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ORIGINAL ARTICLE

Improving the success of simulation projects using 3D visualization and virtual reality

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ABSTRACT

Achieving success in computer simulation projects has been a long-standing challenge. A recent study identifies 193 success statements (SSs) distributed across 5 critical success factors (CSFs) and 15 key performance indicators (KPIs) for evaluating simulation projects. This article employs text analytics and sentiments analysis to evaluate the effectiveness of two-dimensional (2D) display and three-dimensional visualization/virtual reality (3D/VR) on the success of a simulation project. The study matches the sentiments from the literature selected through a systematic review process against the SSs, CSFs, and KPIs. The results establish that visual display can influence simulation projects in four ways. First, the combined visualization techniques in 2D and 3D/VR affect nearly half of the SSs across all the CSFs and KPIs, indicating an essential contribution to the success of simulation projects. Second, the 3D/VR is significantly more potent and influences more SSs across all the KPIs and CSFs compared to the 2D display. Third, the 2D display affects fewer but vital SSs, CSFs, and KPIs, especially those related to the time-sensitivity of project delivery, offering a logical explanation to the continued use of 2D visualization by simulation providers. Fourth, ensuring success in a computer simulation project requires multifaceted evaluation criteria.

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KEYWORDS
Computer simulation projects; critical success factors; key performance indicators; sentiments analysis; text analytics; visualization techniques

1. Introduction

The challenge of achieving success in computer simulation projects has remained a long-standing concern for the simulation community. Over the years, several studies have offered different suggestions to improving the outcomes of simulation projects, ranging from the choice of simulation software (Hlupic & Paul, 1999), effective and efficient performance of simulation tasks/activities (Akpan & Shanker, 2017; Brooks & Robinson, 2001; Law & McComas, 2002), stakeholders' involvement (Kamat & Martinez, 2003, 2007), techniques for simulation project management (Nordgren, 1995), and managing stakeholders' expectations (Robinson & Pidd, 1998).

Similarly, some studies also propose ways to improving the performance of simulation tasks, activities and processes from problem definition to conceptual modelling, model development, experimentation and analysis of results, with the purpose of ensuring the success of simulation projects (Banks, Carson, Nelson, & Nicol, 2005; Kamat & Martinez, 2001; Law & McComas, 2002; Robinson, Lee, & Edwards, 2012). Other works propose the use of advanced visualization techniques (2D display, 3D visualization, and virtual reality) as the simulation and modelling approach and practice as ways to enhancing simulation tasks' performance, quality, and usability and achieve a successful outcome (Akpan & Brooks, 2012, 2014; Hurrion, 2000; Kamat & Martinez, 2003, 2007; Robinson, 2002).

The above discourse highlights the complexity of any simulation project. Besides, there is a lack of a generally accepted definition of what constitutes a successful computer simulation project. While a traditional project is successful once the project is completed on time and within budget, the standards for adjudging success in simulation projects are more complex and demanding (Martinelli & Milosevic, 2016; Robinson, 2002; Robinson & Pidd, 1998). Consequently, the simulation providers/consultants and the managers or users tend to use different perspectives or perceptions of measures of success (Robinson & Pidd, 1998), a situation which Salt (2008) identifies as one of the causes of a simulation project's failure.

Recognizing the complex requirements and assessment criteria for evaluating simulation projects' success, Jahangirian, Taylor, Young, and Robinson (2017) proposed some 193 success statements (SSs) distributed into 5 critical success factors (CSFs) and 15 key performance indicators (KPIs). These SSs, CSFs, and KPIs, which are explained later in this article, capture the multi-dimensional perspectives and perceptions of success that also cut

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Table 1. Perspectives, perceptions, and challenges of a simulation project's success.

Robinson and Pidd (1998): Established a four stage-model of simulation project success from the perspectives of simulation providers and customers. Here, success implies achieving the objectives of a simulation study and offering benefits to the customer; ensuring that the results from the simulation are acceptable to the customer; the customer implements the results; there is a positive outcome from the implementation of results proving that the results were accurate.

Lorscheid et al. (2012): From the perspective of the providers, the interdisciplinary audience involved in a simulation study/project hampers the reporting of simulation results, while the perception of users about simulation as black box with little or no understanding hinders acceptance.

Pidd (1996): Identifies five categories of stakeholders in a simulation project including, model developers, programmers, project managers, customers, and users, emphasises the need for visual interactive modelling/simulation (VIM/VIS) to be user-centred based on the human-computer interaction (HCI) framework (Lee et al., 2010) and accommodate the user-needs for simulation providers and other stakeholders. The essential needs include "familiarity with the real-world constructs," tasks simplification, and visual appeals. Achieving the above attributes helps to fulfil the objectives of a simulation project.

Poon and Wagner (2001): Evaluates the critical success factors for decision support systems, which also apply to computer simulation, e.g., systems accessibility and usability, user satisfaction, diffusion/increased number of users. Poon and Wagner (2001) further stressed the need for the system to offer benefits to the organization.

Jahangirian et al. (2017): The paper proposes 193 success statements (SSs), distributed across the 5 critical success factors (CSFs) and 15 key performance indicators (KPIs); further details in Section 2.3.

across different phases including the pre-simulation project planning activities to stakeholders' involvement, performing simulation and modelling activities. Others include post-simulation activities, such as model usability, implementation of simulation results, and change management.

The proponents of visual interactive simulation/modelling (VIS/VIM) in 2D and 3D visual displays and virtual reality (VR) believe that the application of these visualization technologies can significantly improve simulation tasks' performance and ensure the success of discrete-event simulation (DES) as a decision support system, amongst other benefits (Hurrion, 2000; Van Orden & Broyles, 2000). This article seeks to evaluate the impact of two visualization techniques (2D display and 3D/VR) on the success of a simulation project.

The rest of the article is organised as follows: the next section provides the theoretical background on the success of simulation projects, discusses the SSs, CSFs, and KPIs proposed by Jahangirian et al. (2017), and explains the role of visual display on the success of computer simulation projects. Section 3 presents the research method. Section 4 presents and analyses the results. Section 5 discusses the results, while Section 6 concludes the article.

2. Theoretical background

2.1. The perspectives and perceptions of a simulation project's success

Computer simulation typically involves creating a model and simulating a system of interest that produces results to support essential business decisions based on set objectives (Akpan & Shanker 2017, 2018; Pidd, 1996). However, for a simulation project to be considered a success, the user needs to accept the results as credible, implement the recommendations, and achieve a successful outcome (Akpan & Brooks, 2012; Akpan & Shanker, 2017; Jahangirian et al., 2017; Robinson & Pidd, 1998).

Several studies show that achieving the success standards for simulation projects remains a challenge for several reasons (e.g., Jahangirian et al., 2017; Van Lent, Vanberkel, & Van Harten, 2012). First, some studies argue that managers or model users who are non-experts in simulation do not often understand the connection between the model and the results, and therefore cannot rely on it to implement the recommended outcomes (Akpan & Brooks, 2005b). Secondly, computer simulation and modelling activities can be complex rather than follow a linear or straightforward top-down process (Pidd, 1996). Thirdly, a simulation project can involve a diverse and "interdisciplinary" team of stakeholders (Lorscheid, Heine, & Meyer, 2012; Pidd, 1996); for example, practitioner/provider, customer, decision-maker, project manager and other users) with different levels of knowledge and expertise in simulation and application domains sometimes attract conflicting expectations and perceptions of success (Pidd, 1996; Robinson & Pidd, 1998; Shrivastava & Mitroff, 1984). Table 1 presents a few selected literature to highlight the complex nature of a simulation project and the different perspectives to success and identifies the diverse stakeholders in a given simulation project.

2.2. The role of visual display in the success of simulation projects

The visual display of 2D VIS/VIM, 3D visualization, and VR offer significant benefits that can enhance the success of computer simulation as a decision support system. The 3D display employs stereographic images to represent the model elements and other parts of the real system, while the 2D animation uses bitmap and vector graphics that lacks any depth effects. Model developers also use numbers, charts, and texts to display vital statistics on the interface to complement the graphics in both displays (Akpan & Brooks, 2014). Further, the DES literature presents a loosed view of 3D visualization, equating it with VR, implying that both displays offer a three-dimensional perspective view (Akpan & Brooks, 2012). Although the 3D experience can provide the ability to alter the viewpoint of the observer including being able to "fly through" the system, it does not provide a complete VR experience in the conventional sense (Akpan & Brooks, 2014; Akpan & Shanker, 2018). Thus, the human-computer interaction literature defines VR as a variety of systems with different levels of immersion, including full immersion into the virtual environment, and uses specialised hardware devices such as gloves and head-mounted displays (Hoffmann, Stefani, & Patel, 2006). However, this article uses the term 3D display and VR interchangeably and classifies both in the same category.

Simulation is used to model complex non-linear systems with several elements and components interacting with each other, and the ability to visualise the modelled systems or operations using a computer-generated animation is what makes the model less mysterious to the less technical users (Akpan & Brooks, 2014; Lorscheid et al., 2012). The visual display is what positively differentiates simulation from other operations research techniques, such as linear programming, mathematical modelling, which non-technical people can barely understand but are expected to accept the solutions as "gospel truth" (Akpan & Brooks, 2014). Given that human beings are naturally good at visually processing information (Rohrer & McGregor, 2002), the visual display makes DES as a decision support system more engaging for users. The visual simulation also enhances the understanding of the system and the model and improves the decision-making (Akpan & Brooks, 2012, 2014; Kamat & Martinez, 2003). Other benefits of the visual simulation to the end-users include helping the entire project team (model developer, analyst, managers, and non-technical managers) gain insight into the model and the system. It also facilitates the involvement of domain experts and non-technical personnel (Bruzzone, Briano, Bocca, & Massei, 2007; Kamat & Martinez, 2008).

The DES literature identifies other significant benefits of visualization. These benefits include the positive impacts of visual display on user performance of simulation tasks and activities throughout the simulation process from problem definition to presenting results to the clients or simulation project owners. For example, the visual display can facilitate model development (Chen & Huang, 2013), verification and validation (Akpan & Brooks, 2014; Kamat & Martinez, 2003; Qu et al., 2010), and communication with clients (Akpan & Brooks, 2012; Whyte, 2003). These gains further improve model credibility, acceptance, and usability (Al-Hussein, Athar Niaz, Yu, & Kim, 2006; Mujber, Szecsi, & Hashmi, 2004).

