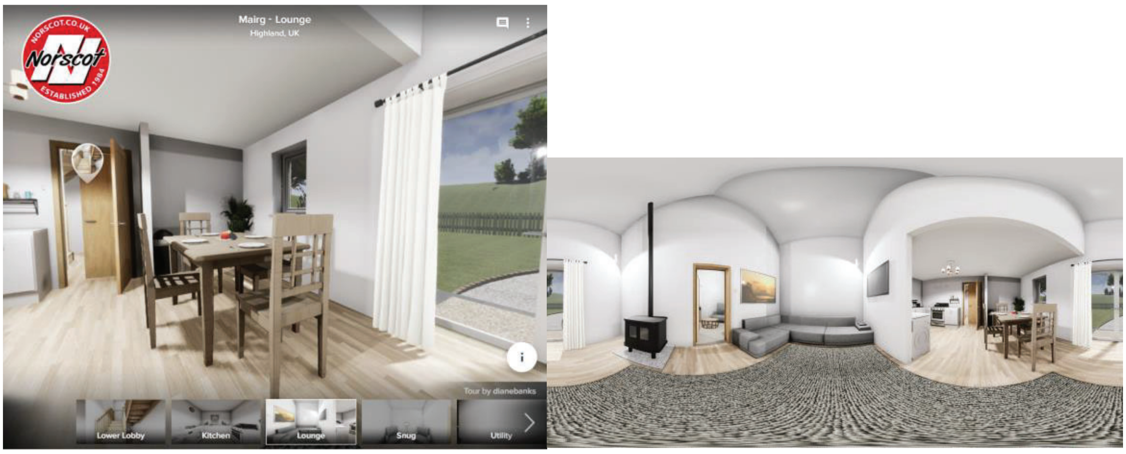


*Figure 2: 360 Architectural Scenes Demostration for Web and Mobile Platforms. From Left to Right: (1) Lounge Demonstration, (2) Unwrapped 360 image of the same room*

Once company credibility and reputation are demonstrated, and a client has committed working with a specific company, the next stage - **option selection** would require much more detailed functionality. Possible amendments discussed at this stage will include plot geography-related design adjustments, wall extensions, client personal preference plan amendments, doors and windows positioning and styles. A client's decision motives on preferred design would typically include available budget, plot location, size and geographical parameters, estimated completion timescale, design energy saving estimates, lifestyle and room functionalities, furniture content, necessary disability adjustments, aesthetic preferences, etc.

Summarising the above research and with the current level of hardware and software development, following virtual reality functionality was proposed for the stage:

- **Landscape visualisation**. The available plot location and size are crucial factors influencing design choice, vertical and horizontal spread, rotation depending on views, sunset and sunrise positions, energy efficiency and daylight optimisation. Among the pool of the technological solutions for landscape visualisation following options were considered: downloadable 3D maps, 3D landscapes obtained from various geographical databases, scanned point cloud data. Due to budget and time constraints for each self-build project in the optimal solution of 360 photographs of the construction site were offered. Carefully aligned 360 photographs of a plot placed into VR along with the design provide a basic understanding of a future build position and location. At further client request and available budget, more detailed landscape visualisation could be provided. Interactive day and night cycle functionality was offered.

- **Floor plan visualisation**. Due to not having any technical background, many clients have difficulty to visualise technical drawings and floor plans. Establishing a connection in VR environment with the existing floor plan will help clients to navigate with ease and quickly locate the zones that require changes. Authors have studied a number of architectural walkthroughs and gaming experiences. Among options tested were: (1) motion-controller-attached 2D floor plan with teleport locations, (2) location-based menus with images of teleport options and return button, (3) minimap, which demonstrates real-time location on the floor plan and option to return to the start, (4) scroll menu with room names and teleport destinations. The scroll menu appeared to be the easiest in terms of creation of speed workflow and reusability for each new scene. However, it was the least effective for giving the clients perception of space. On the contrary minimap as frequently used gaming directions tool appeared to be most effective for providing understanding the link between the floor plan and virtual space. The Return to the Start Button was agreed to be effective for many users to restart the journey.


