

Construction industry offsite production: A virtual reality interactive training environment prototype

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ABSTRACT

The 'traditional' construction industry has constantly been challenged to improve its inherent problematic practices. Offsite production (OSP), under the umbrella of modern methods of construction (MMC), has been acknowledged as a means to help improve construction industry performance as well as meet new market demands through the provision of improved, adaptable, and sustainable buildings. However, the deployment of OSP systems, if not managed properly, may adversely affect the end result and be counterproductive. It is therefore imperative that the construction industry stakeholders learn and appreciate the specifics, merits, as well as the risks associated with OSP systems in order to achieve the desired outcomes and consequently improve industry performance.

On-the-job-training (OJT) is usually sought to facilitate 'experiential' learning, which is argued to be particularly effective where a great deal of independence is granted to the task performer. However, OJT has been criticised for being expensive, limited, and sometimes devoid of the actual training context. In order to address the problems encountered with OJT, several virtual reality (VR) solutions have been proposed. This paper introduces one such VR solution prototype, in order to provide a risk-free environment for learning without the 'do-or-die' consequences often faced on real construction projects. The proffered solution provides a unique VR environment for practicing new working conditions associated with OSP practices. While the 'scenes' of the VR environment take place on a construction site, the environment predominantly targets professionals, such as project managers, construction managers, architects, designers, suppliers and manufacturers, to allow multidisciplinary learning to occur, and hence overcome 'knowledge silos' or 'knowledge compartmentation'. The VR environment enables unforeseen problems often caused by professionals' decisions, faulty work, and health and safety issues to occur; where the implications of which can be evaluated in respect of time, cost and resources. The VR environment proposed does not aim to resolve problems associated with OSP per se, rather aims to allow 'things to go wrong' and consequently allows users not only to 'experience' the resulting implications but also to reflect on those implications as part of the learning process. This paper discusses and presents the prototype for the first development phase of the VR interactive training environment. While the prototype was tested and validated with domain experts from industry, the research community, and academia from different EU countries, the data used in developing the prototype was constrained to one project in the UK which may limit the generalisability of results.

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1. Introduction

The European Union (EU) construction sector is one of the largest industrial employers, encompassing more than 2.4 million enterprises, with approximately 14 million employees. Hence,

represents a significant importance to the EU, with a Gross Domestic Product (GDP) contribution of 9.9%, and an overall employment rate of 7% of the European workforce [1]. However, the EU construction industry is constantly facing several challenges, not least, regarding its poor performance compared to other sectors/industries. Often, it is argued that construction firms pass up opportunities in new markets due to the lack of relevant skills; which has been attributed to, among others, the reduced attractiveness of construction activities [2]. Furthermore, the construction industry tends to lag behind other industries in terms of

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taking advantage of new technologies and innovative practices. Thus, can compromise improvements in safety, cost effectiveness, quality of life, competitiveness, productivity, etc. [3].

Despite the acknowledged high quality results of EU construction research projects, dissemination and adoption of results by the construction industry have not been overtly prominent [4]. This has been partially attributed to the 'unpreparedness' of the workforce to embrace such technologies [5–7]. Thus, contextualised training and education is anticipated to facilitate the seamless uptake of (new) technologies.

OSP represents an attempt to learn from the manufacturing industry by employing production and industrialisation concepts to the construction industry [8]. In its simplest terms, OSP involves manufacturing the building components/elements in a factory then transport and assemble these on site. OSP components vary considerably, the nuances of which include panelised, volumetric units, and hybrid variants – which involves panelised and volumetric approaches [9]. In applying OSP systems, care need to be taken to not merely move work from site to the factory, as this approach in isolation is unlikely to procure extended benefits from production technology, industrialisation or automation per se [10]. In this context, OSP is not just merely confined to a particular product; rather is broadly based to encapsulate an industry wide business which would require an industry wide strategy to underpin the OSP business [11].

OSP often require the extensive transfer of knowledge and technology across the whole supply chain [12]. Knowledge absorption, diffusion and dissemination require change to take place across cultural silos throughout the whole business process, including organisational structures, roles, and responsibilities. In essence, a collection of mutually shared values, beliefs, strategies and corresponding skill sets are needed to allow stakeholders appreciate and comprehend the specifics of OSP practice. In this respect, the implementation of effective training is expected to strengthen and broaden the impact of OSP to the whole industry by addressing and fulfilling the needs of the disparate stakeholders. However, 'typical' learning models are often criticised for providing general instruction, with the anticipation that the prospective employer would be responsible for delivering 'on-the-job training' (OJT); i.e. providing experience-based training.

Experience-based or 'experiential' learning has the dual benefit of predominantly appealing to the adult learners experience base, as well as increasing the potential of performance change within the organisational environment. OJT has emerged as a core method for capitalising on the value of experiential learning as a tool to develop new employees more effectively through the use of experienced co-workers [13]. This however, is particularly effective where a great deal of independence is granted to the task performer, however invites criticism of being expensive and context constrained [14].

In order to address the problems encountered with OJT, this paper presents a bespoke context-focussed VR solution, the VR Interactive Training Environment. This VR environment was proposed as a way of providing a risk-free environment for learning and experiencing OSP practices, thus, spares users the 'do-or-die' consequences often faced on real construction projects; and consequently, helps learners' upgrade their OSP knowledge and skills to meet new challenges [15].

This VR environment is predominately concerned with projects that employ OSP concepts. The scenes used in the interactive VR environment use a construction site as the focal medium, where unforeseen problems, often caused by: 'inappropriate' high level/strategic decisions, faulty work, unforeseen health and safety issues, etc., would occur. The implications of these decisions can be evaluated in respect of time, cost and resources. The VR environment development concept adopts a 'scenario-based' learning

approach, which specifically allows things to 'go wrong' in order to give learners the opportunity to reflect upon the implications of their decisions and actions. Key messages that may be conveyed through the environment include, but are not limited to, the need for: an overall OSP strategy to underpin the OSP business, OSP business processes, and OSP organisational models which represent the backbone for a successful OSP implementation [8,11].

2. Background

The OSP VR Training environment is one of the deliverables of the Open Building Manufacturing (*ManuBuild*) research project (2005–2009). *ManuBuild* (€10 million), part-funded by the EU IP Framework 6, was a 4 year industry-led research project involving 24 partners across Europe. The project targeted a radical breakthrough from the current 'craft and resource-based construction' to 'Open Building Manufacturing', combining ultra-efficient (ambient) manufacturing in factories and on sites with an open system for products and components offering diversity of supply in the market [16]. One of the aims of *ManuBuild*, was to introduce OSP knowledge, innovative results, and technologies to the EU construction industry using innovative training mechanisms. The VR interactive training environment was sought as a proactive training approach [17] to leverage the *ManuBuild* resultant new technologies and processes; hence help with the acquisition of an extensive range of relevant (new) skills.

The main concept of the VR training environment drew on the Chinese proverb "*I hear and I forget, I see and I remember, I do and I understand*"; stressing that learning can be more effective through 'doing' rather than just through 'hearing' or 'watching' [18–20]. This approach enables linking theory with practical experience, using the VR interactive training/learning environment [21,22].

3. Virtual reality

Virtual reality is subjected to numerous definitions [23]: e.g. 'a computer generated simulation of the real world', 'the illusion of participation in a synthetic environment rather than external observation of such an environment', or 'a computer generated simulation of three-dimensional (3D) environment', in which the user is able to both view and manipulate the contents of that environment'. Hence, VR provides an opportunity to view problems through more than one symbolic representation in order to achieve greater understanding.