Viewing from the human-computer interaction perspective, the outcome of a simulation project must satisfy essential usability requirements and quality standards for DES to fulfil its purpose as a decision support system (Abran, Khelifi, Suryn, & Seffah, 2003; Lee, Eastman, Taunk, & Ho, 2010; Sharlin et al., 2009). The International Standards Organization addresses the issues of usability and software project quality including systems models through ISO 9241 and 9126. There, it defines usability as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (Abran et al., 2003). Evidence from research and DES practice show that meeting these requirements in a simulation project can be challenging, which explains why several simulation projects record some failure as discussed in detail elsewhere (Salt, 2008).

Other essential features of the visual display include the effects on user-involvement in the modelling and simulation project, problems associated with not understanding of the simulation model of complex systems, and performance of DES tasks. These DES activities amongst others include verification and validation, which in turn affects model credibility and acceptance (Akpan & Brooks, 2012; Robinson, 2002; Robinson & Pidd, 1998; Savolainen, Ahonen, & Richardson, 2012). As identified in the decision support systems (DSS), the rationale for proposing the adoption of appropriate visualization technique is due to the potential positive contributions towards enhancing simulation project success. Based on the assertion by Poon and Wagner (2001), the visual display will affect the following:

- Interactivity: A DSS with real potential for success should possess threefold interactivity namely, expert's interactivity with the technology, manager or decision maker's ability to interact with the system intuitively, and good interaction amongst all the stakeholders. Figure 1 shows an example of a system or model, which depicts an attempt by the non-technical managers/users to interact with the system, and how the help of visual interface in 2D and 3D/VR enable two-way interaction between the human user and the information system.
- Model use: A system that is not easy and attractive to use will not have any potential to succeed.

- User satisfaction: Once the users are satisfied they will continue to use the system to solve problems.
- Impacts on the user: Make the system impactful and almost indispensable for the user in the tasks performance.
- Increased number of users after the initial deployment: If more people use the system after the initial launch, the system will have a higher potential to succeed.

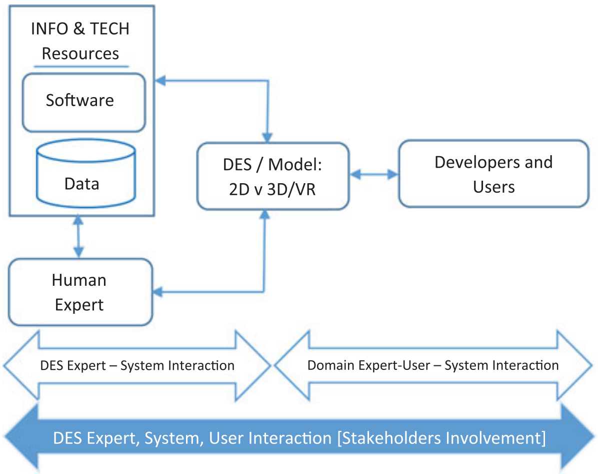

Figure 1. An interaction framework in a discrete-event simulation.

2.3. Success statements (SSs), critical success factors (CSFs), and key performance indicators (KPIs)

The criteria for evaluating the success of a simulation project are multifaceted. A recent study by Jahangirian et al. (2017) proposed a comprehensive list of measures to evaluate the success of a simulation project. The measures include 193 SSs categorised into 5 CSFs and 15 KPIs (Figure 2). Also, Tables 4–8 contain the full list of the SSs, CSFs, and KPIs. These success measures encompass every aspect of any simulation project, including the pre-planning activities, stakeholders' involvement, simulation, modelling tasks, and post-simulation activities, such as model usability, implementation of simulation results, and change management (Nordgren, 1995; Pidd, 1996; Robinson & Pidd, 1998).

The five CSFs include "communication and interaction," "frequency of communication," "communication effectiveness," "responsiveness," and "information to share." Each CSF contains three KPIs. For example, we have the following three KPIs under the CSF—"communication and interaction," namely, "frequency of communication," "communication effectiveness," and "information to Share," (Figure 2). Also, Tables 6–10 present complete lists of all the SSs, CSFs, and KPIs.

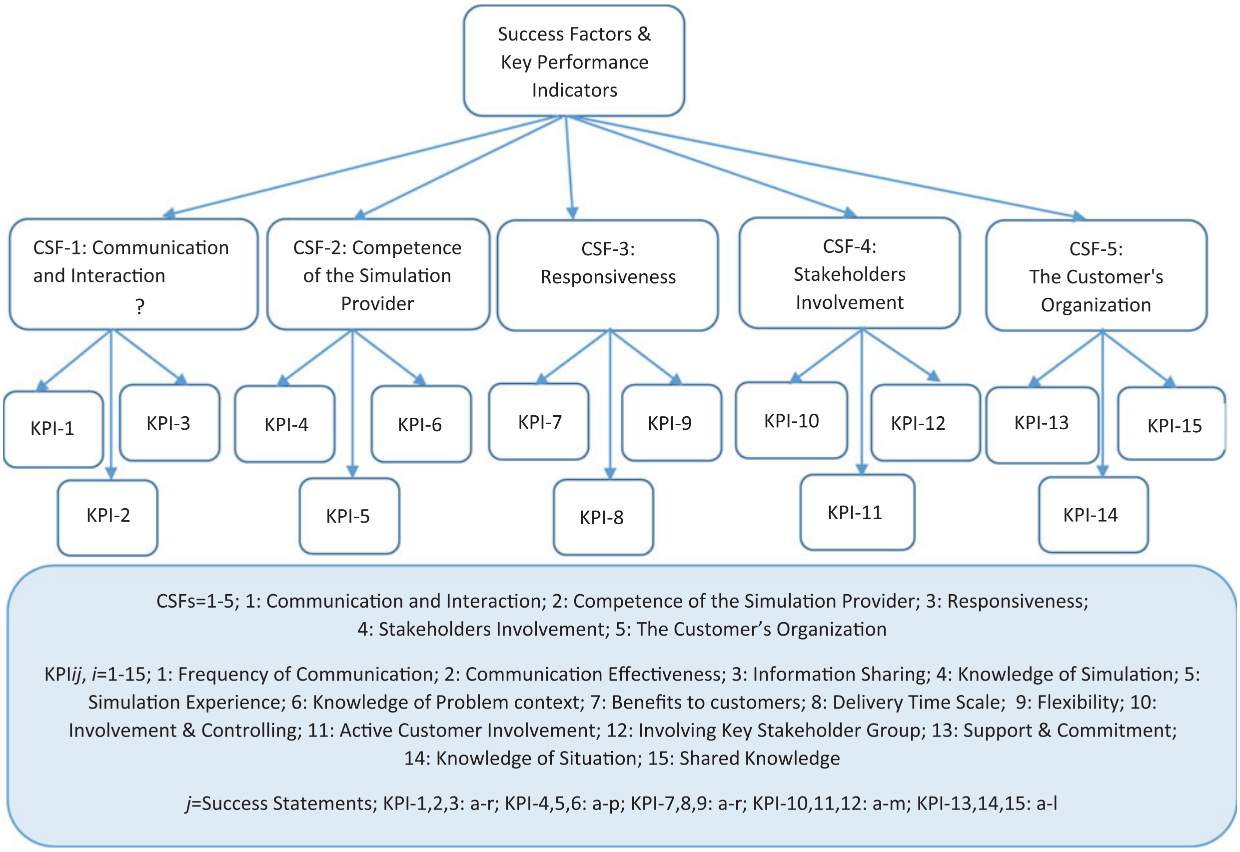

Figure 2. CSFs and KPIs for evaluating the impacts of visualization on DES projects success.

Table 2. Text analytics tasks and matching the visualization techniques and SSs, CSFs, and KPIs.

Steps	Tasks	Technique
a. Data extraction	Extracted the abstracts, research highlights and conclusions from the selected articles onto MS EXCEL in a textual form.	Manual operation
b. Data export	The MS EXCEL file containing the textual data are exported onto the Text Analytics Software (NVIVO Pro 11).	NVIVO Pro 11
c. Text coding based on the SSs, CSFs, and KPIs	Coding of the 193 statements of success distributed across 5 CSFs and 15 KPIs as proposed by Jahangirian et al. (2017).	Manual coding using NVIVO Pro 11
d. Sentiments analysis	Conducted sentiments analysis: identifies the positive, negative and neutral sentiments as presented in Table 5.	NVIVO Pro 11
e. Matching SSs, CSFs, and KPIs	Matching the sentiments identified in (d) above with the SSs, CSFs, and KPIs.	NVIVO Pro 11 with manual presentation

Table 3. Articles' search, filtering, screening, and selection criteria of articles.

Activities/focus	Criteria
Search terms	Simulation/Modeling AND ("Visual Display" OR Visualization OR "Virtual Reality" OR "Visual Interactive Simulation"); AND ("3D Visualization" OR "2D Visualization" OR "Three-Dimensional Display" OR "Two-Dimensional Display").
Sources	Web of Science/Knowledge, Scoupus, and Google Scolar.
Year of publication	Peer-reviewed articles published in journals and conference proceedings from 2000 to 2017 (print/online sources).
Publication sources	Journals and conference proceedings. All unpublished works were excluded.
Language	Only publications in English or formerly translated into English are included.
Articles' selection	The selected articles addressed the effectiveness of visual display, 2D visualization and 3D /VR.

Table 4. Journals and conference proceedings of the selected publications.

Journals	*n*	Journals	*n*
Expert Systems with Applications	7	*Journal of Computing in Civil Engineering*	7
Simulation	6	*Simulation Modelling Practice & Theory*	6
Automation in Construction	6	*Proceedings of the Winter Simulation Conference*	6
Journal of the Operational Research Society	4	*Decision Support Systems*	3
MIS Quarterly	3	*International Journal of production research*	2
Computers & Industrial Engineering	2	*Advances in Engineering Software*	2
Proceedings of the Fourth International Conference on Advances in Computer-Human Interactions	1	*ACM Transactions on Modeling & Computer Simulation*	2
Journal of Information Technology in Construction	1	*The Journal of Defense Modeling and Simulation*	1
Journal of Construction Engineering and Management	1	*Visualization & Computer Graphics*	1
International Conference on Computational Science and Its Applications	1	*Displays*	1
Construction Management and Economics	1	*Engineering with Computers*	1
Systems Analysis Modelling Simulation	1	*Journal of Archaeological Science*	1
Building Research & Information	1	*Journal of Materials Processing Technology*	1
Canadian Journal of Civil Engineering	1	*International Journal of Human-Computer Studies*	1
Journal of computer-aided Molecular Design	1	*International Journal of Digital Earth*	1
Journal of Civil Engineering and Management	1	*European Conference on Modelling and Simulation*	1
European Journal of Operational Research	1	*Science and Technology of Welding and Joining*	1
Advanced Engineering Informatics	1	*Organization Science*	1
Computers in Biology and Medicine	1	*Molecular Simulation*	1
Computer Standards & Interfaces	1	*Procedia CIRP*	1
Assembly Automation	1	*Computers and Graphics*	1
Computers in Industry	1	*Virtual Reality*	1
International Journal of Computer Integrated Manufacturing	1	*Proceedings of the International Conference on High-Performance Computing and Networking*	1
Total = 89			

3. Research method

3.1. Text analytics, visualization techniques and SSs, CSFs, and KPIs

This article employs the text analytics method and sentiments analysis to evaluate how visualization techniques in 2D display and 3D/VR match the 193 SSs distributed across five CSFs and fifteen KPIs (Section 2.3) as measures of computer simulation projects' success. Tables 6–10 show a complete list of the SSs, CSFs and KPIs. We employed the popular text analytics software known as NVIVO (Professional version 11). Auld et al. (2007) used NVIVO successfully for a similar research in the past.

