A CONCEPTUAL FRAMEWORK AND TOOLS CHARACTERISTICS FOR DEVELOPING AN IMMERSIVE TECHNOLOGY-BASED OCCUPATIONAL HEALTH TRAINING MECHANISM

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Training and education are crucial in tackling occupational safety and health risks, such as manual handling for construction workers as they help workers identify and handle hazards. Concurrently, integrating immersive technologies (ImTs) in training and education has shown promising results in enhancing how construction workers approach manual handling, consequently diminishing the risk of musculoskeletal disorders. However, there is a noticeable gap in research, with limited studies focusing on creating an ImT-based tool to train construction workers on manual handling. Furthermore, the variations between numerous ImT-based software and hardware make it challenging to adequately determine whether an optimum solution will be achieved when developing such platforms. To address this gap, this study applies design science research methodology in providing insights into the development of an ImT-based training tool specifically tailored for construction workers and to describe the characteristics of prominent software tools that are integrated through a conceptual framework. It is intended that an improvement in the proficiency of construction workers in addressing manual handling challenges is achieved. However, challenges to applying the tool could include users experiencing simulation sicknesses.

Keywords: Construction industry, Health and Safety, Immersive Technologies, Training and education.

INTRODUCTION

Training and education are essential for addressing construction workers' health and safety risks, especially in tasks like manual handling. They teach workers to recognise and manage hazards, follow safety guidelines, use protective gear properly, and respond to emergencies (O'connor *et al.*, 2014). At the same time, using immersive technologies in training has proven to be effective in improving how construction

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workers handle manual tasks, reducing the risk of musculoskeletal problems (Babalola *et al.*, 2023). According to literature, manual handling hazards which are a key cause of musculoskeletal disorders (MSDs) in the construction sector accounts for 53% of work-related illnesses in the United Kingdom (Health and Safety Executive, 2022). Due to this significant impact and given the potential of immersive technologies with regards to occupational health training and education as seen in literature, it is important to explore how to develop immersive technologies in addressing manual handling and MSDs among construction workers via training and education. Therefore, the aim of this study is to provide descriptions of the characteristics of the most popular tools in literature used for the development of an immersive technology training tool and provide insights on how the tools can be used to develop a training tool specifically tailored for construction workers.

LITERATURE REVIEW

Manual handling can be described as activities that involve using the hand or any other part of the body to lift, pull, push, carry or put down objects, animal or person (Eyre, 2021). Manual handling is the movement of a load or the support of a load in a static posture (Health and Safety Executive, 2016). Manual handling is a risk factor for MSDs posture (Health and Safety Executive, 2016). MSDs can be described as an injury to the musculoskeletal system such as repetitive strain injury, back injury and slipped disc (Oakman *et al.*, 2019). MSDs usually involve damage to the muscles, ligaments, nerves, tendons or blood vessels (National Institute for Occupational Safety and Health (NIOSH), 2007). Some of the symptoms experienced by an individual suffering from MSDs include pain or discomfort, inability to perform controlled movement and loss of sensitivity to touch, heat or pressure (Punnett and Wegman, 2004). MSDs can be caused by repetitive movements (such as frequent carrying), forceful exertions (such as lifting heavy loads), awkward postures (such as twisting or bending) and static postures (such as maintaining fixed positions for a long time) (National Institute for Occupational Safety and Health (NIOSH), 2007). The musculoskeletal system consists of the skeletal system (bones and joints) and the skeletal muscle system, which work together for the movement and the support of the body (Eyre, 2021). There is the prevalence of MSDs among construction workers with 87% of workers in Korea, 80% of workers in India and 59.6% of workers in Pakistan experiencing MSDs in the construction industry (Lee *et al.*, 2023). An effective method of addressing MSDs caused by manual handling in the workplace is the training of workers and it is most effective when it provides hands-on practice and use visual aids of actual tasks in the workplace (National Institute for Occupational Safety and Health (NIOSH), 2007). However, the traditional methods of training which include lectures, tool-box training and seminars have limited engagement of the trainees (Ojha *et al.*, 2020).