From a training perspective, using a VR interactive training environment can often provide means to get learners to experience the training goals [24], help support learning transfer, as well as accelerate learning [25]. In this context, an 'ideal' VR interactive training environment is argued to require a richly defined world, with large amount of actions available to the learner, thus simulating the real world. Each time the learner enters the system/environment, different interactions would lead to different experiences and outcomes, thereby maximising the learning experience. The use of a VR interactive environment approach was therefore seen as an important driver for further enhancing the underlying concepts of the subject matter in general [26,27], especially if it was flexible enough to allow learners to formulate responses and rehearse activities within a controllable environment, build confidence and self-esteem, as well as extend their potential and natural abilities [28].

In an attempt to measure the effectiveness of VR training on learners, an experiment was conducted on Serious Games for Police training (SGTAL). The experiment recorded a minimum of 15 percent up to 50 percent improvement in the performance of the control group [29]. Further success stories have been recorded using VR simulations in large organisations; for example, DELL

used VR environments to allow learners to evaluate how decisions they made would impact their business [30]. Even though this approach was acknowledged as being expensive, it was proved to be effective. Concomitant to this, VR has been recognised as an effective alternative to conventional training approaches, as it can often mitigate the need for dedicated equipment and space requirements [30]. Studies to maximise the effectiveness of learning also noted the need to consider, the age of learners as well as entertainment habits [31], such as playing games, watching films or television, surfing the internet or listening to music. Arguably, it is the approach to that entertainment activity, and the support of peers, mentor or tutor that shapes how and when learning would take place [22]. This may be linked to the theory of motivation which has been evidenced to represent a key aspect for effective learning, which may further be sustained through feedback responses, reflection and active involvement in order for the designed learning to take place [22,28,32,33].

From a pedagogical perspective, examples for the use of pedagogically structured game-based training in various fields and disciplines can be recorded. Eelect Bilat Simulation for example [34] allowed students experience bilateral meetings, which require familiarisation with the cultural context, gathering intelligence, negotiating, and following up on meeting agreements. The scenarios used for this training was based on problems encountered in different locales around the world. Another example can be found in training health emergency first responders [15]. This environment used a semi-autonomous virtual assistant (VA) which receives commands from the trainee (the decision maker) who is put under stress to simulate real-life situation. Another face-to-face interactive learning environment [35] used animated life-like autonomous characters, pedagogical agents, who interact with students through verbal interaction, demonstrate complex tasks, and convey emotional responses to the tutorial situation e.g. naval training tasks, family medicine, and graduate level geriatric dentistry [35].

Within the context of the construction industry, VR has been mainly employed for analysing issues occurring on the construction sites, such as: engineering design, process, logistics concerns, as well as operatives training [36]. However, these initiatives have often been criticised for simulating the construction processes on the assumption that all circumstances are optimal; that is, there are no external interruptions (such as human failures), assuming ideal weather conditions, in addition to the absence of health and safety issues etc. which could adversely impact the progress [37]. Therefore, there was a pressing need for real world events to be appropriately captured and managed within a VR environment in order to 'engage' learners by putting them in the role of decision-makers and 'pushing' them through these 'unpredictable' challenges and hence, proactively promote learning through direct

interaction and feedback with the real world context [28,32,38]. Further progress on this theme, a VR construction training initiative in the Netherlands, the "Construction Manager Training Simulator (BMSC)" (Fig. 1.), has made a positive inroad into the exploitation of this technology [37]; and a similar arrangement has been recently launched in the UK under the project ACT-UK (<http://www.act-uk.co.uk/>). Both of these VR training systems were designed to ensure that (potential) construction managers encountered similar situations and problems usually faced on 'real' construction projects using virtual building sites. Notwithstanding the success of these, the primary beneficiary is functionally targeted towards a job-specific operation, e.g. construction managers, and the successful deployment of this approach requires 'real' actor support in order to fully manage the learning process. A downside to both systems (BMSC and ACT-UK) is that they do not facilitate direct learner interaction with the VR environment (apart from the walkthrough the environment); consequently, they do not allow learners to experience the progressive impact of their actions.

4. VR interactive training environment development concept

Pairing instructional content with certain game features can arguably engage users' motivation to achieve desired instructional goals. This rationale was approached and underpinned by applying the input-process-output model of instructional game characteristics matched to specific learning outcomes [40]. The objective was to design an instructional programme that incorporated certain features or characteristics of games which could 'trigger' cycles of interaction, such as: user judgment, enjoyment levels, persistence or time on task pressures, competitiveness, and bespoke system feedback (Fig. 2).

Recent work of adopting gaming characteristics to enhance blended learning solutions has been openly acknowledged to follow a four dimensional framework (Fig. 3), namely: learner's dimension; representation; context; and pedagogy [22,28]. The learner's dimension involves a process of profiling and modelling learners and their characteristics in order to ensure there is a match between the learning activities and the required learning outcomes. The representation dimension outlines the interactive learning experience, such as immersion, fidelity, and level of interactivity which affects the level of engagement and motivation. The context dimension defines the place where learning takes place, e.g. in a school/work environment, as this can affect the disciplinary context, particularly whether the learning is conceptual or applied. Finally, the pedagogy dimension analyses the pedagogic perspective of the learning activities, and considers the learning and teaching models/styles adopted and the methods used for



Fig. 1. Construction Manager Training Simulator Centre (BMSC) [39].

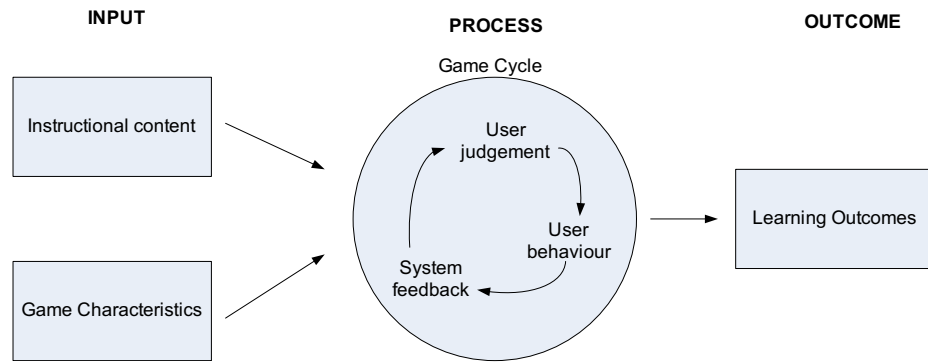


Fig. 2. Instructional game model input-process-outcome [40].

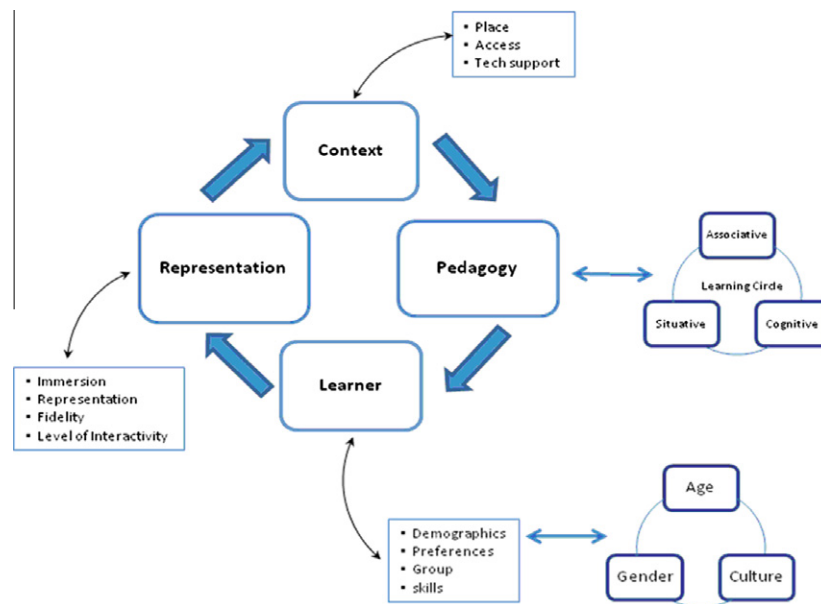


Fig. 3. The four dimensional framework [22].

supporting the learning processes. The efficacy of this approach has demonstrated several benefits, including the importance of formative feedback delivered through high quality virtual environments in the support of accelerated learning [25].