In this study, we performed the text analytics and sentiments analysis on textual data extracted from the abstracts, research highlights and conclusions from 89 peer-reviewed articles on the impacts of 2D and 3D/VR visual displays carefully selected through a systematic review process (Moher, Liberati, Tetzlaff, & Altman, 2009). The 89 articles reported several simulation projects in 32 different application domains. The articles were selected using the

Table 5. Matching the conclusions from research on the effectiveness of the 2D and 3D/VR against the statements of success (SSs), critical success factors (CSFs) and key performance indicators (KPIs).

References	Research conclusions	3D/VR v 2D	CSFS-1; KPI-1,2,3 (see Table 6)	CSFS-2; KPI-4,5,6 (see Table 7)	CSFS-3; KPI-7,8,9 (see Table 8)	CSFS-4; KPI-10,11,12 (see Table 9)	CSFS-5; KPI-13,14,15 (see Table 10)
Aigner, Miksch, Müller, Schumann, and Tominski (2007)	Certain data, e.g., volume display require the 3D for expressive data visualization.	3D	a		l	g	
Akpan and Brooks (2012)	The drawback of 3D is the additional cost, the longer time and complexity of building the 3D model. Detailed graphics of the 3D display “helps a little.”	2D	q	l, o	c, o, g		c
Akpan and Brooks (2012)	The 3D displays can often be more effective and takes shorter time than 2D displays in communication, verification and validation, and experimentation; leads to a better project outcome with an improved understanding of the model and the real system and leads to a better solution for the decision maker. It helps the simulation experts in demonstrating the model to the clients with clear presentation and communication of the results. Users have confidence in the 3D model, which also enhances credibility, acceptability and makes model usable. Potential implications for modelling in general are the importance of being able to relate the model to the real system and of involving the decision maker in the modelling process.	3D	a, b, c, e, f, g, h, j, l, p	h, k, m	b, c, d, e, f, h, j, k, o, p, q	a, b, c, d, e, f, g, h, j, l, m	a, b, e, g, i, j
Akpan and Brooks (2014)	3D makes it easier to validate and verify simulation models in less time, it enhances user’s understanding, helping both the non-domain experts and customers to gain insight about the systems and helps simulation users to make better and quality decisions, leads to increased confidence in the simulation, credibility and usability	3D	e, j, m	a, b, d, h, k	a, b, c, d, f, g, h, n, i, j, o, r	a, c, g, h	a, d, e, f, g
Akpan and Brooks (2014)	“However, there was a small number of comments in the survey that 3D could be a hindrance with unnecessary graphical detail making it harder to see important aspects of the (model) behaviour.”	2D	q				
Akpan and Brooks (2005a)	It is easier and faster to spot errors in 3D/VR model than in 2D. It takes less time to spot error in 3D/VR model than in 2D. Users can easily understand the modeled operation in 3D/VR display compared to 2D, irrespective of their background or technical ability. VRSIM enhances more accurate model than 2D display. The effect of 3D offers greater impacts in spotting more difficult errors that may lurk hideously in the 2D display, the more difficult an error is, the more helpful it is to use VRSIM. VRSIM enhances. It generally takes less time to spot all types of errors in the 3D model than 2D.	3D	j, m	n	c, f, o	c	
Akpan and Brooks (2005b)	Majority of 3D /VR modellers/users (and 2D modellers/users) are concerned about the significant set-up costs, possible long learning curve for 3D modelling/software. 3D /VR model is more difficult and takes longer to build than 2D.	2D		l, p	o		
Akpan and Brooks (2005b)	VRSIM enhances better communication between the model builder and the decision-maker about the problem than 2D display. VRSIM modellers and users also cited good communication capability of the 3D as the major reason that influenced their adoption of VR technology. VRSIM improves clients’ understanding of the modelled system. VRSIM makes it easier and quicker for managers, decision-makers and non-technical personnel to understand the modelled system than using 2D display. VRSIM increases client’s confidence in the simulation model/results; the increased confidence of clients in the simulation results when 3D/VR display can facilitate model credibility and acceptance.	3D	a, l, c, j	n	b, h, f, o, d	c	b, j
Akpan and Brooks (2012)	About 77% of the surveyed 3D model users viewed that, decision-making takes longer time with the 3D display.	2D			c, h		
Al-Hussein et al. (2006)	The 3D display accurately depicts complex construction operation; properly communicates the essence of a simulated system; enables domain experts to understand and model an operation easily. The 3D also provides valuable insight into the subtleties of the operations. The dynamic graphical animation mimics the reality enhancing model verification and validation. Users gain the confidence to accept the results and use it for decision-making.	3D	c, e, i, j	d, h, o	a, b, d, i, j, n, r	c, f, g, h	a, b, e, d, f, g, j
Baracca, Clai, and Ornelli (2001)	The capability to produce 3D animations, visualizing the evolution of a bioremediation process, is crucial for demonstrating the reliability of the visualization application as a powerful tool for planning and designing actual interventions.	3D	l, n, p		i		
		3D	e, f, h, k	d	b, d, k	c	a, e

(*continued*)

Table 5. Continued.

References	Research conclusions	3D/VR v 2D	CSFS-1; KPI-1,2,3 (see Table 6)	CSFS-2; KPI-4,5,6 (see Table 7)	CSFS-3; KPI-7,8,9 (see Table 8)	CSFS-4; KPI-10,11,12 (see Table 9)	CSFS-5; KPI-13,14,15 (see Table 10)
Bailey, Leonardi, and Barley (2012)	The simulation of vehicle assembly in 3D highlighted accurate performance helping engineers to validate the models easily against the processes and operations, which gained the trust of managers in simulations more than developers and analysts producing it leading managers to predict a future of complete virtual engineering process.						
Behzadan and Kamat (2009)	Three-dimensional (3D) visualization is an effective tool for communicating, verifying, and validating the results of a simulated operation. Traditional visualization tools used for this purpose are typically based on the paradigm of virtual reality.	3D	a, p			c	
Behzadan and Kamat (2007)	3D visualization is a powerful method for verifying, validating, and communicating the results of a simulated model. Lack of visual understanding about a simulated model is one of the major reasons inhibiting contractors and engineers from using results obtained from discrete-event simulation to plan and design their construction processes and commit real resources on the job site; the use of modem visualization applications (makes it) more appealing to engineers and scientists in different domains.	3D	c, k, j, p		b, d	c	
Berglund, Lindskog, Johansson, and Vallhagen (2014)	Using 3D visualization technique, the spatial data of an entire production system can be captured and digitalised in a matter of hours; provide a current state representation of the real system; supports most steps in a DES study and acts as a reference model when formulating the conceptual model and collecting input data; provides physical measurements for accurate positioning of simulation objects during model building. The main benefits include comprehensive visualization and the ability to conduct spatial measurements at will; facilitates communication with non-simulation stake holders.	3D	b, l, n, p		h		
Bielli, Boulmakoul, and Rida (2006)	3D graphical interfaces and VR provide insight into the model workings even to the operators with limited technical background.	3D	d		n, r		d
Bruzzone et al. (2007)	3D offers elaborate and realistic presentation and makes it easy to involve stakeholders in the modelling process. The graphic animation in 3D shows the dynamic evolution of the storage level for each single item in each shelf and provides tailored feedback and clear solutions to domain experts to analyse the store layout; improve store decision processes.	3D	a, b, c, f, g, j	c, f, i, k	b, h, i, k	a, b, c, h, i, j	
Buche and Querrec (2011)	VR enhances pedagogical decision making on the implementation of Artificial Intelligence based system.	3D			h, i		
Calabrese, Corallo, Margherita, and Zizzari (2012)	The reality of the 3D display enhances situational awareness of operators, enabling them to promptly identify and assess problems and results, and take fast/effective actions.	3D	a	d, e, f, i	i, l		e
Chabal, Proietti, Mante, and Idasiak (2011)	VR can contribute to improved knowledge regarding project preparation and validate technical choices.	3D				c	
Chan (2003)	Modelling with 3D graphics and color scheme helps to analyse the system interactively, highlights collisions, violations, near misses; validate the model and sequence for assembling components in minutes; provides managers and engineers with clearer and reliable picture of impacts changes in systems and processes, detects problems and enhances communication among project's stakeholders.	3D	a, h, j, l, n, p	d, e, f, g, h, i	b, e, k	a, b, c	
Chen and Huang (2013)	The 3D based STROBOSCOPE provided realistic visualization, which users found easier to learn and use, with minimal learning curve, offering accuracy, precision and efficiency in model creation, with intuitive presentation.	3D	b, j		l, j		c, g
Chen and Huang (2013)	It is easier to use 2D sketches during conceptual modelling.	2D			j		c
Chen et al. (2013)	The facility managers can interact with the 3D model to gather information to support operations and faster decision-making and can access the backend database through the model for the managers to view.	3D	i, j, o		a, i, h, r	g	g
Choi, Park, and Park (2003)	3D makes it easier for both the domain and simulation experts to build the model of a target system, validate it and enhances communication with stakeholders.	3D	i, l, o, p			a, b, c, h	
Droste, Hadlich, Wiechert, and Qeli (2008)	Communication processes between experimentally working biologists and modellers. The transfer of results from systems analysis and simulation studies can be greatly facilitated by using visualization techniques. The 3D representations are an option here.	3D	l, p				

(*continued*)

Table 5. Continued.

