Towards a Mixed Reality System for Construction Trade Training

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Mixed Reality and Activity tracking for Construction Manual Training

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Abstract

Apprenticeships are at the heart of the UK government skills policy and using cutting edge ICTs for construction training can help in attracting youth to an industry that is traditionally characterised by having a poor image and being slow in up-taking innovation. This paper reports on the application of novel Mixed Reality (MR) and wearable motion tracking technologies in a training system which is called the Immersive Controlled Environment (ICE). ICE attempts to address the shortcomings of existing construction training, in particular: (1) lack of solutions for enabling students to train in realistic and challenging site conditions whilst eliminating H&S risks; (2) difficulty to provide comprehensive, objective and quantitative feedback to trainees' H&S and productivity performance. While the wearable and tracking technologies are initially considered in the context of training, they also have the potential to be deployed on real construction sites for providing continuous performance feedback. To the authors' knowledge this is the first time that a training system like ICE is developed specifically for training of construction 'manual' trade workers. The scope of the paper is focused on a review of the literature to highlight the current application of Mixed Reality (MR) and wearable motion tracking technologies in construction. The concept of ICE for construction manual trade training is then presented, along with early and encouraging results revealing the potential for further work to tailor the technology further to

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the context of construction training. The alignment of the technology with the training needs of the construction industry is a challenge. Future work would include the development of the technology around a specific training scenario to ensure that the research is even more applied and relevant to industry stakeholders.

Keywords: Apprenticeship; training; mixed reality; activity tracking; wearable technology; work at height.

1 Introduction

1.1 Background

The construction industry, and particularly SMEs, has historically shown low levels of participation in training when compared to other industries. Nonetheless, a continued investment in training is essential for the industry to further develop and prosper, particularly given the on-going development in new technologies (e.g. BIM, green technologies) and change in work processes (e.g. Lean construction).

Latest figures from the UK Office of National Statistics (ONS) reveal a 2.8% growth in the third quarter (Q3) of 2013 (ONS, 2013). To support the projected growth in the industry's workload, it is therefore imperative to ensure that there are sufficient numbers of new entrants joining the construction industry. A sustained investment in construction apprenticeship[1] training is thus essential, and it could also act as a means of tackling the high levels of youth unemployment. In 2011, the British government has allocated funding to 40,000 extra apprenticeships for young people out of work, in addition to funding for 100,000 new work experience placements (Budget Report 2011). The investment in apprenticeship training is also at the heart of Scotland's Youth employment strategy with £100 million investment aimed at 16-19 year-olds, which includes 25,000 Modern Apprenticeships, in addition to training allowances of £55 per week to young people on Get Ready for Work courses which include work experience (The Scottish Government, 2012). Furthermore, the

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[1] *Construction apprenticeship training combines college learning with on-site experience to ensure the right balance of technical skills and practical experience (ConstructionSkills 2011). Apprenticeship training has to comply with an apprenticeship framework, which is intended to address the statutory requirements (as per the Apprenticeship, Skills, and Children Learning Act 2009) for an apprenticeship programme, and comprises of: NVQ level 2/3, key skills, and Employment Rights and Responsibilities (ERR) (Apprenticeship Frameworks online 2011).*

Construction Industry Training Board (CITB) administers a Levy/Grant scheme (LGS) on behalf of the construction industry – as mandated by the Industrial Training Act 1964. It raises approximately £170m annually from training levies which is re-distributed to the industry in the form of training grants. Approximately 50% of the levy is spent on training grants for apprenticeships in order to attract, retain and support new entrants into the industry. Notwithstanding the on-going efforts for supporting apprenticeship training over the past decade, only 5,500 places were offered by employers in England, despite 30,000 apprenticeship placement applications by young people (ConstructionSkills 2008). The low uptake of apprenticeships is further compounded by the industry's failing to embrace the *ethos and culture of training* as advocated by the Cross-Industry Construction Apprenticeship Task Force (CCATF, 2010).

Arguably, a decline in new employment opportunities for apprentices has led to an increasingly ageing workforce[2] within the sector. There is now a serious risk that the ageing workforce, coupled with a failure to attract and train sufficient numbers of young people, will result in a skills vacuum and manpower shortage that will hamper the UK Government's projected growth (UK Parliament, 2012a; UK Parliament, 2012b).

Furthermore, a comprehensive review of apprenticeships in construction, conducted by the Union of Construction, Allied Trades and Technicians (UCATT), called for improvements in the standards of vocational education and training (Davies 2008) to address the current concerns of employers regarding the poor quality of apprentices on the job. The UK Government's 'Skills for Growth' white paper similarly called for: 1) Improving the quality

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[2] *The number of 16-19 year olds in the industry has fallen by 52% (to 56,781) since 2008, with 16-24 year olds now accounting for just over one in ten (12%) of the construction workforce. In contrast 17% of construction workers are now aged 55 and over (UK Parliament, 2012a).*

of provision at FE colleges and other training institutions, and 2) Developing a training system that provides a higher level of vocational experience; one that promotes a greater mix of work and study (Department for Business, Innovation and Regulatory Reform, 2009). And recently, the UK Minister for Universities and Science, David Willetts, announced the introduction of tougher standards to drive up apprenticeship quality (BIS, 2012).