Drawing on the Four Dimensional Framework (Fig. 3), and due to the complexity and richness of the envisioned end product, the OSP VR interactive environment is anticipated to undergo at least three stages of development (Fig. 4) with regards to the representation dimension particularly the degree of immersion and level of interactivity. The first stage representation is primarily a desktop-based representation, where the degree of immersion is increased as the development progresses to the second and third phase, where full immersion is anticipated.

From a context point of view (Fig. 3), the environment was designed to take place at a Higher Education (HE)/university setting to support OSP multidisciplinary education. The scenario complexity is tailored to accommodate the knowledge of users and intended learning outcomes. In this respect, as the design rubrics were established to meet industry needs, some priori cognate knowledge is required to maximise learning outcomes. The learning outcomes were therefore aligned to Level 'M'/Level 7 descriptors (postgraduate) in order to engage critical thinking abilities; which was deemed particularly important, as learner decisions at all stages of the scenario often had multiple outcomes. This

approach was also adopted to address commercial and strategic drivers required by industry and professional practice. The second stage of development is expected to allow the VR environment to be used for assessment through Continuing Professional Development (CPD) and short course training provision. Notwithstanding this, the first two stages of development (and in preparation for the final stage of development), further practical case studies will need to be collected and collated in relevant databases to support the third and final stage. This final phase is anticipated to incorporate artificial intelligence technology to support the provision of a fully immersed rich training environment, which can then be commercialised and used for certification and qualification purposes (Fig. 4).

5. Scenario development – phase I

The first stage of development – the scope of this paper (Fig. 4) was primarily concerned with training and education/awareness purposes, and was designed to fulfil a number of criteria. In this context, OSP working practices were incorporated in the design of the different scenarios. In order to satisfy the representation element, all scenarios and scenes would take place on a virtual construction site using real construction project

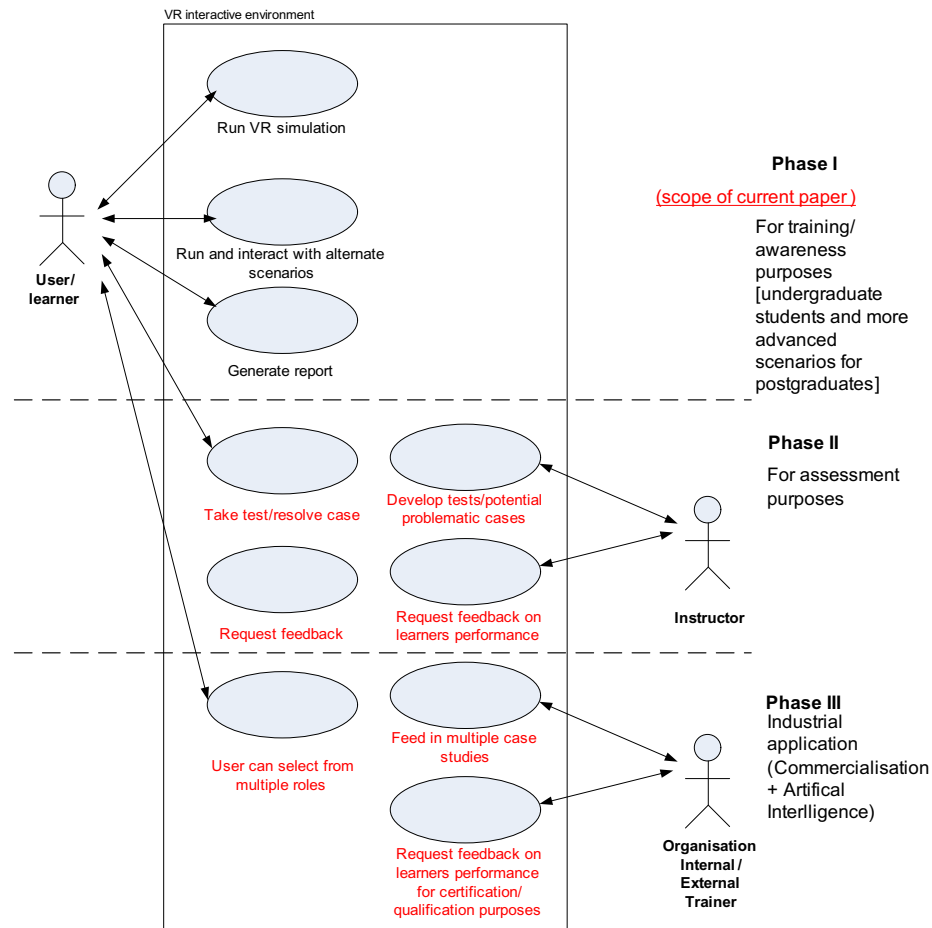


Fig. 4. The three development stages of the VR interactive training environment.

information. Using the environment, learners would predominantly play the role of a construction manager. However, messages and training objectives would target multidisciplinary stakeholders involved in a construction project e.g. project managers, designers, architects, consultants, suppliers, manufacturers, etc.; to help overcome the problem of 'compartmentation' of knowledge [41].

The main training objectives were concluded from a synthesis of seminal literature covering the potential risks and threats facing OSP practices in general [9,11,42,43], and open building in particular [16]. These objectives were validated with six domain experts representing industry, academia, and research who were involved in OSP to verify relevance, priorities, and nature of intended learning outcomes (Fig. 5). The capture of this knowledge was perceived

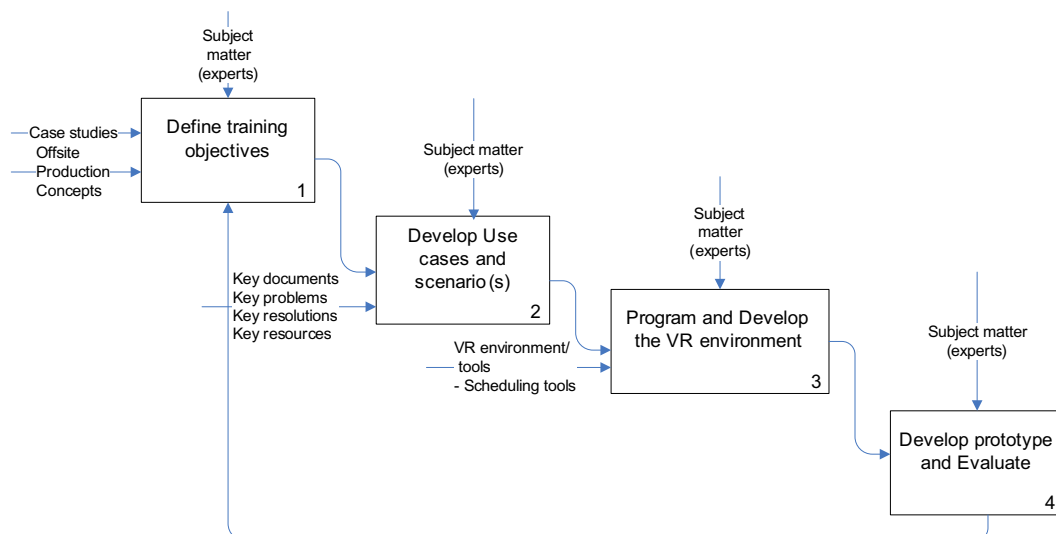


Fig. 5. The concept for scenario development.