References	Research conclusions	3D/VR v 2D	CSFS-1; KPI-1,2,3 (see Table 6)	CSFS-2; KPI-4,5,6 (see Table 7)	CSFS-3; KPI-7,8,9 (see Table 8)	CSFS-4; KPI-10,11,12 (see Table 9)	CSFS-5; KPI-13,14,15 (see Table 10)
Droste et al. (2008)	The 3D representations are more difficult to handle than their 2D counterparts.	2D		l, p	o		
Dangelmaier et al. (2005)	3D/VR saves time and costs for several simulation tasks, overcoming error-prone modelling of complex simulation: provides an intuitive man-machine interfaces that is easy to understand and use by inter-disciplinary project team with non-simulation experts, which enhances validation, verification, and analysis, and helps to communicate results, and avoiding complexity and interpretations.	3D	a, c, e, g, j, p	d, e, f, g, o	d, c, e, f, k, o, j	a, b, c, d, f, g, h, i	g
den Hengst, de Vreede, and Maghnouji (2007)	The true-to-scale 3D features can help resolve any complexities and facilitates the understanding model behaviour, the interaction among the components (e.g., AGVs, conveyors) and the results by the stakeholders and management team with limited simulation experience.	3D	a, b, c, d, e, h, j	d, f, g, k, o	d,	a, b, c, d	a, c, e, g
Dorozhkin, Vance, Rehn, and Lemessi (2012)	VR-based simulation offers realistic display that allows users to interact with the model as in real-life during the runtime, interactively and dynamically change the inputs parameters at model runtime, seeing outcomes in real-time.	3D	a, c, o	m	e, f	a, d, e	c
Farooq, Wainer, and Balya (2007)	Cell-DEVs (3D) makes modelling and experimentation easier than using the 2D display, helps to view a realistic operation, observe the interaction and view results. Users can visualise and capture the snapshots of the stages and interactions in the simulation; enhances easy debugging and verifying the correctness of the results and improve the test protocols.	3D	a, c, i	c	d, e, f, j	c, g	c
Fishwick, Davis, and Douglas (2005)	3D (aesthetic computing) helps in modelling and in communicating concepts to non-engineers.	3D	f, p				c
Fishwick et al. (2005)	3D modelling (aesthetic computing) is time consuming compared to 2D.	2D			c, f, o		
Fishwick (2004)	3D visualization uses realistic and familiar icons, which is far superior to the 2D display in its ability to illustrate the effects of changes in variables, effective in explaining or presenting the concepts and models to stakeholders.	3D	b, g, h, j, o		e		
Golparvar-Fard, Peña-Mora, Arboleda, and Lee (2009)	The 3D visualization enhances effective communication of the construction progress and identify discrepancies, enabling timely corrective decisions.	3D	b, l, p		c, i, h, l, o		
Hajdasz (2008)	The simulation and 3D visualization platform of the intelligent support system enhanced the what-if analysis of the construction operations, solutions and managerial decisions, and improved the managing of repetitive processes on the construction site	3D		c	e, h, i, k		c
Hartmann and Fischer (2007)	The 3D visualization helps in the generation and communicating the construction ideas, collaboration and knowledge sharing among participating stakeholders in a simulation project team. The photo realistic 3D display of construction tasks making it easier for managers (simulation experts and analysts) to understand.	3D	b, h, j, p	a, d, j, e, k	k, n	a, b, k, h	d, g
Hollocks (2006)	VR provides improved ease of use of the simulation and modelling tools.	3D			j		c, g
Hong et al. (2002)	The 2D model is easier to develop conveniently and rapidly.	2D		l	c, f		c, g
Hong et al. (2002)	Model verification is not an easy task for users, but the 3D display can simplify this, although it can be complex to create it.	3D				c	i
Hong et al. (2002)	Visual display enhances communication between the simulation modelers and the users, either 2D or 3D animation.	2D/3D	g, l, p				
Huang, Kong, Guo, Baldwin, and Li (2007)	The 3D modelling is tedious and time consuming, whereas 2D is easier.	2D		l	c, f, o		c, g
Huang et al. (2007)	The 3D mimics the real-world physical property, offers intuitive interactive interface that enhances creativity of the project team, effective and efficient communication and transmission of designs ideas and solutions to the stakeholders and decision-makers. Domain experts can also run and optimise the model and evaluate resource utilization.	3D	a, b, j, l, p	d, j	a, e, h, i, l, m, n, p, q	b, e, h	d
Hurrion (2000)	The interactive 3D animation made it possible to rotate or view a neural network simulation surfaces from different positions, helps to understand and interpret the results.	3D	a, c, j		e	c	g
Kamat and Martinez (2005)		3D	b, e, g, j, i, l, o, p	d	b, d, h, i	b, c, h	a, g

(*continued*)

Table 5. Continued.

References	Research conclusions	3D/VR v 2D	CSFS-1; KPI-1,2,3 (see Table 6)	CSFS-2; KPI-4,5,6 (see Table 7)	CSFS-3; KPI-7,8,9 (see Table 8)	CSFS-4; KPI-10,11,12 (see Table 9)	CSFS-5; KPI-13,14,15 (see Table 10)
	3D display helps in model presentation, enhances effective communication with stakeholders, improves understanding of the simulation, and enhances better validation, verification, as well as credibility and decision-making.						
Kamat and Martinez (2008)	The 3D display enhances familiar representation of system, which is impossible to depict accurately and when modelling in a 2D space and communicating details about the system to managers and users.	3D	e, h, l, n, p		a	c	
Kamat and Martinez (2007)	The 3D helps to correct any discrepancy that may exist in the simulation model as intended by the simulation expert and the real-system. In the case in this study, it also helped to determine the motion path in accurate way.	3D	a			g	
Kamat and Martinez (2001)	The 3D based dynamic construction visualiser (DCV) helps domain experts to identify complex errors in simulation, which developers of the model may not spot. It also help construction planners to obtain more realistic results and feedback from simulation analysis.	3D	a, o		d, k, l	c, g, h	c, i
Kamat and Martinez (2003)	3D reveals all the logic errors in the model “in a few minutes” and helps the domain experts to detect errors caused by using bad data, which the simulation experts may never detect.	3D				b, c, g, h	
Kamat and Martinez (2003)	3D display provides subjective details about the operations, highlighting the interactions among model components, helps both the domain and simulation experts to resolve errors easily. Visualizing the output in 3D effectively and accurately communicate results to stakeholders who are not proficient in simulation, improve understanding of construction process and improve decision-making.	3D	a, c, h, j, p	f, g, k	a, d, h, i	b, c, h	g, i
Kamat and Martinez (2008)	The 3D display helped the domain experts involved in the simulation project easily observe and spot unusual model behaviour and errors which simulation expert may never identify. This in turn enhances credibility and usability.	3D		k	b, d, j	b, c, d, e, f, g, h, i, j, l	a, i
Kamat and Martinez (2008)	3D provides the spatial info and geometric details of construction facility components captured into simulation models. It also helps in validation and verification.	3D			a	g	
Kamat and Martinez (2008)	3D animation of the construction processes enables project owners to understand the simulation when involved in the project, especially during model verification. This helps to detect and correct any abnormal or unrealistic behaviour and errors in the model, which the developers find it difficult to detect.	3D	j	d, k	p, q	b, c, f, g, h, j	g, d, i
Kamsu-Foguem et al. (2012)	3D/VR presents information in symbolic and familiar manner to users. It visually magnifies subtle aspects of diagnostic, therapeutic, patient management, allowing new thinking, communicates feedback to caregivers in a hospital environment via displays that are easy to understand. The insight that is gained and the elaborate information display and analysis enhances better decisions.	3D	a, b, c, j, m, p	e, f, g, h, i, j, k	a, h, i, m, n, k, j, r		g, d
Kang, Chi, and Miranda (2009)	3D enables creation of realistic building erection activities models. Being able to visualise these activities and results enhances clear understanding of the operation and make decisions, help identify and eliminate many unforeseen problems and risks ahead of time.	3D	a, c, l, j	d, f, g, h, j, k	c, d, h, i, l, o		g, e
Khosravi, Nahavandi, and Creighton (2010)	Modelling the baggage handling system in 3D enhanced precise representation of the operations and outcomes.	3D	a, d, e, k				
Khoury, Kamat, and Ioannou (2007)	The 3D visualization is effective in model validation and verification, which enhances credibility	3D	e		d	g	a
Korošec, Bole, and Papa (2013)	The 3D visualization provides a better understanding of the problem definition process and help the management team and systems’ planners to gain insight about the problem tackled, and in evaluating and determining the optimal and clear solution.	3D	a, h	a, b, d, e, f, g, h, i, j	i, n, r	b, k	a, b, d, g, h
Kumar and Benbasat (2004)	The 3D display enhances clear presentation of results and better insights.	3D	a, b, c, g		a, r		d
Li, Ma, Shen, and Kong (2003)	3D/VR allows for 3D computer-generated simulation, offering superior real-time performance, acceptable realism and presence for construction planners, enables the project teams to check and validate constructability through visualised 3D models of projects to experiment on construction methods in a what-if analysis.	3D	d, e	e, m	b, e, k, n	b, c, d, e, f	a, b, c, e, j
Li et al. (2003)	The project teams can use 3D models efficiently to support knowledge generation needed during the constructability review on construction projects, supporting communication.	3D	b, l, n, p	a, b, e, f	n, j, p, q, r	b	

(*continued*)

Table 5. Continued.