Maintaining both the quantity and quality of apprenticeship training in-line with the industry's needs is essential to support its future development and prosperity. The government monetary incentives to support apprenticeship training, on their own, are insufficient, as the quality and delivery of apprenticeship training is dependent on the provision of adequate work experience by construction employers who even often fail to provide placement opportunities for apprentices. Arguably, if policy makers do not consider exploring alternative ideas for supporting the current provision of apprenticeship training, other than *'pseudo'* employer engagement and PR propaganda, the problem of skills shortages in the construction industry is likely to persist in an industry that historically has a poor training record (Abdel-Wahab, 2011).

1.2 Training and technology

The above discussion highlights the need to consider alternative ideas and innovative approaches for supporting apprenticeship training, by enhancing the learning experience of trainees at FE colleges. However, the construction industry is traditionally slow in the uptake of innovation, particularly in areas such as ICT (Egan Report, 1998). For this reason, innovation in construction continues to be at the top of the UK government agenda – as evidenced by the recent publications of its construction strategies (UK Government, 2011; UK Government, 2013), in addition to the publication of the Scottish construction strategy (Construction Scotland, 2013).

The UK Minister for Universities and Science, David Willetts recently stated that: *"for Britain to get ahead in the global race we have to back emerging technologies ... This will drive growth and support the Government's industrial strategy"* (Heriot-Watt University, 2013). Moreover, James Wates, Chairman of CITB, stated that: *"we need to show that construction is a high-tech, world class industry with outstanding career prospects"* (CITB, 2013).

Novel technology can enhance trainee experience, improve training standards, eliminate or reduce health and safety risks, and in turn induce performance improvements on construction projects. A well-trained construction workforce is more likely to perform better on-site and maintain the highest level of safety standards thereby reducing accidents. For example, the use of simulators for equipment operator training can allow testing trainees to ensure that they can demonstrate a certain skill level prior to start working on mines. It is reported that, as a result of using simulators in the mining industry, there was a 20% improvement in truck operating efficiency and reduction in metal-to-metal accidents (Immersive Technologies, 2008).

This paper reports on a research project aiming to develop an *Immersive and Controlled Environment (ICE)* for construction 'manual' trade training that uses state-of-the-art technologies in Mixed Reality and activity tracking. The ICE is funded by the UK Construction Industry Training Board (CITB). To the knowledge of the authors, this is the first ever attempt to apply the proposed MR and activity tracking technologies for supporting construction 'manual' trade training.

The paper commences with a literature review of the current applications of MR and motion tracking in construction training (Sections 2 and 3) and then reports on the on-going development of the ICE, its innovative contributions, and its application in the context of construction trade training (Section 4). It should be noted that this paper is more conceptual in nature, and does not cover technical aspects of ICE in detail. Some early results will be summarized, with details on technical developments already available elsewhere – e.g. see (Carozza et al., 2013).

2 'Reality-Virtuality' continuum of construction training

2.1 Real Environment

Figure 1 depicts a 'Reality-Virtuality' continuum in the context of construction training. At one end, there is training within **'Real'** construction project environment. For example, the Construction Industry Training Board (CITB) has set-up the National Skills Academies for Construction (NSAfC) with the aim of providing project-based training that is driven by the client through the procurement process. NSAfC included projects such as the 2012 Olympic which provided 460 apprenticeship opportunities.

However, training on real construction projects is constrained by the type of activity taking place on site, project duration, in addition to health and safety (H&S) risks. Trainees may not be allowed to perform certain tasks on real projects as this can cause delays and errors can be costly, especially when it comes to high profile projects such as the Olympics. To address this issue, attempts have been made in recent years to 'simulate' real project environments where trainees can conduct real tasks without compromising project performance and H&S. An example is 'Constructionarium' in the UK which is a collaborative framework where university, contractor and consultant work together to enable students to physically construct scaled-down versions of buildings and bridges (Ahearn, 2005). This enables students to experience the various construction processes and associated challenges that cannot be learned in a traditional classroom setting. Auburn University in the US, and the University of Technology Sidney in Australia have run similar schemes (Burt, 2012; Forsythe, 2009).