to be fundamental in order for learners to fully appreciate the distinct nuances of OSP in relation to traditional working practices, especially where multiple stakeholder perspectives are involved. The captured training objectives are then used to inform the development of use cases (Fig. 9) and scenarios (Appendix) which encompass real-life problems, resolutions, and resources. The scenarios were developed by ‘mapping’ the implications of potential problems arising against potential mitigation actions. In this respect, OSP practices associated risks encompass issues related to the design and planning phases such as late design changes and unpredictable planning decisions. From the manufacturing side, potential risks include loss of factory production, failure to meet delivery times, and manufacturer bankruptcy [9,11,42,43]. In this context, mitigation may be achieved through numerous actions such as involving manufacturers/suppliers at an early stage, ensure effective communication takes place to allow to prepare for peak production periods. This need to further allow greater standardisation and collaboration between stakeholders; which eventually would need embracing good procurement and management practices [9,11,42,43].

The main concept for scenario development was based on identifying all possible problems/issues and interruptions (i.e. problem 1, problem 2, etc.) arising that new learners to OSP would typically face. These problems were mapped using a decision tree approach (Fig. 6). For each of the identified problems, there are a number of possible decisions and associated actions that need to be taken. Depending on the action chosen and time taken by the learner, the programme schedule, along with corresponding costs, time, and resources would be automatically affected (Fig. 6). These scenarios were used to mirror how OSP processes typically operate in real-life (as opposed to conventional practice), in order to directly provoke learners to think ‘how’ and ‘why’ things went wrong. This mandate was adopted in order to allow learners to holistically reflect on their ‘traditionalist’ thinking, as opposed to the ‘new’ thinking required for OSP. Rigidly following existing practice

(without changing the thought processes) would invariably mean that OSP would end-up being more expensive than the traditional way of working and thinking. Therefore, as part of the learning process, learners are ‘pushed’ to think and reflect on ‘how’ these problems could have been avoided from the outset – see Appendix for scenario.

From a learner’s perspective, the challenge set at the outset is to successfully manage a construction site using OSP practices. In this respect, a VR model was developed based on an actual construction site in the UK. This allowed the development team to mirror issues faced in real life, in order to capture and represent these in the VR environment. This posed several challenges, not least the myriad of issues and outcomes that needed to be incorporated into the decision engine. Therefore, in order to provide clarity of purpose, it was decided that learners should be given a variety of choices before they actually ‘enter’ the scenario. Their selections would have a direct impact on the scenario triggered during the course of the session. These initial selections addresses issues related to the building structure/design, site layout, work plan and associated processes, as well as manufacturing options. The information required to feed in, develop, and run the different scenarios based on the initial selections include the characteristics of the structure, the construction activities sequences, and potential interruptions (Fig. 7). From Fig. 7, scenario information is presented in a work breakdown structure. This identifies the main areas (design; site layout; work plan; manufacturing) that have causal influences on preceding/succeeding events (and on project success). Therefore, any decisions made in these areas would more often than not influence the options available upstream. For example, changing one aspect the physical characteristics of an element could affect the means of transportation required, logistics management arrangements needed, resources required, etc. This approach allows learners to gain an overall understanding of the different OSP building components/classifications, and hence, the associated constraints. This also applied to the different site layout/location requirements

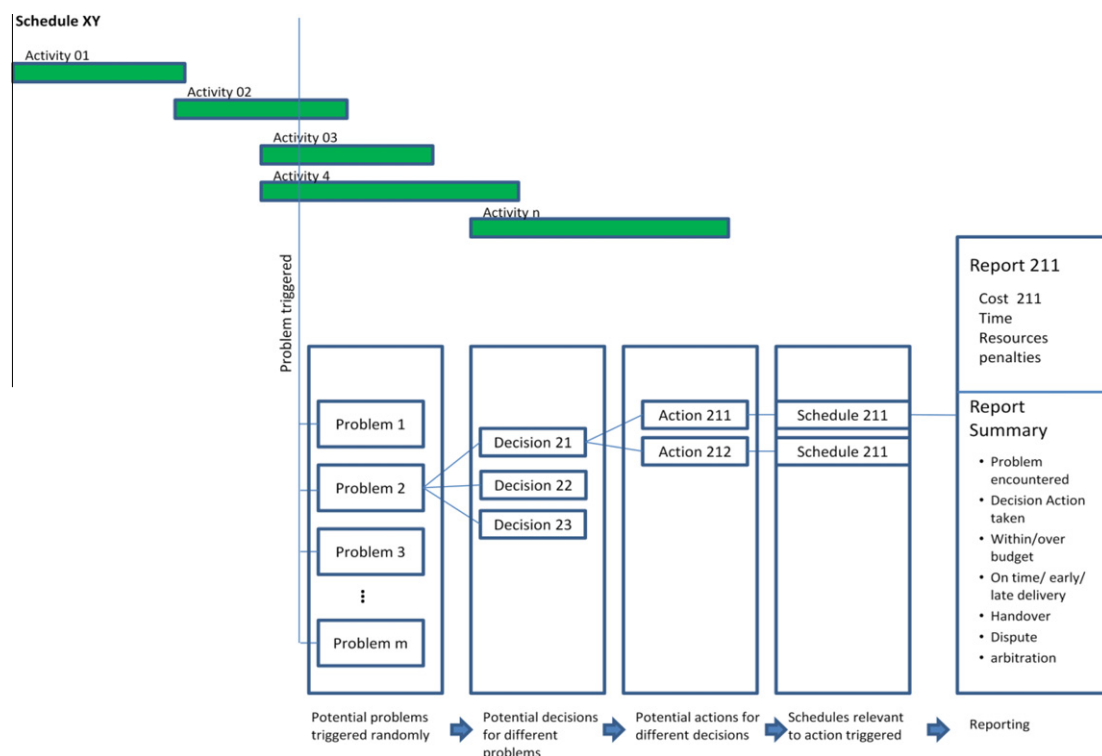


Fig. 6. Mapping potential interruptions and implications [21].