References	Research conclusions	3D/VR v 2D	CSFS-1; KPI-1,2,3 (see Table 6)	CSFS-2; KPI-4,5,6 (see Table 7)	CSFS-3; KPI-7,8,9 (see Table 8)	CSFS-4; KPI-10,11,12 (see Table 9)	CSFS-5; KPI-13,14,15 (see Table 10)
Lindskog, Berglund, Vallhagen, and Johansson (2013)	Creating a 3D model is time consuming (compared to the 2D) and may result in unnecessary over simplification.	2D		l	c, o		
Lindskog et al. (2013)	The 3D display and VR ensure accurate representation of model as in the real life, and very effective in communicating with stakeholders; provides better support for group decision-making enabling the team members with diverse backgrounds to understand and form a common view about the operation based on clear and realistic results.	3D	a, b, f, h, j, p		d, h, i	a, b	g
Lloret, Omtzigt, Koomen, and De Blois (2008)	Three-dimensional (3D) visualisations are an interesting method for representing model outcomes. When the visualisations need to be adapted frequently, a faster and more flexible 3D method is needed; first step being to create the 3D elements.	3D	a, g, l, p, r		f, o		
Lu, Zhen, Mi, and Huang (2015)	Representing model components of assembly, subassembly sequences and production operation in realistic 3D , helps the users to correct the obvious errors and ensure that the final assembly sequence is clear and feasible.	3D	a, c, d, g, p			c	
Meier, Holzknecht, Kabelac, Olbrich, and Chmielewski (2004)	A distributed system for 3D visualization of molecular simulations in parallel computing environments successfully implemented. It provides an efficient method to explore simulation results in a high-performance networking and 3D graphics environment with only slight additional computational load on the simulation. It enables smooth animations of molecular simulations with stereoscopic viewing options and interactive 3D navigation.	3D	a, f, h		b, d		
Moghadam, Al-Hussein, Al-Jibouri, and Telyas (2012)	The 3D model of studio building construction scheduling simulation proved very effective in communicating the value and simplicity of a minute-by-minute schedule, and effective in analyzing the construction methods and ensuring fast project completion.	3D	i, j, l, p	c, f, i	K, g, o		
Moon, Cho, Kim, Sunwoo, and Jung (2006)	3D display is very effective in verifying automotive assembly simulation.	3D				g	
Mujber et al. (2004)	3D/VR matches the model behaviour with real world, helping the users to understand the simulation capabilities and tools; aiding the people who have not built the model to verify and validate it, enhancing credibility; helps to communicate the results clearly to stakeholders, and improves decision-making and senior management buy-in.	3D	a, c, h, i, j, o, p	d, k	b, d, h, j	c, f, g	a, b, d, g, k, l
Mueller-Wittig et al. (2002)	The system enhances 3D replay of the results and output of animation script; a system for modelling virtual prototypes, verifying the existing manufacturing processes by animating the behaviour has been developed; the visualization of the system makes its use becomes fast and easy. In general, this rapid 3-D visualization of assembly processes based on simulation models has the potential to support in decision management allowing the identification and removal of bottlenecks to avoid costly errors.	3D	m	a	i, j, m	g	
Nah, Eschenbrenner, and DeWester (2011)	The 3D model display indirectly affects behavioural intention, leading to positive perception of the virtual hospital and a decision to visit the real-life hospital based on positive perception from DES.	3D	a	k	d, i		
Nandan, Roy, Lienert, and DebRoy (2006)	The 3D material was more accurate when presenting numerical values from the simulation analysis of the heat transfer flow during a friction stir welding of stainless steel.	3D	b, e, g, p	i	d, k		
Oerter et al. (2014)	3D/VR enhances collaborative modelling without losing the engineering specifications. The user can explore the 3D platform from a first- or third person viewpoint, run, properly visualise and explore the simulation. The greatly improved display makes it easier to use, reduces the project's time and costs for the customers.	3D	a	c, l	c, d, f, j, o	a, b, e, i, g, h	c, g
Okulicz (2004)	VR can be considered an attractive technology introduced to aid manufacturing and layout process planning. It seems very useful where experience and intuition of a planning engineer are needed. A VR-based planning system enables the simulation and visualization of "real" objects. Since workforce models have also been implemented, important conclusions about the ergonomics and cumulated loads may be derived.	3D	a		i	f	
	Creating a 3D model is time consuming compared to the 2D.	2D		c, f, l	c, o		

(*continued*)

Table 5. Continued.

References	Research conclusions	3D/VR v 2D	CSFS-1; KPI-1,2,3 (see Table 6)	CSFS-2; KPI-4,5,6 (see Table 7)	CSFS-3; KPI-7,8,9 (see Table 8)	CSFS-4; KPI-10,11,12 (see Table 9)	CSFS-5; KPI-13,14,15 (see Table 10)
Otamendi, Pastor, and Garcia (2008)							
Otamendi et al. (2008)	The 2D display is not appealing and unfamiliar compared to the realistic display of the 3D visualization that improves model understanding.	3D	a, j	d, k			g
Qu, Zhu, Guo, and Lu (2010)	3D model and simulation outputs vividly mimic the appearance and shape of the real grown eggplants.	3D	a, c, f				
Quarles, Fishwick, Lampotang, Fischler, and Lok (2010)	3D enhances transparent reality and provides users with an interactive and accurate visualization of internal structure, processes and outcomes.	3D	a, b	k			
Rekapalli and Martinez (2011)	The interactivity features of 3D visualization improve model validation, credibility and usability. Helps to detect logic errors by the simulation engineer. Construction engineers must be convinced of the model's accuracy (i.e., model credibility) before relying on any simulation results. DES-based VR, specifically the user interaction capabilities afforded by the technology, can be an effective method to test and validate complex simulation models, especially to validate infrequent events using complex earthmoving operation.	3D	o	c, g, o	b, d, j	c, g	a, k, l
Robinson et al. (2012)	2D display enhances knowledge elicitation for decision-making. The slower run-speed of 3D model reduces the rate of information gathering.	2D		a, j, e	a, h, l, r		
Rodriguez, Hilaire, and Koukam (2007)	3D/VR offers the user a new way to interact with intuitive platform that the decision-maker can easily evaluate new design traffic network and react to unexpected situations.	3D			i, j	f, h	c
Rohrer (2000)	Animation can help simulation in the following areas; Verification and validation; Understanding of results; Communication of results; Getting buy-in from nonbelievers; Achieving credibility for the simulation. Rohrer referred to visualization generally but acknowledged that 3D offers an improved animation.	3D	a, c, l, j, p		b	c, g	a, k, l
Rojas and Mukherjee (2003)	The situational simulations in virtual reality enhances managerial decisions on risky construction events and offers the opportunity to collaborate with stakeholders ensuring successful modelling and simulation projects. Using 3D in situational simulations, via interactive and graphically appealing environments, encourage the study of "what if" scenarios and the acquisition of decision-making skills.	3D	e		b, h, l, p, q	a, b	
Rua and Alvito (2011)	The 3D models mimic the real world, which are far more than a simple medium for exhibition and a suitable procedure for discussing, sharing and disseminating info about an object, a city or a whole civilization, which are fundamental to archaeological studies.	3D	j, i			b	
Rua and Alvito (2011)	3D is better suited to real-time manipulation, experimenting with objects reconstruction and analysis of the space on a human scale.	3D	d	c, m, g	c, e, k		
Rubio, Sanz, and Sebastián (2005)	Simulation of any manufacturing devices equipment or processes aided by VR offers effective way to obtain manufacturing systems knowledge at a low cost and a fast analysis tool. It can be a very useful tool from the strategic, educational and safety points of view. VR allows simulation results to be shown in a realistic, intuitive, economic and safe way; users gain knowledge of the system's behaviour.	3D	a	k, l	f, k		
Sacks, Gurevich, and Belaciano (2014)	The 3D is easy to understand and helps in observing, recording and analyzing operations for resource allocations decisions with high accuracy in relatively short times.	3D	j	d, k	c, h, i, j, o		g
Sampaio, Henriques, and Studer (2004)	The VR technology applied to construction field enables the user to interact with the virtual model of the wall, impose any sequence time in the construction process, select from the wall's model any component or parts of element and manipulate the camera as desire in order to observe conveniently any detail of the components' configuration.	3D	o		o		g
Sharlin et al. (2009)	The 3D (CMP) platform uses an interface that is intuitive, easy to see, and simple to manipulate, which proved invaluable during work with the elderly.	3D			j		c, g
Shen, Carswell, Santhanam, and Bailey (2012)	3D visualization provides better decisional assistance than several separate 2D displays.	3D			h, i		

(*continued*)

Table 5. Continued.

References	Research conclusions	3D/VR v 2D	CSFS-1; KPI-1,2,3 (see Table 6)	CSFS-2; KPI-4,5,6 (see Table 7)	CSFS-3; KPI-7,8,9 (see Table 8)	CSFS-4; KPI-10,11,12 (see Table 9)	CSFS-5; KPI-13,14,15 (see Table 10)
Shendarkar, Vasudevan, Lee, and Son (2006)	VR provides an illusion of realism and credibility.	3D			d		a
Somasundaram and Kalaiselvi (2010)	An experiment of medical surgery simulation showed that, the 2D display misled medical experts undertaking brain surgery to a wrong problem, while the 3D visualization enhanced accuracy and performance.	3D		d, k, j		d, e, h	
Son and Kim (2012)	3D display enhances communication of the position and posture of an underwater vehicle.	3D	g, l, p				
Su and Huang (2014)	It is easier and quicker to build and verify 3D model, which is easier for non-experts to understand and use.	3D	i, j, m, o	c, d, f, h, k, l, n	g, j	g, h	c, g
Suh and Lee (2005)	3D/VR generated more insights and higher cognitive fit, enhancing purchasing decisions and higher number of participants recalling the operation.	3D			a, h, i, n, r		d
Sun, Lee, Chew, and Tan (2012)	3D/VR visualization System helps to reduce modelling effort.	3D		l			
Talmaki et al. (2015)	The real-time 3D visualization scheme provides realistic graphical model views that are not possible through a conventional 2D display; offers better analysis of results and feedback to aid accident avoidance.	3D	a, c	g, j	d, f, k		
Talmaki et al. (2015)	Analysing model development processes and the results in 3D takes longer time to perform.	2D		c, k, l	c, f, g, o		
Tory, Kirkpatrick, Atkins, and Möller (2006)	The 3D helps in explaining ideas to other physicians to understand more easily.	3D	b, j		n		
Van Orden and Broyles (2000)	3D model and objects are more familiar and appealing to users.	3D	b, e, f				
Vasudevan and Son (2011)	The 3D visualization of the model is highly detailed to provide a realistic situation to the subjects participating in the experiment compared to the 2D display.	3D	a, j		a	d, e	
Vasudevan and Son (2011)	The 3D visualization of the model is highly detailed … compared to the 2D display.	2D	q				
Wainer and Liu (2009)	The 3D display provides the general users with a variety of easy-to-use environments that are familiar, which helps in results analysis and promotes simulation adoption by practitioners and researchers.	3D	a		d, k, j	b	c
Waisel, Wallace, and Willemain (2008)	Using 2D sketches during problem formulation helps to generate insight about the problem and the creation of better models.	2D		d, e, g, i, j	r		i
Waly and Thabet (2003)	3D enhances communication with clients as well as the involvement of stakeholders in the simulation and modelling, and teamwork.	3D	b, i, l, p			a, b, h, c, g	d
Waly and Thabet (2003)	Running model in 3D display makes it slower.	2D			c, f		g
Weber, Teckentrup, and Briem (2002)	The 3D modelling platform Flexsim-R is able to capture real life, which is easy for non-simulation experts to understand. This is not obvious in the 2D structures.	3D	j	d, h, k, p		h	g
Wenzel and Jessen (2001)	3D visualization is an effective communication tool between the simulation experts and the client and other stakeholders, making it easier to Illustrate results for decision-makers.	3D	a, c, l, m, p		d, h, i	b, h	
Whyte (2003)	Simulating building interiors and exteriors in photo realistic 3D improves presentation of new units and outputs; enhances communication among stakeholders than using 2D.	3D	a, b, f, g, i, l, p			a, b	

Table 6. Critical success factors-1 (CSFs-1): communication and interaction and the associated key performance indicators (KPIs).