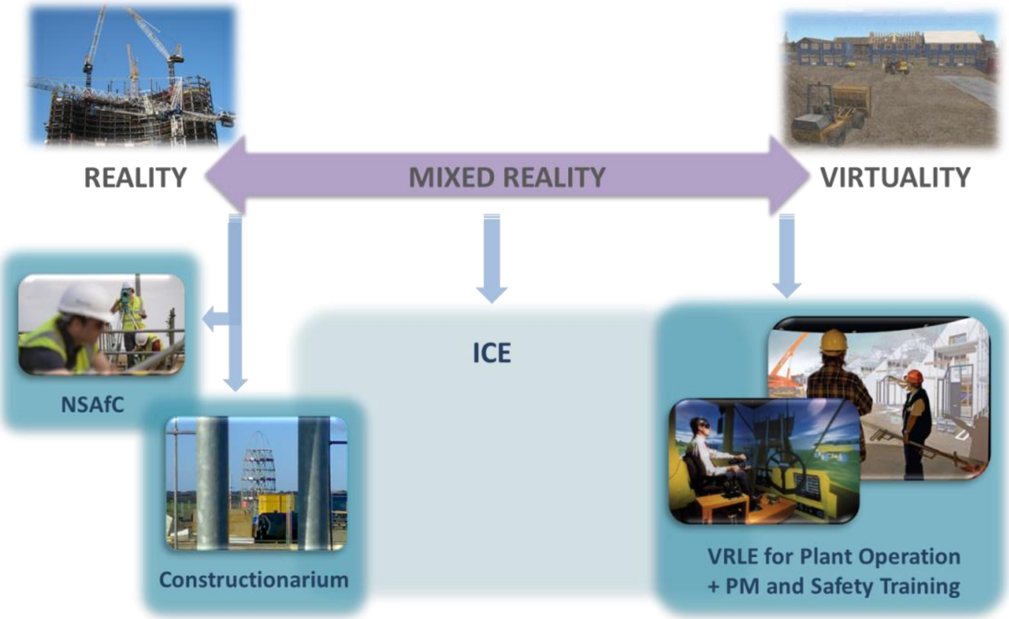


Figure 1: Reality-Virtuality Continuum in the context of construction training

2.2 Virtual Reality (VR)

At the other end of the ‘Reality-Virtuality’ continuum (Figure 1), *Virtual Reality* (VR) is increasingly used for construction training. VR development boomed in the 1990’s and is in fact still under intense development, with education and training an important area of application. Mikropoulos and Natsis (2011) define a Virtual Reality Learning Environment (VRLE) as “*a virtual environment that is based on a certain pedagogical model, incorporates or implies one or more didactic objectives, provides users with experiences they would otherwise not be able to experience in the physical environment and can support the attainment of specific learning outcomes.*” VRLEs must demonstrate certain characteristics that were summarized by Hedberg and Alexander (1994) as: *immersion*, *fidelity* and *active learner participation*. Other terms employed to refer to these characteristics are *sense of presence* (Winn and Windschitl, 2000) and *sense of reality*.

VRLEs can be classified as: *Desktop*, where the user interacts with the computer generated imagery displayed on a typical computer screen; or *Immersive*, where the computer screen is replaced with a head mounted display (HMD) or other technological solutions in an attempt to fully 'immerse' the participant in the (3D) virtual world (Bouchlaghem *et al.*, 1996). Most *simulators* are VRLEs that are commonly developed for *plant operation training* (e.g. tower cranes, articulated trucks, dozers and excavators). For example, Volvo Construction Equipment (Volvo CE, 2011) and Caterpillar (2010) have developed simulators for training on some of their heavy equipment range, such as excavators, articulated trucks and wheel loaders.

Simulators enable training in realistic construction project scenarios with high-fidelity, which is made possible by force feedback mechanisms, and without exposing trainees or instructors to H&S risks. They support fast and efficient learning thereby increasing trainees' motivation (Volvo CE, 2011; TSPIT, 2011). As mentioned previously, the ITAE simulator, employed in mining equipment operation training, is used to ensure that apprentices can demonstrate a certain skill level prior to working in mines. The simulator has proved to be effective in modifying and improving operators' behaviour as well as enhancing the existing skills levels and performance of employees (Immersive Technologies, 2008).

VRLEs have also been developed for *supervision/management training*. The first UK construction management simulation centre has opened at Coventry University in 2009 and is known as ACT-UK (Advanced Construction Technology Simulation Centre). The centre is aimed at already practicing foremen and construction managers, and potentially students (Austin and Soetanto, 2010; ACT-UK, 2012). Similar centres exist with the Building

Management Simulation Center (BMSC) in The Netherlands (De Vries *et al.*, 2004; BMSC, 2012) or the OSP VR Training environment collaboratively developed as part of the Manubuild EU project (Goulding *et al*., 2012). In these VRLEs, trainees can be immersed in simulated construction site environments to safely expose them to situations that they must know how to deal with appropriately. These may include H&S, work planning and coordination, or conflict resolution scenarios (Harpur, 2009; Ku, 2011; Li, 2012). Other VRLEs have also been investigated for other applications for enhancing communication and collaboration during briefing, design, and construction planning (Duston, 2000; Arayici, 2004; Bassanino, 2010).

VRLEs can generally provide significant benefits over traditional ways of training and learning. The main benefit is to enable trainees to "*cross the boundary between learning about a subject and learning by doing it, and integrating these together*" (Stothers, 2007). The controlled environment enables skills to be developed in a wide range of realistic scenarios, but in a safe way (Stothers, 2007; Austin and Soetanto, 2010).

Nonetheless, despite the general agreement on the potential of VRLEs to enhance education, Mikropoulos (2011) and Wang and Dunston (2005) noted that there is a general lack of thorough demonstration of the value-for-money achieved by those systems, which may be due to implementation cost, but possibly also to the quantity and quality of training scenarios that could be development and their impact on learning and practice.

It is interesting to note that VRLEs and Constructionarium are two learning approaches at the opposite ends of the continuum and may be regarded as complementary. Arguably, a blended learning approach can be employed whereby VRLEs are used for initial learning exercises, and approaches like Constructionarium are used for subsequent more real learning-by-doing activities and thereby supporting the transition before going on-site.

2.3 Mixed Reality (MR)

Within the Reality-Virtuality continuum, *Mixed Reality* (MR), sometimes called Hybrid Reality, refers to the different levels of combinations of virtual and real objects that enable to produce new environments and visualisations where physical and digital objects co-exist and interact in real time (De Souza e Silva and Sutko, 2009). Two main approaches are commonly distinguished within MR. *Augmented Reality* (AR) specifically refers to situations when computer-generated graphics are overlaid on the visual reality, while *Augmented Virtuality* (AV) specifically refers to when real objects are overlaid on computer graphics (Milgram and Colquhoun, 1999).