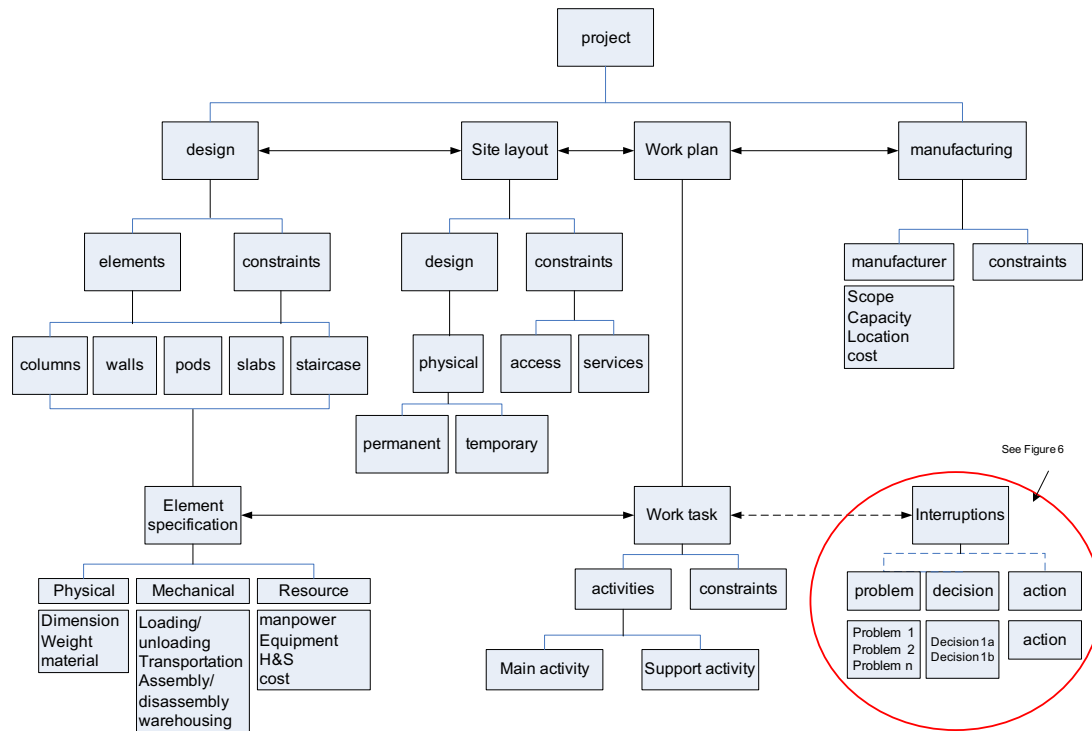


Fig. 7. Scenario information breakdown structure [21].

including any temporary work required which would vary based on the OSP system chosen, as well as on the selection of the manufacturer. In this respect, for each option chosen, a series of sub-options become available with their respective implications which would have a direct impact on the project when it commenced.

6. System architecture

The VR training environment prototype system architecture encompasses three main components: the content management system (CMS), the data framework, and the 3D visualisation engine

(Fig. 8). The CMS encompasses a relational database, which stores all the operational data for the scenarios (i.e. scenario content, project data, manufacturer data, equipment data, 3D model, etc.). In this respect, the CMS is the conduit for the organisation and throughput of tasks allocated to learners for each particular scenario. Tasks are organised according to a pre-planned decision tree (Fig. 6, Appendix), the rubrics of which are built up from a number of scenario steps, each one of which contains one or more decision sets [15]. Learners are therefore systematically guided through each scenario based upon preceding decision(s). This approach is further supported by 'virtual characters', which interact with and instruct learners using emails generated through the system when

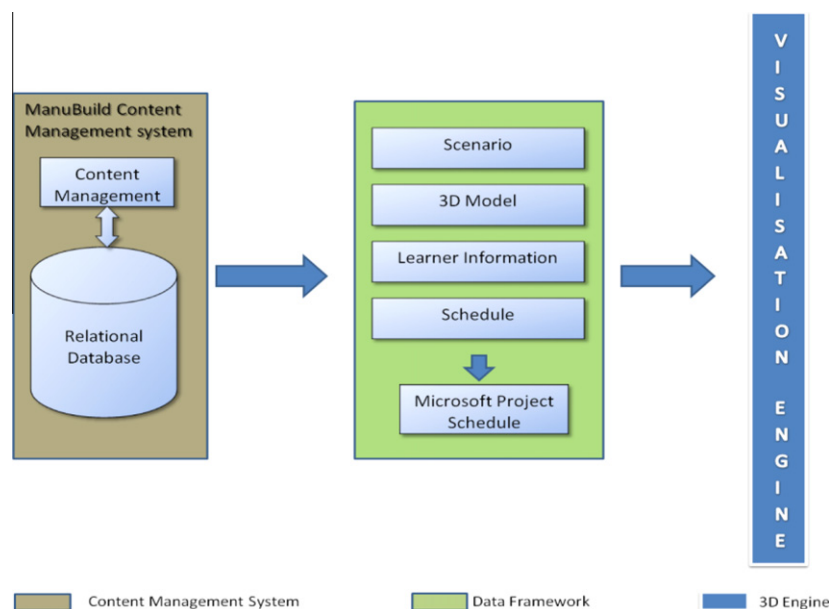


Fig. 8. VR environment system architecture [45].

Use Case:	User learns about and experiences OSP related concepts and working conditions
<u>Design Scope:</u>	Virtual Reality interactive Learning Environment
<u>Context of use:</u>	user learns about OSP concepts
<u>Primary Actor:</u>	construction manager
<u>Target Stakeholders:</u>	<ul style="list-style-type: none"> - project manager - designer - consultants - suppliers - manufacturers, etc.
<u>Simulation Requirements</u>	<ul style="list-style-type: none"> Simulate site operations Generate reports Save/reload sessions Run possible 'scenario directions/alterations' randomly Interrogate learners knowledge (Phase II and III of development) Generate feedback to learner
<u>Main Scenario</u>	<ol style="list-style-type: none"> 1. User initiates and saves a session (creating username and password) 2. User selects a site location (urban – rural – suburban) 3. User selects construction system (panelised, volumetric, hybrid, component subassemblies) 4. User selects manufacturer 5. User selects equipment 6. System prompts with the total budget and time frame of the project 7. System simulates site operations (delivery – transportation – assembly) based on decisions/selections made by user 8. User interacts with/interrogate environment 9. System triggers problems (problem1, 2, etc.) 10. User takes action 11. Scenario affected according to action 12. User requests report(s) 13. System generates report (planned/actual) 14. System saves session

Fig. 9. VR training environment use case.

problems are triggered. These emails either prompt users for an immediate decision, or provide them with further details on a particular issue, so that learners are then able to act upon this 'advice' to make more informed decisions. The data framework is the formal interface between the user and the system, and is used for triggering the relevant scenario, generating the 3D model, and accessing the project schedule. Finally, the 3D visualisation engine is the means through which this data is visually represented. The visualisation engine used in this simulation model is based on the parallel graphics virtual reality modelling language (VRML) Cortona client [44]. This arrangement allows a seamless transfer of data between the data framework and the relational database held in the CMS.

The visualisation component of the VR environment plays a major role in communicating and conveying the intended learning outcomes; hence, it was deemed pivotal for allowing experiential learning to take place. The VR environment is therefore affected by the decisions made by the user, reflecting real life situations. For example, if the user takes a long time to make a decision, this will consequently affect time and cost involved. This would be visualised by equipment and resources becoming idle and consequently the delay of succeeding activities. In this context, if the user's decision/action resulted in exceeding the project timeframe, then liquidated damages would apply. According to contractual obligations, the user would receive (through the system) notification of the liquidated damages, which would be 'sensed' in the project time schedule linked to the environment that the user can review and interact with at any point of time during the session (Figs. 10 and 12).

From a systems development perspective, the Graphical User Interface (GUI) was designed to be simple and straightforward with respect to data input and navigation in line with the intended use case for the VR environment prototype (Fig. 9). After making

the initial selections, learners are given the opportunity to 'walk-through' the environment from the outset in order to experience and appreciate the complexity of the selected project before the simulation commenced. Other navigation and interaction aids include the ability (at various stages of the scenario) to interact with the different elements of the environment in order to retrieve further information to aid their decision making e.g. technical specifications, videos on selected OSP construction systems/details, project data, etc. [15]. Examples of these interaction points, along with the supporting rationale and associated learning outcomes can be seen in Fig. 10.