*Figure 3: Floor Plan Visualisation. Left to Right: Floor Plan Attached to Left Controller; Reusable Teleport Buttons System; Aligned Floor plan.*

- **Interior Swaps**. With a number of VR game experiences tested and analysed, this paper concluded that the individual object and material swaps appear to be time consuming and ineffective. Instead, batch interior swaps were offered. When entering an empty room, a user was presented with a selection panel options of standard interior presets, e.g. converting each room from single to double bedroom, to a nursery and to study. Natural colours and standard furniture sizes would enhance spatial perception and give clients directions if there is a need for design extensions.


*Figure 4: Visualising Room Sizes. Left to Right: Choosing Furniture Size; Choosing Interior; Changinge Door styles.*

- **Quantification and Product Range Demonstration**. Virtual Space is an ideal environment for demonstration of additional product range, including elements like doors and window styles. Frequently, the main criteria for selecting either option is aesthetic preferences and a price difference. Architectural software packages like Revit are ideal tools for quantifying all elements and their options. However, for Virtual Reality users, it would be too time-consuming and overwhelming to expect an update for every door and window style and price change. The game engine functionality is successful in bringing the database information and coding available total estimated savings depending on choosing either option. As an example, The Door Sales Logic was scripted and demonstrated for the clients. Automated Python scripts were used inside the game engine to swap Revit exported doors to Game Door Actors with scripted behaviour and price. Selecting a particular door style, would change the doors according to it and give an update to total price change.

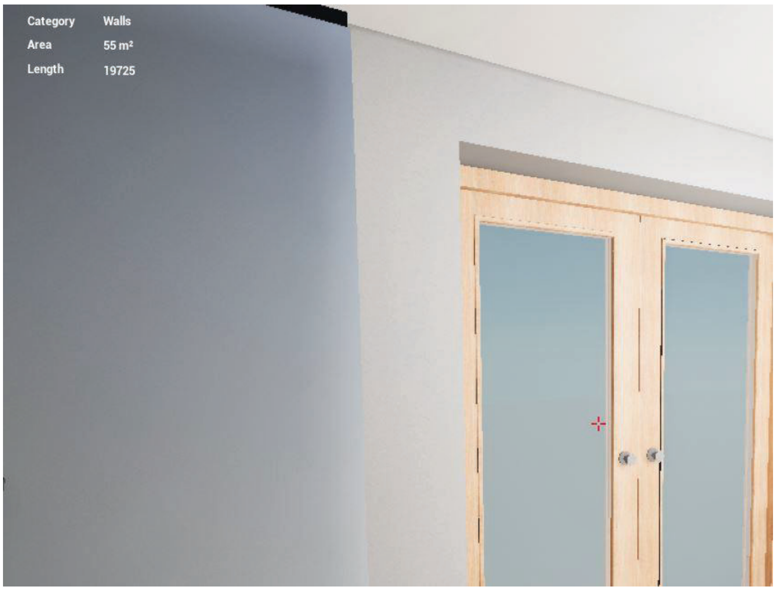


*Figure 5: Quanitification Demonstration.*

Thirdly, the final stage for client-designer/salesperson interaction in VR is the final check and approval. Once a client has agreed on all the adjustments and options, it is essential to have the functionality of saving the game and printing out the final bill of quantities for a client to sign.

# 6. Conclusion

The aim of this paper was to review existing literature on the implementation of BIM, VR and AR technologies and assess their applicability to TFSBS. The number of published scientific works on the VR/AR/MR in construction registered exponential growth in the last five years. The classification and content analysis of the literature revealed a few trends and gaps in this subject. This study achieved the mentioned aim by suggesting applicable directions for software development.

The Virtual Reality Experiences for TFSBS are characterised by shorter, and more repetitive workflows compare to other real-time architectural visualisations for bigger projects. Therefore the proposed framework is more focused on templates creation rather than providing accurate detail for each specific project. There is a major discussion still active in understanding which functionality is effective in-game environment or predefined in architectural software. The future research agenda will focus on parametric amendments inside the game engine and updating architectural software accordingly, further exploration of navigation aids with the voice-controlled interface and multi-user functionality.

# Acknowledgements

The authors wish to gratefully acknowledge the generous funding received from InnovateUK, Norscot Joinery Ltd to support this study as a part of the Knowledge Transfer Partnership hosted by the University of Strathclyde, Glasgow. The authors also would like to acknowledge contributions of all people involved in this study, especially Dr Ian Heywood (Knowledge Transfer Adviser, InnovateUK) and Jason Fraser (Technical Operations Manager, Norscot Joinery Ltd) for providing Business and Technical Guidance.

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