MR has a distinct advantage over VR for delivering both immersive and interactive training scenarios. The nature and degree of interactivity offered by MR systems can provide a richer and superior user experience than purely VR systems. In particular, in contrast to VR, MR systems can support manual interaction of the user with real and/or virtual objects, which is key to achieve active learner participation and skill acquisition (Wang and Dunston, 2005; Pan *et al.*, 2006). However, developments in MR are more recent and still in their infancy, essentially because of the higher technical challenges surrounding specific display devices, motion tracking, and conformal mapping of the virtual and real worlds (Martin *et al.*, 2011).

With regard to construction training, MR systems reported to date mainly focus on equipment operator training, with human-in-the-loop simulators. According to the definitions above, these simulators can be considered as AV systems. For example, Keskinen *et al.* (2000) developed a training simulator for hydraulic elevating platforms that integrates a real elevator platform mounted on 6-DOF Stewart platform with a background display screen for visualization of the virtual environment. Standing on the platform, the operator moves it within the virtual environment using its actual command system and receives feedback stimuli through the display and the Stewart platform.

Noticeably, this and other similar AV-type systems are not fully immersive and thus, from a visual perspective, do not provide a full sense of presence. In an attempt to address this limitation, Wang *et al.* (2004) have proposed an AR-based Operator Training System (AR OTS) for heavy construction equipment operator training. In this system, the user operates a real piece of equipment within a large empty space, and feels that he and the piece of equipment are immersed in a virtual world (populated with virtual materials) displayed in AR goggles. However, this system appears to have remained a concept, with no technical progress reported to date.

To the knowledge of the authors, no work has been reported to date on developing MR systems for the training of 'manual' construction trades, such as roofing, painting and decorating, bricklaying, scaffolding, etc. The particularity of manual trades is that the trainee must be in direct manual contact with tools and materials. Immersing their work thus requires specific interfaces for tracking the limbs of trainees (particularly the arms and hands), and integrating the manipulations with virtual environments. Research has been widely conducted to develop such interfaces. Haptic gloves or other worn devices are investigated (Tzafestas, 2003; Buchmann *et al.*, 2004), but are invasive. Non-invasive vision-based body tracking solutions have also been considered (Hamer *et al.*, 2010), but are usable only within small spaces. Thus, despite continuous improvements, current solutions for manual interactions with virtual environments do not provide the richness and interactivity required for effective manual trade training. MR should not (yet) be used for virtualizing 'manual' activity; traditional training approaches using real manipulation of real materials and tools must remain the standard. Nonetheless, existing student training in college workshops does not allow for skills development within challenging realistic site conditions, such as working at height. MR could thus still find its place in the training of ‘manual’ construction trades, but with the sole purpose of visually immersing trainees in varying and challenging virtual environments (not virtualizing their activity) and thereby providing exposure to site experience.

As mentioned earlier, construction site experience is a vital and integral part of apprenticeship training and therefore MR technology could help in preparing trainees for actual site conditions. However, it should be viewed as complementary to real site experience and not a replacement. It could be used as a transition to establish the trainees’ readiness before they can actually go on-site.

3 Activity Tracking in Construction

Activity tracking involves monitoring and analysing physical activities of workers in minute details, which can in turn provide objective (and quantitative) performance feedback in relation to occupational safety, ergonomics and physiological aspects, and productivity. Appropriate body poses and systematic methods of carrying out physical activities would not only improve labour efficiency but also address long term health well-being of the worker (Li and Lee, 2011; Peddi *et al.*, 2009; Cheng *et al.*, 2013; Escorcia *et al.*, 2012).

Figure 3 summarizes the process of activity tracking using motion tracking. Previous research on temporal tracking of construction activities has largely focused on the domains of health and safety, progress monitoring and productivity analysis (Figure 4). Various technologies have been trialled for sensing positional information for activity tracking. They include vision, depth sensors, GPS, RFID and Ultra Wide Band (UWB) (see Figure 2) (Teizer and

Vela, 2008; Teizer *et al.*, 2009; Cheng et al, 2011; Gong and Caldas, 2009; Yang *et al.*, 2011).

Vision based techniques are available at low costs. Gong and Caldas (2011) presented a concept and preliminary results on using videotaping to track construction resources, classify work state, and subsequently infer performance. Li and Lee (2011) proposed a video based 3D human skeleton reconstruction, using dual network surveillance cameras, specifically for back-bending activities. Revolutionary depth sensing techniques, using laser range finders (Cheok and Stone, 2004) and infrared vision-based solutions, such as Kinect, are complementary to pure vision based techniques. Escorcia *et al.*, (2012) and Ray and Teizer (2012) both proposed using off-the-shelf depth sensors to track construction worker's postures, and particularly body joint angles and spatial location, for the purpose of analysing ergonomics in construction activities. Notwithstanding the potential value of these techniques, they require dedicated physical infrastructure to be installed at the location where the activity is being conducted, only work with line-of-sight, and are affected by the lighting conditions. All this prevents them from being used ubiquitously.

Global Navigational Satellites Systems (GNSS), e.g. GPS, are widely used for positional and navigational measurements, (Peyret *et al.*, 1997; Sacks *et al.*, 2005). The main issue is that they require a good line of sight with the satellites, enabling them to be used only in open outdoor environment.

RFID and UWB are radio frequency based technologies that can be used for real-time location tracking. While their value to material and tool tracking has widely been demonstrated (Chen *et al.*, 2002; Jaselskis and El-Misalami, 2003), their positioning accuracies are too limited for fine body motion tracking (Teizer *et al.*, 2013).