Immersive technologies can be described as technologies that enable users to feel physically present in a virtual environment through virtual graphics (Calvet *et al.*, 2019). They have been applied for occupational safety and health training of construction workers in addressing different safety and health hazards in literature. Specifically, they have been used to train construction workers in identifying and addressing fall from height hazards in workplaces (Eiris *et al.*, 2020). It was revealed that immersive technological based training provides comparable outcomes to the conventional method of training while also saving the time required for learning (Eiris *et al.*, 2020). Another study developed an immersive technology training tool for the training of construction workers in addressing struck-by hazards environment (Xu and

Zheng, 2021). The study revealed that training through immersive technologies enables workers to memorise critical points better than the conventional method of training (Xu and Zheng, 2021). Whilst immersive technology has shown potential for safety training, there have been limited studies regarding its potential for MSDs training. This study is therefore focused on exploring the application of immersive technology to enhance training on MSDs. Key considerations in this regard are the training content and tools required to develop and test an immersive technology-based MSD training.

Meanwhile, different approaches have also been used to develop the training content for immersive technological training tool. For example, studies such as Eiris et al. (2020), Adami *et al.* (2021), Bhagwat *et al.* (2021) and Zhao and Lucas (2015) developed the training content based on an accredited training manual. Some other studies developed the training content based on interviews with OSH experts ; Seo *et al.*, 2021). However, focusing on just the activities of a construction site may not be adequate as construction projects are unique (Zhang and Gambatese, 2019). In addition, combining multiple techniques could increase the quality and robustness of the training content. This study therefore proposes a combination of multiple approaches – literature, an actual MSD training content by a training organisation, followed by interviews with experts to further refine training content.

RESEARCH METHODS

Design science research methodology (DSRM) is utilised for the development of the immersive technology training tool. This is because DSRM which aligns with qualitative methodology aims to obtain insight into solving real-world problems by creating useful artifacts and contribute to the body of knowledge (Brocke *et al.*, 2020). It is therefore applied in the design and development of the tool for training on manual handling activities to mitigate the risk of MSDs. DSRM is used to provide an effective and efficient solution to the manual handling problems that cause MSDs among construction workers. DSRM involves three steps which are: (1) problem identification and requirements capturing; (2) design and development; and (3) evaluation (Prabhakaran, 2022). This paper addresses the first step and the design aspect of the second step in the DSRM. Based on DSRM, the problem has been identified as the poor OSH in construction and the potential for immersive technologies to assist in addressing the problem via training. Requirements capturing is then conducted by examining accredited training modules, standard guidelines, and peer-reviewed academic and grey literature to establish the appropriate content for manual handling and MSD training in this research. Furthermore, one-to-one interviews with professionals, who have at least 5 years of experience in occupational health and safety management on manual handling and MSDs,were conducted. Interviews were conducted until saturation was achieved resulting in the interview with 12 participants. The information obtained from the experts included their demographics, their knowledge on what the learning outcomes, training contents for OSH regarding manual handling and MSDs should be. The information also included their opinion on the suitability of the initial learning outcomes and training contents developed based on the literature review, and their perspectives on immersive technologies for delivering OSH training. Thematic content analysis was used to analyse the interviews. The initial learning outcomes and training contents were then revised based on the results of the interviews.

Technically, the development of immersive technologies comprises the three-dimensional (3D) modelling of real-life objects and the rendering of the virtual environment (Xu and Zheng, 2021). Different software tools are used for the modelling of 3D objects. Table 1 shows a brief description of the software tools that can be used for modelling 3D objects while Table 2 shows a brief description of the software tools called game engines that can be used for the dynamics of the virtual environment.