Communication and interaction (CSFs-1)	Frequency of communication KPI-1		Communication effectiveness KPI-2		Information sharing KPI-3	
	3D better	*2D better*	*3D better*	*2D better*	*3D better*	*2D better*
a. The (simulation) results will be in a format that is familiar to the customer			39	0		
b. Presentations by the provider will be easily understood			20	0		
c. The (simulation) results will be easily understood			20	0		
d. The provider will be clear/concise about what the simulation will/will not do			6	0	6	0
e. The (simulation project) reports will be as agreed to be appropriate			14	0		
f. Presentation materials will be excellent			9	0		
g. Successful presentation of results					12	1
h. The results will be demonstrated to senior managers.					12	0
i. The customer will be informed of how the model has been built.					11	0
j. The provider will check the customer's understanding (of the model/simulation)			32	0		
k. There will be a plan defining the deliverables and timing for each stage					3	0
l. Regular communication with the customer	20	1				
m. The provider will understand and use the language of the customer			6	0		
n. The benefits of the work will be identified and communicated to management					5	0
o. The customer will see the model					10	0
p. Information will be communicated using right media (e.g., presentations or written reports).			30	1		
q. Presentations will not be too detailed			0	3	0	3
r. Information is regularly communicated in small amounts	1	0				
Total	**21**	**1**	**176**	**4**	**59**	**4**
CSFs-1 measures identified by Jahangirian et al. (2017) but not related/addressed by visualization	**KPI-1**		**KPI-2**		**KPI-3**	
Customer is constantly informed about the progress on the project	X				X	
Provides Status-Interim Reports	X				X	
A written report of the findings will be provided			X		X	
Documentation and paperwork will have a neat appearance.			X			
Minutes of meetings will be provided.			X			
Telephone communications will be excellent			X			
Email will be used for communications.			X			
Results will be presented graphically in reports.			X			
The customer will not be given too much details in reports			X		X	
The output from the model will be well marketed			X		X	
The provider will influence people and make them aware of problems.			X			
A project specification will be provided.					X	
The project specification will be split into its constituent parts, giving options for each level of modelling.					X	
Reports will be distributed to the relevant people.					X	
The project will be documented.					X	
Agendas will be provided.					X	
The customer will be informed of how the data have been collected.					X	
All the results will be provided					X	
The customers will be given the information they want					X	

Table 7. CSFs-2: competence of the simulation providers, and the associated key performance indicators (KPI-4,5,6).

Competence of the providers (CSFs-2)	Knowledge of simulation KPI-4		Simulation experience KPI-5		Knowledge of problem context KPI-6	
	3D better	*2D better*	*3D better*	*2D better*	*3D better*	*2D better*
a. The provider will have a good knowledge of the process being modelled					5	1
b. The provider will be knowledgeable about the customer's industry					3	0
c. The provider will be proactive in suggesting improvements to the process					8	2
d. The provider will have a good understanding of the problem					19	1
e. The provider will be knowledgeable about the customer's business					8	2
f. The provider will correctly estimate the complexity of the process					12	1
g. The provider will correctly estimate the complexity of the model required.	10	1				
h. The provider will normally be able to solve any modelling problems.	9	0	9	0	9	0
i. The provider will be able to analyse the customer's requirements					7	1
j. The provider will have some good ideas on how to simplify the model.	7	2	7	2		
k. The provider will understand what is going on in the process.					19	1
l. The provider will be able to build models quickly.	4	8	4	8		
m. The provider will use methods of experimental design	4	0				
n. The provider will be able to quickly assimilate all the information required.	3	0				
o. The provider will be used to developing very complex models.	4	1				
p. The provider will demonstrate a good level of expertise with the simulation package.	1	2				
Total	**42**	**14**	**20**	**10**	**90**	**9**
CSFs-2 measures identified by Jahangirian et al. (2017) but not related/addressed by visualization	**KPI-4**		**KPI-5**		**KPI-6**	
The provider will be technically competent.	X					
The provider will be well trained in simulation	X					
The provider will have support from expert simulation modellers.	X					
The provider will have a knowledge of a wide range of disciplines.	X		X			
The provider will employ a formal process for model development.	X					
The provider will be very good	X		X		X	
The provider will have a natural modelling ability	X		X			
The provider will use reasonable intelligence to carry out the work	X					
The provider will exclude infrequent events from the simulation.	X					
The provider will correctly estimate the amount and precision of the data required.	X		X		X	
The provider will correctly estimate the amount of work the customer needs to input.	X		X		X	
The provider will be experienced with simulation.			X			
The provider will give accurate time estimates for the project.			X		X	
The provider will use simulation regularly and frequently.			X			
The provider will spend a lot of time up-front planning.			X			
The provider will manage the project.			X			
The provider will have a methodical and sound approach			X			
The provider will know the limitations of the software			X			
The provider will have experience with similar models.			X		X	

Table 8. CSFs-3: responsiveness and the associated key performance indicators (KPI-6,7,8).

Responsiveness (CSFs-3)	Benefits for customers KPI-7		Delivery timescale KPI-8		Flexibility KPI-9	
	3D better	*2D better*	*3D better*	*2D better*	*3D better*	*2D better*
a. The simulation will provide information not otherwise available	11	1				
b. The objectives of the project will be achieved	16	0				
c. The provider will be able to perform the project at the time the customer requires			9	9		
d. The project will provide the results that the customer wants to hear	26	0			26	0
e. It will be possible to perform a lot of experiments					11	0
f. There will be time to perform all the experiments desired			11	5		
g. The project will be completed quickly			3	2		
h. The simulation will enable the customer to make decision faster	22	2	22	2		
i. The customer will learn something from the project and so make better decisions	24	0				
j. The simulation will be used a great deal.	19	1			18	1
k. The provider will analyse any of the customer's ideas that are fed back.	15	0			15	0
l. The provider will ensure that customer's requirements are reflected in the model	7	0				
m. The simulation will identify where the problem really is	3	0				
n. The simulation helps the customer to think about things not previously considered.	11	0				
o. The provider will have time to perform the simulation project			12	8		
p. The project will deliver a benefit	5	0				
q. A problem will be solved through the project	5	0				
r. The simulation will provide a large volume of information	9	2				
Total	**173**	**6**	**57**	**26**	**70**	**1**
CSFs-3 measures identified by Jahangirian et al. (2017) but not related/addressed by visualization	**KPI-7**		**KPI-8**		**KPI-9**	
The provider will adapt to the customer's changing needs as the project progresses.	X				X	
The provider will help in an appropriate fashion	X					
The provider will respond quickly to any requests.			X		X	
The reports will be timely			X			
There will be mechanisms in place for controlling change to the project					X	
The simulation will provide a selection of alternative courses of action					X	
The provider will be flexible (willing to meet the customer half-way)					X	
Backup support will be provided by the provider's organization					X	

Table 9. CSFs 4: involvement of the stakeholders and the associated key performance indicators (KPI-10,11,12).

Involvement of the stakeholders (CSFs-4)	Involvement & continuity KPI-10		Active customer involvement KPI-11		Involve key stake holder group KPI-12	
	3D better	*2D better*	*3D better*	*2D better*	*3D better*	*2D better*
a. The customer is involved throughout the project	14	0				
b. The project will be a team effort	24	0	24	0		
c. The customer will be involved in the validation of the model.	31	0	31	0		
d. Experiments will be performed during meetings with the customer	8	0				
e. The customer will be able to perform experiments himself/herself.	8	0	8	0		
f. The customer will buy-in to each stage of the project			9	0		
g. The project team will be involved in verifying all the data			22	0		
h. Experts in the facility being modelled will be involved in the project					21	0
i. The customer will identify with the simulation as early as possible.	4	0	4	0		
j. Those involved in the project will remain involved throughout	4	0				
k. The customer will have input into how the model looks			2	0		
l. The customer will be involved in data collection	2	0	2	0		
m. Experts in the facility modelled will be involved at an early stage in the project.					1	0
Total	**95**	**0**	**102**	**0**	**22**	**0**
CSFs-4 measures identified by Jahangirian et al. (2017) but not related/addressed y visualization	**KPI-10**		**KPI-11**		**KPI-12**	
A review of how the project went will be performed at the end of the project	X					
Discussions will start at the beginning of the project	X					
There will be several detailed walkthroughs of the model with the customer.	X		X			
Potential experiments will be discussed at the beginning of the project	X					
The customer will be informed about what contribution s/he needs to make to the project			X			
The customer will spend a lot of time working on the project			X			
The provider will understand the level of the customer's simulation			X			
The equipment suppliers (e.g., machinery) will be involved in the project					X	

Table 10. CSFs 5: customer's organization and the associated key performance indicators (KPI-13,14,15).