Figure 2: Examples of existing activity tracking technologies in construction industry

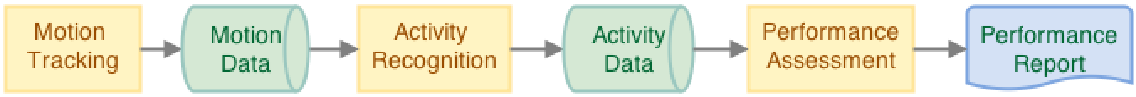


Figure 3: From physical motion tracking to activity tracking

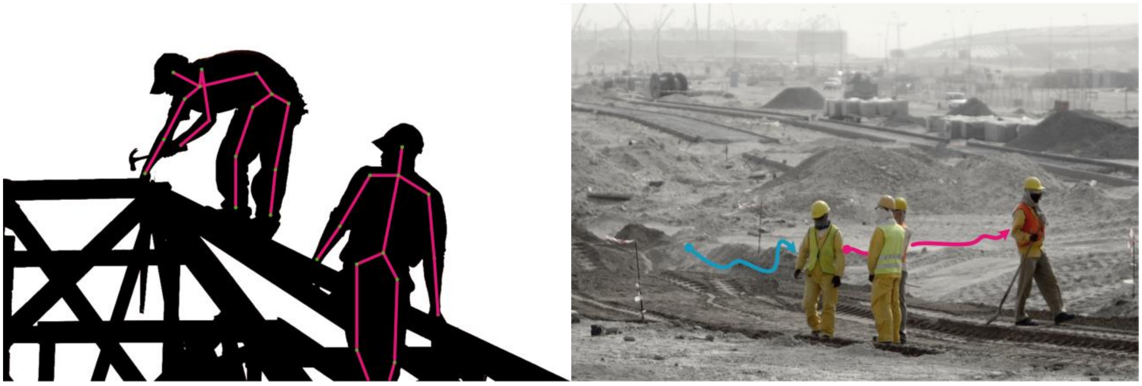


Figure 4: Skeleton tracking based on 3D image sensing (left) and Human motion analysis (right).

All the technologies above are attractive since they are available at declining costs and increased reliability. However, as has been shown, they all present various limitations that prevent them from providing data in sufficient detail for complete body motion analysis, or require specific external infrastructure, which prevents them from covering large areas.

Exoskeleton style devices are investigated for collecting complex kinematic motion data, and are particularly applicable to spinals movements related with back injuries (Marras, 2000). Recently, Alwasel *et al.* (2013) proposed to use magneto-resistive angle sensors for measuring body posture angles (e.g. shoulder joint and knee angles) and characterising injuries. These systems provide detailed and an accurate body motion data, and address the limitations of the previous technologies. Their main limitation is that they can be invasive (which can impact worker mobility and productivity); they are sometimes also expensive, and thus not generalizable.

4 Immersive and Controlled Environment (ICE)

The *Immersive and Controlled Environment (ICE)* aims to develop state-of-the-art MR and Activity Tracking technologies with focus on construction ‘manual’ trade training. The *Immersive Environment* employs MR technology to enable the trainee to experience virtual construction environment while conducting real tasks (with their actual hands and tools). The *Controlled Environment* aims to track the trainee’s motion and activity, and subsequently provide objective feedback on their H&S and productivity performance.

Altogether, ICE will support and enhance the quality of training provided to construction ‘manual’ trade occupations, such as scaffolding, roofing, painting and decorating, bricklaying, etc. To our knowledge, this is the first reported attempt to use such technologies for training of construction manual workers. The next section outlines the concept of ICE which is currently under development with encouraging early results.

4.1 Immersive Environment – MR technologies

It was concluded in Section 2.3 that ‘manual’ trade training can benefit from MR by employing it solely to visually immerse trainees, while they conduct training activities with real tools and materials. Referring to the taxonomy of Milgram *et al.* (1994; 1999), the type of system required appears to correspond to MR systems they classify as *Class 3* or *Class 4* (see Table 1). However, we also observe that, from a visualization viewpoint, this more specifically requires that the trainee be able to see their real body and real work (tools, material), and see these immersed within a virtual world. This means that the system would have to calculate in real-time in which parts of the user’s field of view the virtual world must be overlaid on the real world, and which parts it shouldn’t. This requires that the 3D state of the real world be known accurately and in real-time (the 3D state of the virtual world is naturally already known). Referring again to the taxonomy of Milgram *et al.* (1994; 1999), the type of system required thus needs to have an *Extent of (Real) World Knowledge (EWK)* where the depth map of the real world from the user’s viewpoint is completely modelled (see Figure 5).

Table 1: Some major differences between classes of Mixed Reality (MR) displays (Milgram *et al.*, 1994).

Class of MR System	Real (R) or Computer Generated (CG) world	Direct (D) or Scanned (S) view of substrate	Exocentric (EX) or Egocentric (EG) reference	Conformal mapping (1:1) or not (1:k)
1. Monitor-based video, with CG overlays	R	S	EX	1:k
2. HMD-based video, with CG overlays	R	S	EG	1:k
3. HMD-based optical see-through, with CG overlays	**R**	**D**	**EG**	**1:1**
4. HMD-based video see-through, with CG overlays	**R**	**S**	**EG**	**1:1**
5. Monitor/CG-world, with video overlays	CG	S	EX	1:k
6. HMD/CG-world with video overlays	CG	S	EG	1:k
7. CG-based world with real	CG	D, S	EG	1:1

object intervention				

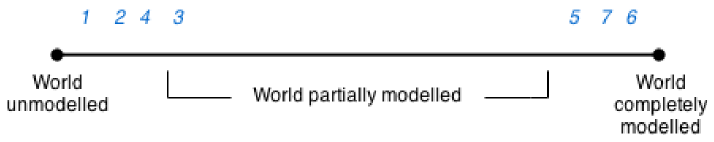


Figure 5: Extent of World Knowledge (EWK) dimension (Milgram *et al.*, 1994).