In order to help learners purposefully interrogate the VR environment to retrieve information related to the scenario e.g. physical and technical characteristics of the different components, technical and logistical information, etc., the use of a pop-up Personal Digital Assistant (PDA) was incorporated (Figs. 10 and 11).

The application of the PDA interface (Fig. 12) enables learners to retrieve relevant information about the project, equipment used, manufacturing information, project schedule status, cash flow position, delays, etc. Learners can also use this interface to make decisions on a number of problems that are triggered during the session, including matters that directly affect the flow of the scenario, and consequently, have an impact on the overall time and cost of the project. Other information available through the PDA interface includes project progress and cost data, site assembly details, manufacturing processes, connection details, and actual videos covering various complex details.

Learner decisions and actions are formally stored in a database for subsequent retrieval and analysis. This legacy archive includes such issues as the time taken to make a decision in any particular part of the scenario, through to a detailed account of what learners did at certain 'trigger points'. For example, whether they consulted

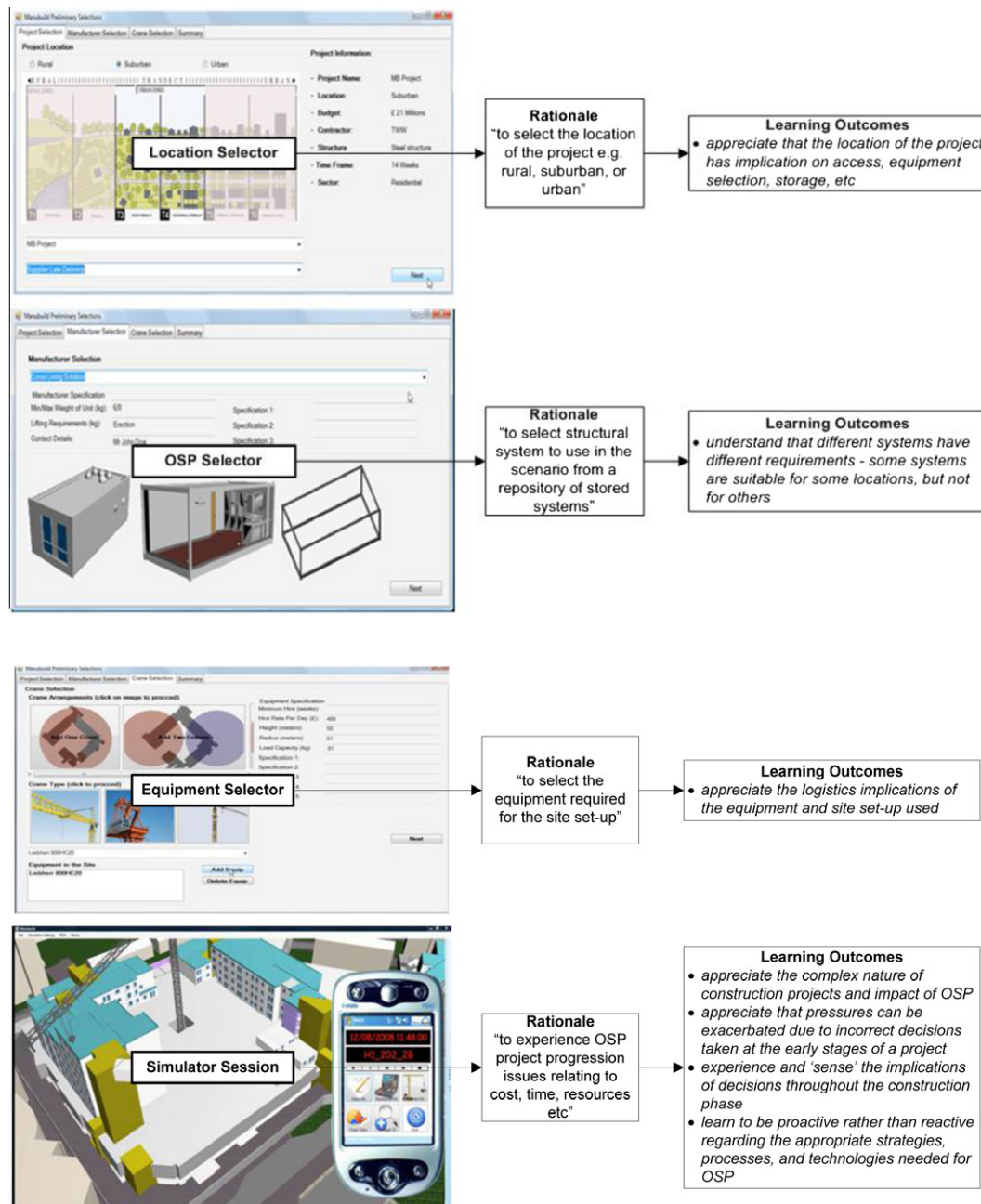


Fig. 10. VR environment main interaction points.

the electronic 'virtual characters' for help, whether they accessed additional information through the PDA, or just selected an option randomly. The main feedback points arising out of this legacy archive are presented to learners in an abridged table format (Fig. 13). This allows learners to see the main decisions they had taken, and how these decisions affected the overall time and cost of the project. However, the real value here on the overall learning process is understanding "why" learners took the decisions they did. The actual level of granularity of detail captured in the legacy archive provides a unique opportunity of personal one-to-one reflection between the learner and instructor and among peers. This detailed critique enables learners to thoroughly understand the nature and consequences of the decisions they have to make in an OSP environment, as opposed to the traditional construction environment. Thus, this debriefing session helps to

disentangle thought processes, and enable critical reflection to take place outside the VR environment [32,47]; where the archetypal issues of "time" and "cost" represent the starting point for discussions.

7. Discussion and conclusion

The VR interactive training environment prototype was iteratively tested and validated with domain experts from industry, research community, and academia, using core expertise from the UK, Finland, Germany, the Netherlands, and Australia, as well as undergraduate and postgraduate students. The validation of the prototype aimed to secure industry as well as academic relevance through validating (a) the relevance of the scenario used, (b) the associated decision tree (see Appendix), (c) user interface, and