The customer's organization (CSFs-5)	Support and commitment KPI-13		Knowledge of situation KPI-14		Shared knowledge KPI-15	
	3D better	*2D better*	*3D better*	*2D better*	*3D better*	*2D better*
a. The customer will believe in simulation.	14	0	14	0		
b. Simulation will be an accepted technique in the customer's organization.			6	0		
c. The customer will understand something of the simulation software.			14	4		
d. The management in the customer's organization will have the foresight to see what simulation can do.			12	0		
e. The customer will listen to the results of the simulation.			8	0		
f. The customer organization will commit to the implementation.	2	0				
g. The customer will understand how to use the model.			25	3		
h. The customer will be able to clearly define the problem being tackled.					1	0
i. The customer will have been designated the task of being involved in the simulation	6	1				
j. The customer's organization will see the simulation as a necessary part of the wider project.	4	0	4	0		
k. Senior management in the customer's organization will be committed to the project	3	0				
l. Senior management in the customer's organization will be willing to listen and be open to change	3	0				
Total	**32**	**1**	**83**	**7**	**1**	**0**
CSFs-5 measures identified by Jahangirian et al. (2017) but not related/addressed by visualization	**KPI-13**		**KPI-14**		**KPI-15**	
The customer will be committed to the project	X					
All involved in the project will be willing to input to the process	X					
The customer will be supportive and helpful	X					
The provider will be accepted by those providing data	X					
Members of the customer's organization will be available as and when they are needed	X					
The customer will have sufficient time-resource to collect the data	X					
The customer will initiate the project	X					
It will be easy to gain access to the customers	X					
The customer will spend time interpreting the results	X					
The customer will not have preconceived ideas about what the simulation will show.			X			
The customer will understand some of the problems the provider might face.			X		X	
The customer will ask for a reasonable number of experiments to be performed			X			
The customer's organization will have formal procedures in place for requesting a simulation			X			
There will be a middle-person between the provider and the customer who understands both simulation and the problem.			X		X	
The customer will have the structure for the model documented before work commences			X			
The customer will not have preconceived ideas about simulation being the correct technique for the problem being tackled			X			
The customer's expectations will not be too high.			X		X	
The customer will recognise that there are limitations to the model					X	
The customer will not change the objectives as the project progresses					X	
The customer will clearly define the experiments before the project starts					X	
The plans for the real facility will be fairly concrete before the simulation is started					X	
The customer will have a good knowledge of the facility being modelled					X	
The provider will have responsibility and accountability to the customer					X	
The customer will communicate his-her expectations at the beginning of the project					X	

method discussed in Section 3.2. Table 2 shows the complete steps, tasks, and the technique that was followed to carry out the text analytics.

The NVIVO software highlighted three types of sentiments namely, positive, negative and neutral, and extracted it in sentences and phrases as follows:

- positive [e.g., "3D makes it easier to validate and verify simulation models in less time"; "the 2D model is easier to develop conveniently and rapidly" (Akpan & Brooks, 2014; Hong, Shi, & Tam, 2002)],
- negative [e.g., "the drawback of 3D is the additional cost, the longer time and complexity of building the 3D model" (Akpan & Brooks, 2012); "… 3D is far superior to the 2D display in its ability to illustrate the effects of changes in variables" (Akpan & Brooks, 2012; Fishwick, 2004)], and
- neutral [e.g., "visual display enhances communication between the simulation modelers and the users, either 2D or 3D animation" (Hong et al., 2002)], as applicable to the 3D/VR and 2D display respectively. We recorded the positive neutral sentiments to the favour of both displays, given that the author considered both the 2D and 3D/VR to be equally beneficial (e.g., Hong et al., 2002, Table 5).

As shown in Table 2, we hand coded the 193 SSs, CSFs, and KPIs, in NVIVO following the hierarchy in Figure 2 (Section 2). We then matched each extracted sentiment from the literature against the coded SSs/CSFs/KPIs. While NVIVO helped to highlight the keywords from the sentiments and the coded SSs, we complemented it by manually reading the phrase or sentence to ensure that the context was a right match. Table 5 presents the complete results of the text analytics.

The rationale for employing the text analytics is that the technique is quickly becoming the favourite research technique in evaluating "big data" that contains unstructured texts (Elgendy & Elragal, 2014). The process of analysing the unstructured texts data commonly involves identifying and evaluating key conclusions or emotions from subjective text such as social media comments, literature review, and other user-generated contents in order to uncover a useful pattern leading to knowledge discovery (Chen, Hou, & Wang, 2013; Elgendy & Elragal, 2014).

3.2. Literature search, filtering, screening and selection of articles

The literature search was carried out using the Web of Science/Knowledge, Scopus, and Google Scholar. Table 3 shows the search terms used and the selection criteria. The search produced 1478 journal articles and conference proceedings. The next step involved exporting the articles onto Endnote Bibliographic Software for screening and removing any duplicate entries, leaving 1205 papers.

Further filtering and screening within the Endnote platform helped to remove the articles that did not address visual display in 2D visualization and 3D/VR, producing 177 articles. The next steps involved extracting the abstracts, research highlights and conclusions of the articles onto MS EXCEL as textual data, and uploading it onto NVIVO 11 Pro software for text analytics and sentiments analysis. The analytics software identified the relevant sentiments (phrases and sentences) from 89 articles. The remaining articles that did not contain the relevant phrases or sentences about the visual display in 2D and 3D/VR were discarded.

Table 4 shows the published sources for the 89 selected articles, which include journals and conference proceedings. Over 79% of the articles appeared in the core information systems/computer science and decision sciences journals, while the remaining of the papers appeared in discipline specific fields (e.g., construction, biosciences sources).

3.3. The application domains reported in the selected articles

The selected articles reported 99 simulation and modelling projects in 32 application domains involving products and services activities. Some of the published articles tackled more than one simulation and modelling projects, especially the publications that are research-based (e.g., Akpan & Brooks, 2014). Some of the most popular application domains include civil engineering projects, systems implementation and manufacturing/production. Others are aerospace, building construction and healthcare (including related medical services operations). Business process management, facility layout/planning, and simulation modelling methodology also received prominent attention (Figure 3). Reporting this information is essential because the acceptance and use of simulation as a decision support system differ by field (Lorscheid et al., 2012).

3.4. Data collection

The data used for analysis in this study was obtained by employing text analytics and sentiments analysis methodology as discussed in Section 3.1. The paper matches the sentiments (positive, negative and neutral) from text analytics of the literature (Section 3.2) against the 193 statements of success,

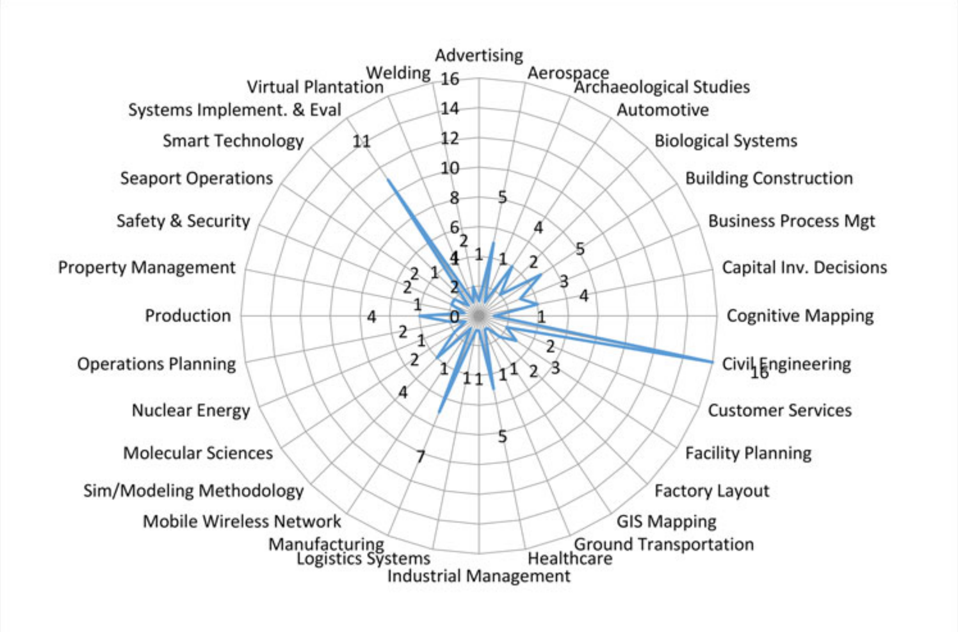

Figure 3. Application domains covered by the selected/reviewed journal articles.

distributed across the 5 CSFs and 15 KPIs as proposed by Jahangirian et al. (2017). The data helps to evaluate the causal effects of the visualization techniques (2D display and 3D/VR) and successful simulation projects. Table 2 presents the criteria used in the selection of the papers. Following a thorough review, the study uses data from 89 selected articles. All the publications came from operations research, information systems, and simulation applications areas and covered the period 2000–2017, and Figure 3. The selected papers tackled problems in over 32 different areas undertaking several investigations and performing various simulation tasks using the 2D display and/or 3D/VR.

Our study follows a similar method that was adopted by Jahangirian et al. (2017), which reviewed nine typical cases of simulation studies published in 2007 and 2008 addressing healthcare problems. However, our study covers broader perspectives and application domains with a higher sample, making it possible to generalise the research outcomes.

4. Results and analysis

4.1. Role of visualization in success of simulation projects

As explained in Section 3, Jahangirian et al. (2017) identified 193 SSs distributed across 5 CSFs and 15 KPIs as the criteria for evaluating the success of a simulation project. This section analysis how visualization techniques (2D display, 3D visualization, and virtual reality) influence the SSs, CSFs, and KPIs.

Tables 6–10 show how the 2D and 3D/VR displays are relevant to SSs, CSFs, and KPIs. Precisely, each of Tables 6–10 corresponds to one of the CSFs and the relevant KPIs and SSs. Each CSF has 3 KPIs and the associated SSs. In other to ensure completeness, Tables 6–10 also list the SSs that are not relevant to visualization. For example, Table 6 illustrates the CSF-1 and the corresponding KPIs 1–3 and SSs (a–r) for which 2D VIS/VIM and 3D/VR displays are influential and relevant. The KPI-1 (Frequency of Communication) has 4 SSs of which 2 relate to visualization, while the remaining two are not. This implies that, under KPI-1, the visual display can influence 50% of the SSs. Similarly, Table 7 shows the CSF-2 and the related KPIs 4–6 and SSs (a–p) that can be influenced by 2D visualization and 3D/VR displays. The said Table also lists the SSs that are not related to visualization.

In addition, Tables 6–10 show the frequency of citations favouring 2D or 3D/VR displays across different CSFs, SSs, and KPIs. Using the frequency of citation of the SSs and CSFs follows a similar approach by Robinson and Pidd (1998) and Jahangirian et al. (2017). Although Jahangirian et al. (2017) also based the KPIs computation on "overall success measure," it is not suitable in this case because some of the SSs that form the KPIs are not related to visualization as explained above.