From this analysis, we have derived a list of required functionalities and corresponding components that include: HMD (preferably, but not necessarily, see-through); 6 DOF head tracker; Depth sensor; Virtual world simulator; Processing unit for calculating the user's view of the mixed real and virtual worlds. Figure 6 shows a diagram of the system's process, highlighting where these components are required.

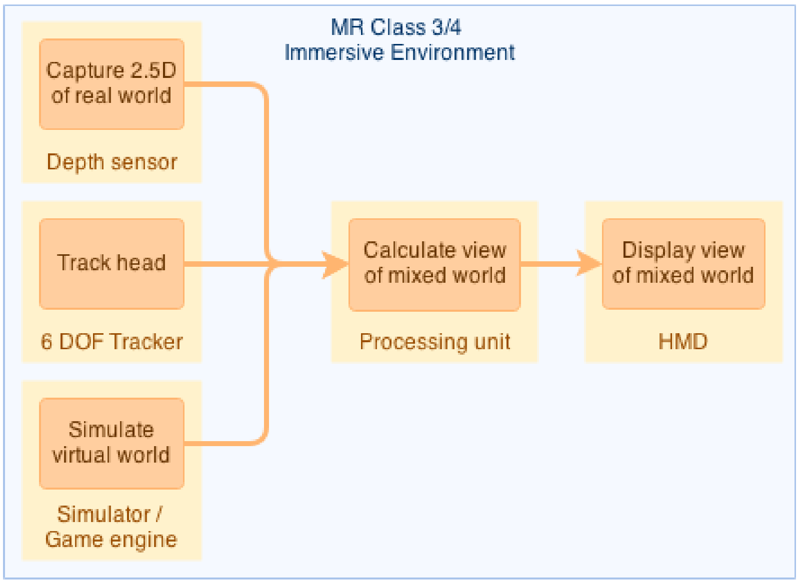


Figure 6: Process and associated components for delivering the envisioned immersive environment.

Some of the above components are readily available. However, some still require development, and their overall integration remains a significant challenge – never attempted in the proposed way. We summarize below what solutions can be used:

- **Simulators / Game engines** are readily available. They can deliver realistic virtual environments with robust and convincing physics. While the first results presented later use a simple static 3D model renderer, we intend to later employ a game engine like Cry Engine.
- **Depth sensors**: Recent years have seen significant progress in and the commercialisation of range cameras. For example, SoftKinetic commercialises two cameras, *DepthSense 325* (SoftKinetic, 2013a) and *DepthSense 311* (SoftKinetic, 2013b), that provide short depth map sensing (<1m and <5m, respectively).
- **6 DOF Tracker**: Inertial Measurement Units (IMU) can integrate numerous sensors like gyroscopes, accelerometers, compass, gravity sensor, and magnetometer. They are mainly used to track orientation, and are now very robust. Although there are claims that IMUs can track translation, our experience – as well as that of others – is that this is prone to drift that very rapidly leads to unreliable information. Alternative motion tracking technologies were reviewed in Section 3 (in the context of motion tracking for performance assessment), but they either do not work indoor (e.g. GNSS) or do not provide the level of accuracy necessary for MR applications (e.g. UWB, RFID).Vision-based approaches with tracked markers can provide accurate 6DOF data, but require significant infrastructure (cost), line-of-sight, and are somewhat invasive. In an effort to address these limitations, we have been investigating a visual-inertial approach for 6DOF position tracking that integrates an IMU and a markerless vision-based system (see Section 4.1.1).
- **HMD:** The *Oculus Rift* (Oculus, 2013) is a non-see-through HMD, i.e. VR, device that is now commercialised, mostly for gaming applications. Even more recently, META has announced its *Spaceglasses* (META, 2013) that is a see-through HMD, i.e. AR, device that will be available in 2014. Oculus Rift and Spaceglasses both integrate

IMUs; and the *Spaceglasses* also integrate a *DepthSense 325* camera (supporting hand tracking). The Spaceglasses thus seem to already deliver the functionality of three of the five components identified in our envisioned system – although the range of the *DepthSense 325* camera is likely too short.

4.1.1 Preliminary Results

We have developed a VR Immersive Environment (Figure 7) that uses the *Oculus Rift* to display the 3D virtual environment to the trainee and implements a novel visual-inertial 6DOF head tracking system. For the head tracking, we use the IMU integral with the *Oculus Rift*, in combination with a dedicated markerless vision-based system that we have developed. The latter relies on texturing the training room with posters, and then conducts an off-line 3D reconstruction of that room using a digital camera. The same camera is then mounted integral with the HMD and its location is identified and tracked on-line by matching image features to those contained in the 3D reconstruction. The IMU data is combined with the vision-based data in the real-time 6DOF localisation algorithm; it particularly helps maintain reliable tracking when the vision-based system has failed and is reinitialising. More details about our approach and initial results on its performance can be found in (Carozza *et al.*, 2013).

Figure 7: Our proposed approach to 6DOF head tracking and HMD-based immersion.