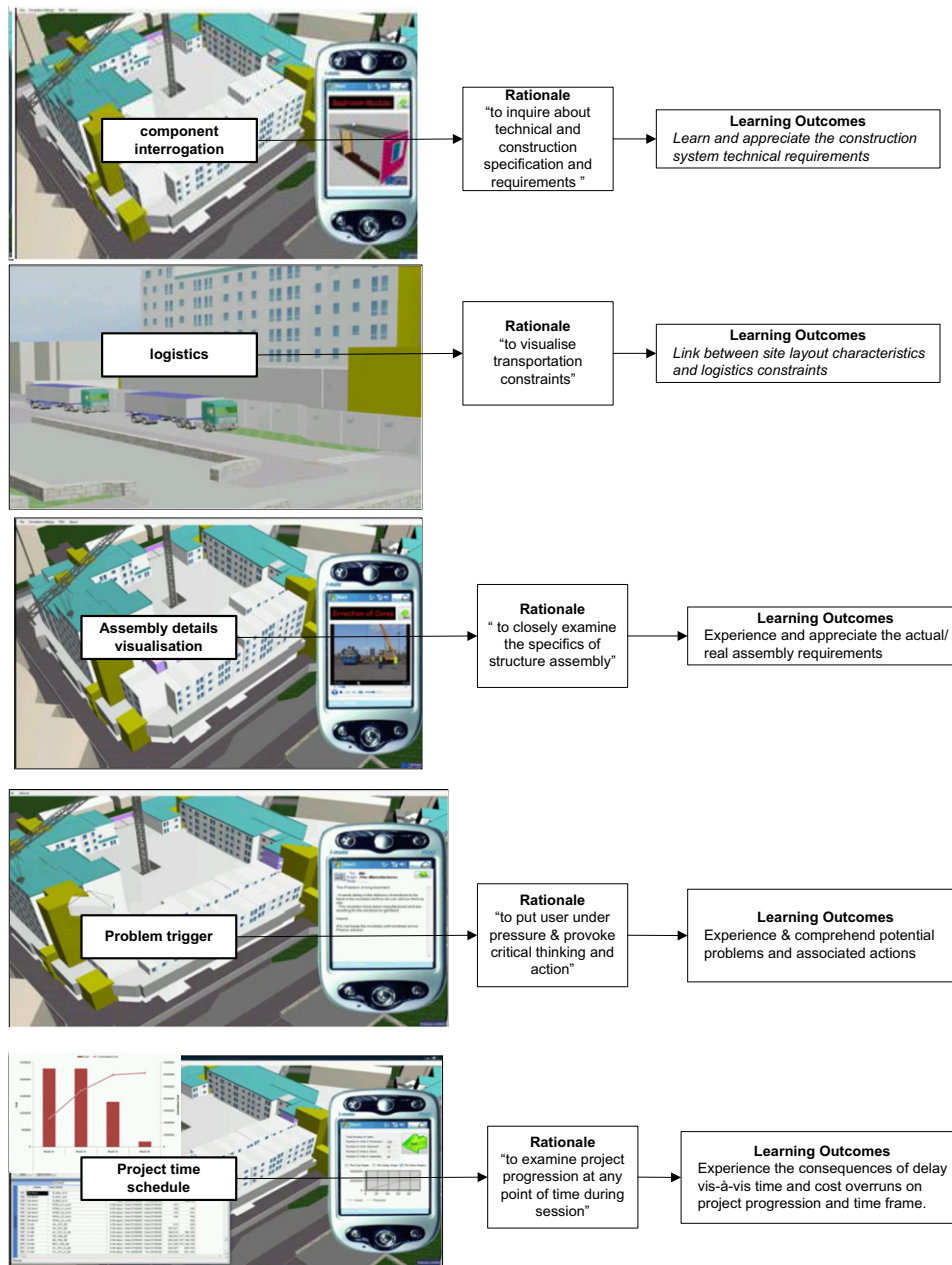


Fig. 10 (continued)

(d) the feedback given to learners at the end of the session. The validation process took place during workshop sessions and on a one-to-one basis where the prototype was iteratively demonstrated to the audience for validation. The following list is a synopsis of the feedback received from the testing and validation process:

- Built environment students thought that the VR environment was "very exciting", and would help them appreciate real life (OSP) working experience – that they are currently missing and would hence, complement and enhance their theoretical studies.
- Manufacturers thought the VR environment was an "interesting tool" to interact with, especially as they could 'see' the implications of their decisions in real time (which would help to 'think' and reflect on 'why' problems occurred, and how issues may be mitigated on real projects).

- Academia and the research community thought that the VR environment would help convey OSP concepts to learners. The inclusion of cost data/implications was welcomed to give tangible hard issues rather than just soft issues.
- Developers/industrialists thought the VR environment would help compare traditional approaches with OSP practice, hence help identify how such issues as core processes and cashflow would be affected.

While the validation process of the prototype suggested strong potentials for the OSP VR interactive training environment, it further highlighted recommendations for further research and development:

- The incorporation of upfront decision processes aiming for targets such as least cost and least time.
- Scenarios to incorporate different types of contracts.



Fig. 11. Pop-up PDA interface for the interrogation of OSP elements.



Fig. 12. PDA Interface components [46].

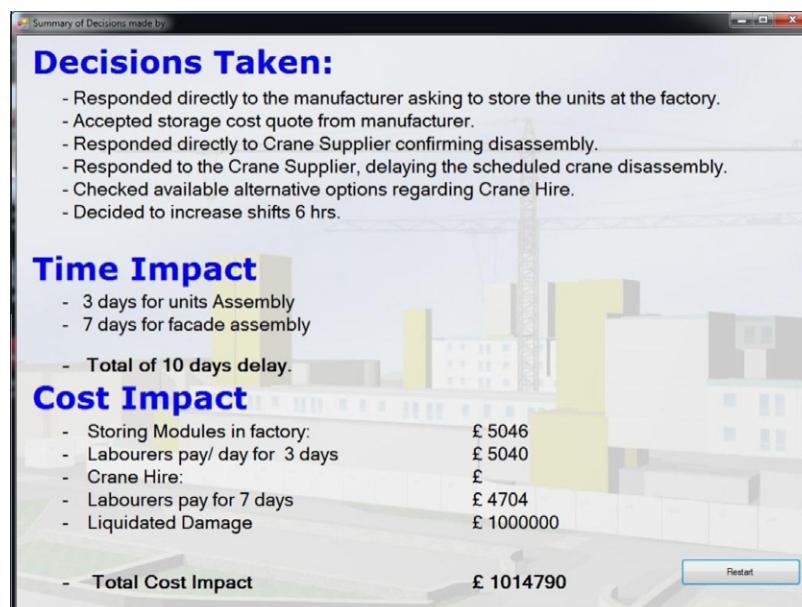


Fig. 13. Typical report generated by the system [46].