Table 1: Different 3D modelling software tools and the specifications

System Attributes	Modelling Software				
	Autodesk 3DS Max	Autodesk Revit	Trimble SketchUp	Autodesk InfraWorks 360	Blender
Name of Provider	Autodesk media and entertainment (Autodesk, 2023a)	Autodesk media and entertainment (Autodesk, 2023b)	Trimble Inc (Trimble, 2023)	Autodesk media and entertainment (Autodesk, 2023c)	Blender foundation (Blender, 2023)
Operating System Compatibility	Windows (Autodesk, 2023a)	Windows (Autodesk, 2023b)	Windows, MacOS (Trimble, 2022)	Windows (Autodesk, 2023c)	Windows, macOS, Linux (Blender, 2023)
Primary Usage	Creation of realistic 3D graphics for virtual environments (Autodesk, 2023a)	Sketching, scheduling, sharing, annotating and visualising objects (Autodesk, 2023b)	3D modelling of objects (Trimble, 2023)	Model and understand design projects (Autodesk, 2023c)	Modelling, rendering, simulation and sculpting of objects. (Blender, 2023)
Subscription Fee	£1,968 per year (Autodesk, 2023a)	£2,940 per year (Autodesk, 2023b)	SketchUp Go - £95 per year SketchUp Pro - £279 per year SketchUp Studio - £599 per year (Trimble, 2023)	£2,106 per year (Autodesk, 2023c)	Free (Blender, 2023)
Strengths	Supports multiple file formats such as FBX, CAD and USD thereby enabling easy share assets. (Autodesk, 2023a)	Consists of features such as Revit cloud worksharing and BIM Collaborate Pro that supports collaboration and a common data environment (Autodesk, 2023b).	Enables viewing of model on mobile device with the SketchUp Viewer app (Trimble, 2023)	Aggregates large amount of data to generate information-rich context models (Autodesk, 2023c)	Blender is a freely available software that supports the entirety of the 3D pipeline which include modelling, animation, rendering, simulation, game creation and motion tracking. (Blender, 2023)
Weaknesses	Supports only Windows operating system (Autodesk,	Supports only Windows operating system (Autodesk,	Lengthy registration process and also requires installation of numerous	Supports only Windows operating system (Autodesk,	It is recommended that Blender should be installed and used on devices

	2023a)	2023b)	plugins (Carmona-Medeiro et al., 2021)	2023c)	not older than 10 years. (Blender, 2023)

Table 2: Different game engine software tools and the specifications

	Game Engine		
	Unity	Unreal	Torque
Name of Provider	Unity Technologies (Unity Technologies, 2023)	Epic Games (Epic Games, 2023)	GarageGames (The Torque Community Contributors, 2021)
Operating System Compatibility	Windows, MacOS, Ubuntu (Unity Technologies, 2023)	Windows, MacOS, Linux (Epic Games, 2023)	Windows, MacOS, Linux (The Torque Community Contributors, 2021)
Programming Language	C# (Jacobsen et al., 2022)	C++ (Fathima and Aroma, 2019)	C++ (The Torque Community Contributors, 2021)
Primary Usage	Game development (Unity Technologies, 2023)	Game development (Epic Games, 2023)	Game development (The Torque Community Contributors, 2021)
Subscription	Free (Unity Technologies, 2023)	Free (Epic Games, 2023)	Free (The Torque Community Contributors, 2021)
Strengths	Unity editor works seamlessly with tools like Blender and any type of game and style can be created because of its flexible architecture (Unity Technologies, 2023)	Unreal engine provides free access to the complete C++ source code for users to study, customise, extend and debug (Epic Games, 2023)	Contains features to handle all types of games (The Torque Community Contributors, 2021)
Weaknesses	Gets revenue for earnings greater than $100k and it is recommended that Unity is installed and used on devices that have Graphics card with DX10 (shader model 4.0) which can be unaffordable (Unity Technologies, 2023)	Gets 5% royalty of earnings over $1 million (Epic Games, 2023)	

The software tools for modelling 3D objectives include Autodesk 3ds max (Pooladvand *et al.*, 2021), Trimble SketchUp (Bhagwat *et al.*, 2021), Autodesk Revit Architecture (Getuli *et al.*, 2020) and Blender (Pedro *et al.*, 2016). Table 1 summarises the features of the 3D modelling software tools with respect to the developer, operating system compatibility, the primary usage of the tools and the subscription fee as obtained. 3D objects are essential components in the development of a virtual environment as they significantly affect the unconscious perception of the users of the virtual environment (Buyuksalih *et al.*, 2017). The developed training tool should be vivid so that the participants will experience the different feelings associated with various tasks such as fear as if they were in that circumstance and their awareness can be intensified (Huang *et al.*, 2021). It is therefore essential to develop high quality 3D objects to effectively immerse users in a virtual environment.