The main focus of this first work has been on enabling trainees to experience height. Note that for H&S reasons, trainees in colleges cannot be physically put at heights above approx. 5m. Two scenarios have been considered: standing on a scaffold at 10m altitude, and sitting on a structural steel beam at 100m altitude. Early presentation of the system to FE college students and trainers shows that such a system could play an important role in enabling trainees to safely experience different working conditions at height, to develop their readiness to such situations that they may later encounter in the real world.

Our next step is to develop the 3D sensing and world mixing functionalities, so that trainees can see their own body and selected parts of the surrounding real world, which is necessary to enable them to conduct actual construction tasks within varying virtual environments. To achieve this, we intend to integrate a 3D camera, e.g. *DepthSense 311*, on top of the HMD, and use the depth information to create consistent views of the mixed real and virtual worlds. Figure 8 illustrates the resulting system.

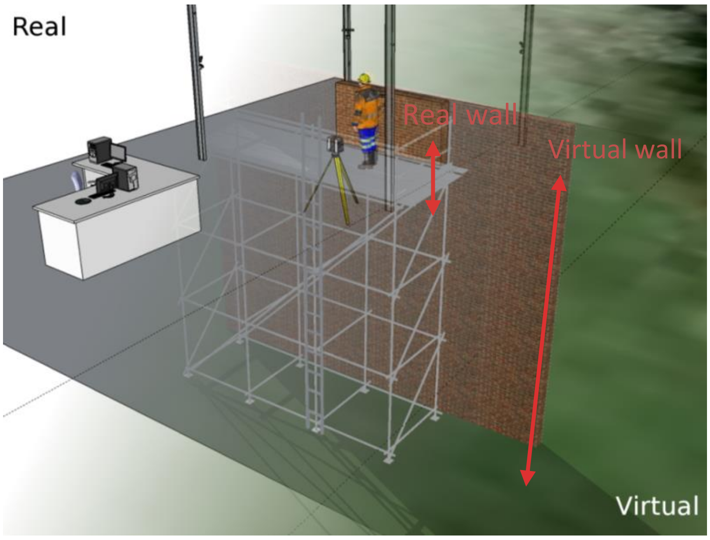


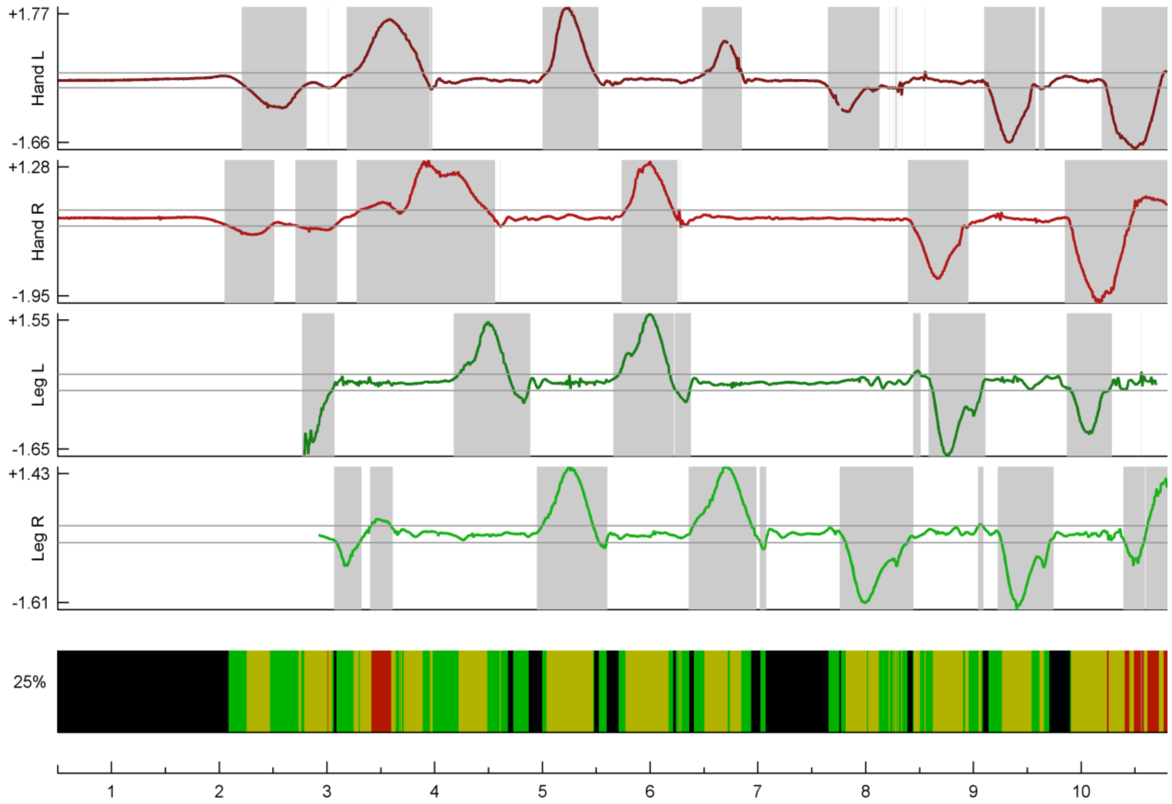
Figure 8: Illustration of the use of the proposed immersive environment to immerse trainees and their work (e.g. bricklaying) within a "work at height" situation.