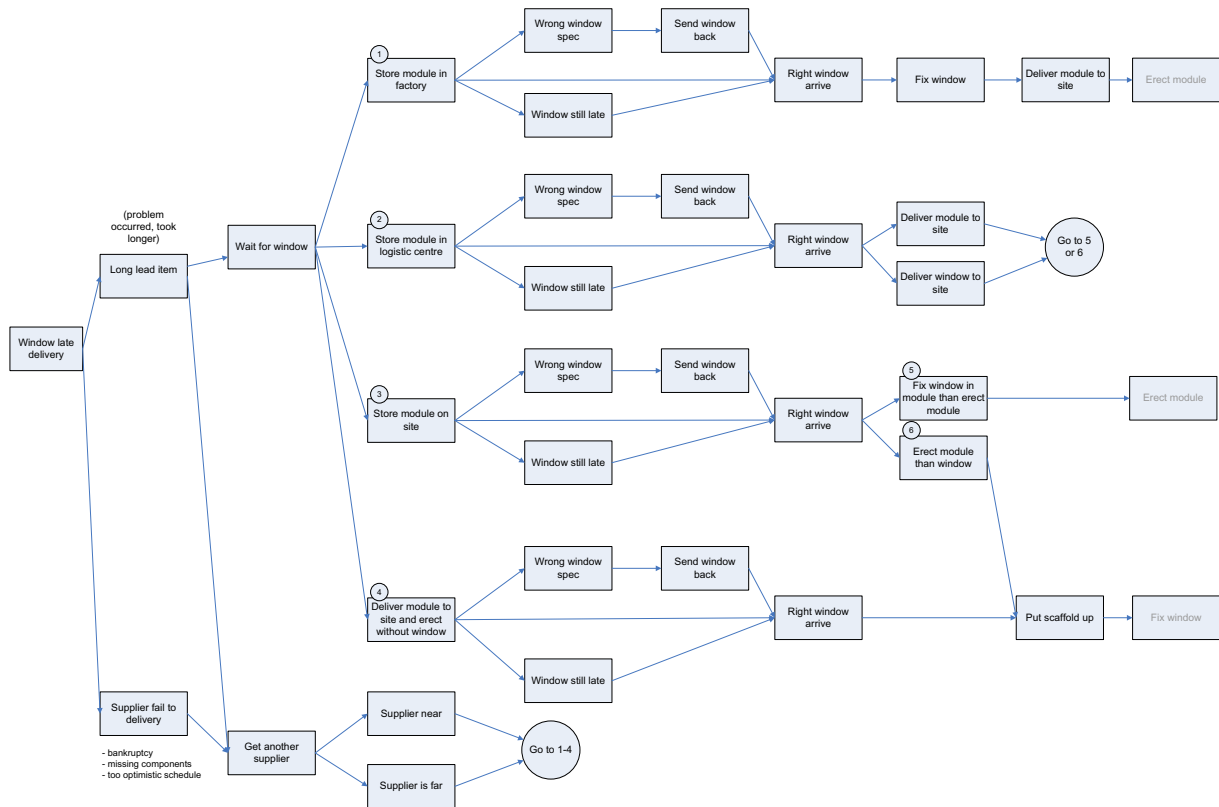


Fig. A1. Scenario 1/2.

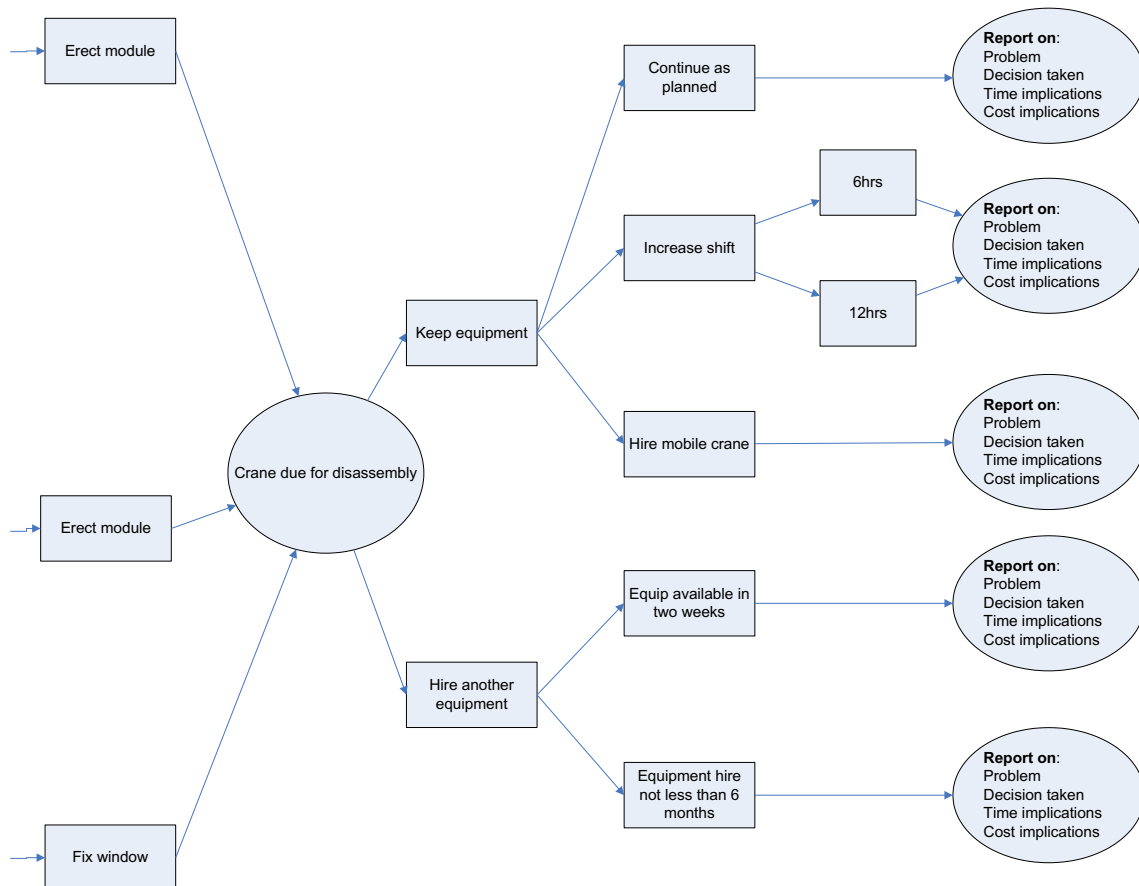


Fig. A2. Scenario 2/2.

- To address different stages of contract i.e. inception stage, completion, facilities management, demolition, etc.
- To consider issues such as the social impact to recruit and manufacture locally, accidents on site, increase in resource prices, short supply of material, and unforeseen conditions.
- The environment to cater to multi-user environment. Thus, the final (summary) report to reflect the different stakeholders objective, i.e. a client would get a different report than that from the manufacturer, contractor, etc.

While OSP has been offered as one potential solution for the construction industry to embrace in order to overcome some of its deeply entrenched problems, this however, requires the industry to holistically reflect upon their current position with regards to working practices and business models, against the potential benefits offered by OSP. This undertaking is significant, real, and critical, as OSP working practices and processes are fundamentally different from traditional practice. Cognisant of this, the main aim of the OSP VR interactive training environment was to help different stakeholders involved in the supply chain appreciate the nature and complexity of OSP projects, by allowing them to 'try out' OSP working practices in a safe and controlled learning environment. Hence, the VR interactive training environment can be considered as essential, as it purposefully allows learners to appreciate new methods, processes and thinking required. In addition, it (i) enables academia to demonstrate the impact of experiential learning in cognate areas; (ii) allows training institutions to reinforce the importance of embedding contextual meaning into their training provision; (iii) enables industry to make informed decisions in order to reflect on lessons learnt; and (iv) contributes to research community by providing a contribution to knowledge for further reflection and agenda setting.

In summary, the vision to transform the construction industry from being a predominantly 'craft/resource-based' industry, to one which is more 'knowledge' and 'value-driven' will require a paradigm shift in thinking. This will also require the provision of innovative and flexible training approaches to underpin, support and deliver this new vision. This paper introduced the core concepts and strategies associated with the prototype design and development of a VR interactive training environment for OSP. This was developed with a specific mandate of allowing learners to experience OSP practices and processes using 'real-life' scenarios. These scenarios were based on a real-life project based in the UK, the representation of which was further endorsed and validated by domain experts to help maximise authenticity.

The iterative approach to testing and validation process was undertaken in order to ensure that the finished product: (a) was 'fit for purpose' [content/level/OSP outcomes]; (b) met the needs of a diverse range of stakeholders; and (c) meaningfully engaged learners [level of detail/interactivity]. It was important to ensure that learners were able to retrieve accurate and appropriate information in order to make accurate and informed decisions. In this respect, there was a need to balance the level of complexity and interactivity offered to learners in the VR environment, against the desired learning outcomes that needed to be achieved.

Further development of this work is suggested to incorporate the Artificial Intelligence technology to further improve the dialogue between the 'virtual characters' and learners. However, from a research limitation perspective the findings presented in this paper are constrained to one context (the UK market), and use of one project (data set) as the core basis for analysis. In this respect, issues surrounding inference gathering, generalisability and repeatability should openly acknowledge this. Further work is expected to capture and capitalise on additional real-life case studies, to drive and inform the development of the second and third stages of the VR environment.

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Appendix A

See Appendix Figs.

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