After the creation of modelled 3D objects, these objects are then exported into a game engine for the development of the dynamics of the virtual environment (Xu and Zheng, 2021). Different software tools are used for the dynamics of the virtual environment with the modelled 3D objects. The software tools include Unity (Nykänen *et al.*, 2020), Torque (Zhao and Lucas, 2015), and Unreal game engines (Kim *et al.*, 2021). Table 2 summarises the features of the game engine software tools with respect to the developer, operating system compatibility, the programming language supported by the engine, primary usage of the game engine, the subscription fee, the strengths and weaknesses.

RESULTS

Learning outcomes and the training contents (mapped to the learning outcomes) have been developed. The mapping is to ensure all the learning outcomes are achieved as summarised in Table 3. These were developed based on the outcome of the interviews.

Table 3: Summary of the developed training content

Learning Outcomes	Training Contents
Trainees should be able to identify key hazards, risks and unsafe practices involved in manual handling.	Prior to a manual handling activity such as lifting and carrying a paving, the construction worker assesses the paving (check the weight of the paving to ensure it is light enough to carry and within the worker's capability and there are no sharp edges or harmful objects around the paving) and the environment (ensure it is not dark, there are no obstructions, checks for space constraints or different floor levels along the routes for carrying, it is not too hot or too cold and checks for rain and strong air movement) based on the task, individual, load and environment (TILE) framework.
Trainees should learn about the use of mechanical aids.	To use a pallet truck to pull a load such as a plasterboard, the worker places arms around the pallet truck to prevent the arms from getting trapped against doors and walls. One leg of the worker is placed behind the other to provide a secure base. The spinal curves are maintained, and the arms are kept as close to the body’s centre line as possible. The feet of the worker are kept away from the plasterboard while keeping to a walking pace. The worker changes direction by using the feet to change direction to avoid twisting.
Trainees will learn about the musculoskeletal system, the risk factors for developing musculoskeletal disorders and the mechanics of movement.	The musculoskeletal system consists of the skeletal systems (bones and joints) and the skeletal system. The spine enables movement, supports the upper body and protects the spinal cord. Muscles and tendons help to provide spinal balance, stability and mobility. Risk assessments can assist in identifying what could go wrong with manual handling activities. Task. Individual. Load. Environment. (TILE) can be used to assess manual handling task. Task – does the task involve carrying loads for long distances, twisting or repetitive movements? Can mechanical aids be used? Individual – what is the capability of the individual? does the individual need personal protective equipment? Load – consider the weight, size and shape of the load. Environment – such as poor lighting, uncomfortable temperatures, uneven or slippery floors, space to manoeuvre.

DISCUSSIONS

Based on the specifications of the modelling software shown in Table 1, Blender was selected as the modelling software because Blender allows users to create very high-quality 3D objects for free including for commercial or educational purposes. In addition, Unity game engine was selected because it works seamlessly with Blender, it has a flexible architecture, and it uses C# which is an available skill for this study. The modelling and game engine software tool and the hardware tool will then be integrated and used for the development of the virtual training tool for this study based on the training contents as shown in the conceptual framework in Figure 1.

Figure 1 shows a flow diagram that depicts the transfer of modelled objects in the form of files from the modelling software (e.g., Blender) to the game engine (e.g., Unity) which can then be viewed using the wearable devices (e.g., HTC Vive Pro 2).