4.2 Controlled Environment – Activity tracking technologies

The *Controlled Environment* of the ICE will employ a state-of-the-art wearable system for motion tracking integrating IMUs judiciously located on the trainees' bodies and wirelessly transmitting the data to a recorder. The IMUs will record the movements of the limbs and the processing of this data will enable the inference of valuable information with regard to health, safety and productivity. The advantage of using such a system over existing ones is that its level of invasiveness would be minimal, and would enable tracking activities in any environment – not just in FE college labs but also in actual jobsites – with minimal costs.

While we are currently developing the IMU sensor system, we have also already conducted experiments employing a proxy system with the aim of proving the concept. As illustrated in Figure 1, the proxy system employs a series of infrared cameras installed on a frame and that can track small markers balls in the 3D volume defined by the frame. Our proof-of-concept experiment consisted of tracking four markers on the hands and ankles of a trainee climbing a ladder (see Figure 9). An algorithm has then been developed that is able to identify from the markers' acceleration data whether the trainee manages to constantly maintain 3-points of contacts when going up and down the ladder – which is considered best practice in terms of safety standards. Figure 10 shows the performance chart outputted by the system that highlights when the trainee failed to maintain 3-points of contact (which is indicated in red), and also gives an overall score (25%) on the performance of the trainee in that regard over the duration of the ladder climbing exercise. These results are very encouraging as to the potential of our proposed IMU-based system. It is interesting to note that these experiments also highlighted the difficulty for humans to identify the issues spoted by our system. This is mainly explained by the fact the motion studied involves several limbs.

Figure 9: Ladder climbing analysis using the proxy vision-based system. The red circles highlight the infrared cameras on their frame. The red arrows depict the location of vision trackers (i.e. the location of IMU sensors in the future system).



Movement Detected in **No Limbs**	⬛
Movement Detected in **One Limb**	🟩
Movement Detected in **Two Limbs**	🟨
Movement Detected in **Three Limbs**	🟥

Figure 10: Ladder climbing data and performance chart obtained using the system depicted in Figure 9. The four graphs refer to the left/right legs/hands. The bottom diagram highlight when the system detected multiple limb movements. An overall percentage score is calculated and presented (on the left) as to the performance for the activity (here 25%).

4.3 Scope of application of ICE

Initially, the application of the ICE is piloted with focus on ‘work at height’ situations. With the Immersive Environment, trainees can experience height; with the Controlled Environment, their performance can be objectively tracked and assessed when carrying-out an activity such as ladder climbing. The reason for selecting working at heights is that it is common across many construction trades – such as scaffolders, roofers, steeple-jacking, painting and decorating – and also because falling from heights is the most common cause of construction fatalities.

Whilst the number of fatalities in construction has considerably decreased from approximately 150 in 1990 to 50 in 2009, there is still a need to do more to realise the vision of Sir John Egan (1998) for having zero accidents on construction sites. In 2009, it was found that falling from height still accounted for nearly 50% of the fatalities. Falls from edges and opening account for 28% of falls, followed by falling from ladders (26%), and finally scaffolding and platforms (24%) (HSE, 2010).

Similarly, in the US the most common risk factors for falls from heights in the construction industry are falling from a scaffold and ladder (Rivara and Thompson, 2000). As such, fall prevention and safety training is an essential part of the scaffolding training in the UK, with the provision of a half-day fall prevention workshop. However, there is a need to assess the impact of training on the reduction of falls from height. Quantifying the effectiveness of craft training using surveys and other subjective techniques (such as site observations) cannot provide objective and quantitative feedback on trainees' performance (Teizer *et al.*, 2013). Therefore, the application of technology in a training environment for automated detection, recording, and replaying of feedback information can become a powerful tool to engage workers and emphasise safer work practices (Teizer *et al.*, 2013).

It would be interesting to conduct a comparative study between traditional forms of construction training delivery and assessment (in a conventional workshop or classroom setting) as opposed to when using MR and activity tracking technologies (ICE) in order to demonstrate the impact of employing such technologies on trainees performance. Furthermore, the use of objective and quantitative feedback for trainees, e.g. using ICE, can provide the basis of comparison and benchmarking of inexperienced trainees against experienced ones, reward systems for safe performance during training sessions (Teizer *et al.*, 2013).

5 Conclusion

The construction industry has traditionally shown poor levels of investment in R&D and innovation and as such is slow in the uptake of new technologies, in particular when it comes to the application of new technologies for education and training (CIOB, 2007). It is claimed that "*courses do not prepare students for the realities of construction sites or even the basics of health and safety and there is a bias towards the traditional trades and sketchy provision for new technologies*" (Knutt, 2012). This underlines the need for investment in new technologies to support construction training. If colleges want to become part of future education they should create change rather than waiting for it to happen to them (Hilpern, 2007).

The ICE presented in this paper is a novel approach that has the potential to transform construction manual training. The VR Immersive Environment enables trainees to experience height, without involving any actual work. This simple exposure already enables trainees to experience such heights and assess their comfort in standing and eventually working in such conditions. Ultimately, it could even enable them to start accustom themselves to such conditions. The next phase of work will aim to develop a mixed reality (MR) environment where the trainee can both experience site conditions whilst performing real tasks. The concept of the Controlled Environment has been presented with early results demonstrating its feasibility. Our next phase of work in this area consists in developing the actual wearable IMU-based system and assessing its performance in capturing motion data that supports the extraction of valuable performance metrics.

The accrued benefits of the application of MR and motion tracking technologies in the ICE can include: enhancing the experience of apprenticeship training, complementing industrial placement and establishing site readiness, skills transfer and enhancement, performance measurement, benchmarking and recording, low operational cost and transferability across the industry. However, all these claims will require further research for validation using actual data.

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