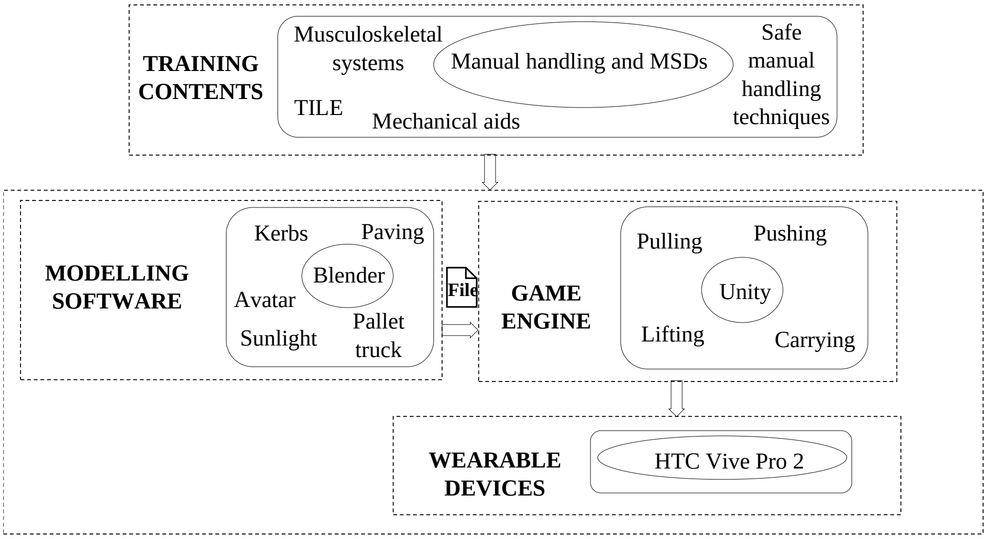

Figure 1: Conceptual framework for the development of immersive technological training tool

Blender is used to model tools used for construction which include paving, kerbs, pallet truck, trolley, and plasterboard. Other modelled objects include the avatar. Consequently, these modelled objects are then exported to Unity game engine for creating the dynamics of the virtual environment. The dynamics of the virtual environment include the manual handling activities such as lifting and carrying a paving, pulling a plasterboard with a pallet truck and pushing a kerb with a trolley by the avatar. These dynamics are based on the training contents developed from the result of the review of literature, participating in an accredited manual handling and MSDs training module and the interview of experts. The dynamics are then created with C# scripts which is used to programme the modelled objects obtained from Blender. After the development of the virtual environment, construction workers can then receive training with the use of HTC Vive Pro 2 which consists of a headset and controllers. The headset will allow the construction workers to have an immersive view and experience of the virtual environment while they use the controllers to control the avatar to perform manual handling activities. The controllers will be used to move the avatar, use the avatar to lift and carry paving and push a kerb with a trolley with the appropriate manual handling techniques as obtained in the training content. Whilst immersive technology training tool may be beneficial for the training of construction workers in addressing manual handling and MSDs, it could also come with drawbacks. These include construction workers might experience simulation sickness when using the training tool and the devices used for the training tool might be expensive.

CONCLUSIONS

Training and education are important in addressing health and safety hazards such as manual handling for construction workers as it guides them to follow standard procedures to prevent or reduce the risk of poor health and safety conditions such as MSDs in the workplace. Simultaneously, as seen in literature, there is potential in applying immersive technologies for training and education to improve on the manual handling skills of construction workers, thereby reducing the risk of MSDs. It is therefore important to explore how to develop immersive technologies in addressing manual handling and MSDs among construction workers via training and education. To accomplish this, accredited training modules, standard guidelines, and peer-reviewed and grey literature were reviewed and experts in safety and health management especially around manual handling and MSDs were interviewed. The training contents were then developed based on the outcome of these exercises. Research was conducted to obtain the various tools for the development of immersive technologies and after a thorough assessment, Blender was selected as the modelling software while Unity game engine was selected as the game engine for this study. In the developed framework, these software were integrated based on the training content. Construction workers can then receive the training using the HTC Vive headset and controllers.

Further work as regards this study will be to develop the immersive technology training tool based on the developed framework. The tool will then be deployed for evaluation based on the perspective of construction workers. The outcome of the evaluation will then inform ways by which the tool can be used to complement existing MSD training in industry.

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