Figure 4 shows the percentage of SSs across different CSFs and KPIs where simulation visualization in 2D and 3D/VR is relevant and influential. The results show that visualization (2D and 3D/VR displays) address 94 out of 193 SSs (i.e., 48%). For the visual display alone to contribute to 48% of the SSs across all the CSFs/KPIs is quite significant reviewing from the multifaceted nature of the success factors that can enhance success in a computer simulation project. Thus, the SSs, CSFs, and KPIs

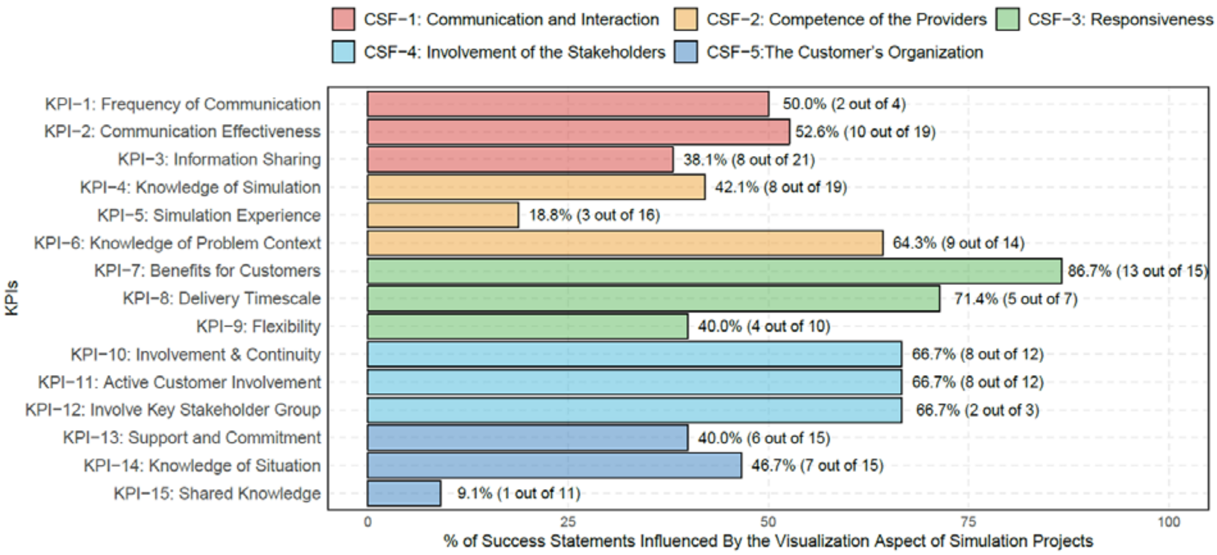

Figure 4. The percentage of success statements across different key performance indicators that are influenced by the visualization in a simulation project.

relate to the different phases in a given simulation project from pre-project planning to implementation, product delivery, presentation of results and decision-making (Akpan & Brooks, 2012; Pidd, 1996; Robinson, 2002). The CSFs, KPIs, and SSs also relate to different modelling/simulation techniques, and the applicable project management methods and strategies (Jahangirian et al., 2017; Nordgren, 1995; Pidd, 1996; Robinson & Pidd, 1998).

Furthermore, it is apparent from Figure 4 that visual display in simulation influences KPI-7 (benefits for customers) the most as visualization is relevant in 86.7% of the SSs. Other KPIs where the visualization affects more than 50% of the SSs includes, KPI-8: Delivery Time Scale (71.4%), KPI-6: Knowledge of Problem Context (64.3%), KPI-2: Communication Effectiveness (52.6%), as well as all of the three KPIs under CSF-4: Involvement of the Stakeholders, namely: KPI-10: Involvement and Continuity (66.7%), KPI-11: Active Customer Involvement (66.7%) and KPI-12: Involve Key Stakeholder Group (66.7%). These results are consistent with previous studies, which concluded that non-technical managers and decision-makers or customers benefit the most from VIS/VIM (Akpan & Brooks, 2005a; 2005b; Bell, 1991; Rohrer & McGregor, 2002). Also, the simulation literature posit that, the application of 3D/VR in discrete event simulation was managerially driven (Akpan & Brooks, 2005a; 2005b; Rohrer & McGregor, 2002). Another area where visualization has significant impact is that it enhances effective communication among the stakeholders in a simulation project (Akpan & Brooks, 2012; Akpan & Shanker, 2017; 2018; Bell, 1991; Kamat & Martinez, 2001).

4.2. Comparing 2D and 3D/VR displays

The results in Section 4.1 showed that a combined impact of 2D display and 3D/VR influenced about 48% of the SSs across all the CSFs and KPIs. In this section, we compare the relative influence of the 2D visualization versus the 3D/VR on the KPIs and SSs for each CSF. Tables 6–10 also show the frequency of citations favouring 2D, or 3D/VR displays across different CFS, SSs, and KPIs. The results show that in a vast majority of cases, 3D/VR displays are the preferred choice. Figure 5 illustrates the number of citations favouring 2D and 3D/VR displays where citation counts aggregate at the KPIs level. In other words, for each KPI, the total number of citations supporting 2D over 3D/VR display (and vice versa) is presented. For example, it is apparent from Table 6 that, there are a total of 21 citations under KPI-1, with 20 favouring the 3D/VR, while only 1 prefers the 2D display under the SS (l—regular communication with the customer).

Figure 5 further shows that across all KPIs, a total of 1043 citations favoured 3D/VR display while there were only 83 citations (i.e., <8%) that preferred 2D display. From the results, it also appears that KPI-2: Communication Effectiveness, KPI-7: Benefits for customers, and KPI-11: Active Customer Involvement, benefit most from 3D/VR displays.

The 2D display offers a more bullish impact on the SS under CSF-2, KPIs-4: knowledge of simulation, and KPI-5: simulation experience, where most SSs relate to the time taken to develop the simulation model and perform other modelling/simulation activities. The positive influence of the 2D display here tends to benefit the simulation provider directly. To further investigate this, Figure 6 illustrates the specific SSs under these KPIs (i.e., KPI 4, 5 and

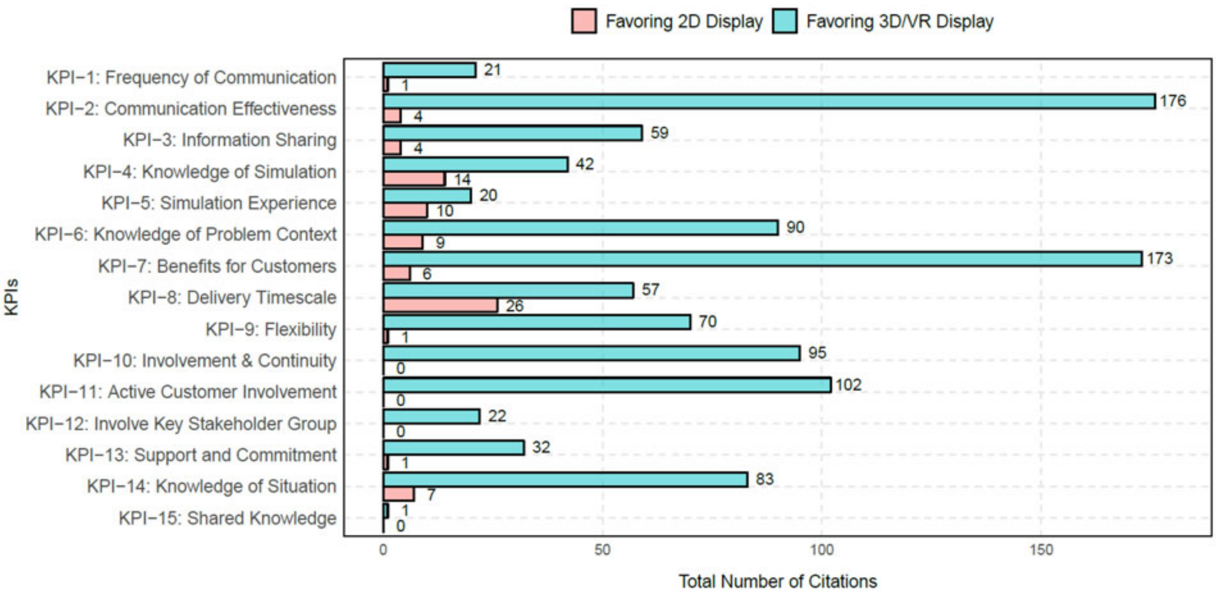

Figure 5. The number of citations favouring 2D over 3D/VR displays and vice versa. The citation counts are aggregated at the KPIs level.

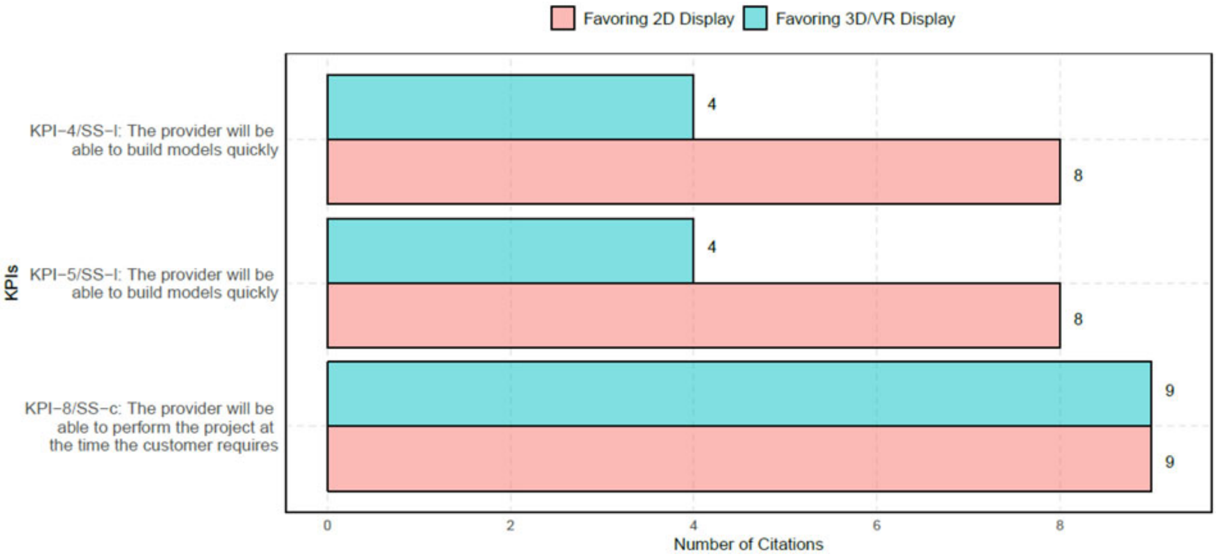

Figure 6. Success statements under KPIs 4, 5, and 8 where the number of citations favouring 2D display is greater or equals the number of citations that favours 3D/VR display.

8) where the number of citations favouring 2D display is higher or equal the number of citations that favours 3D/VR display (see Tables 7 and 8). Also note that, per Jahangirian et al. (2017) notation, SSs (l) is crossed referenced in KPI-4 and KPI-5. From the results, it can be observed that all three identified SSs are related to the delivery timing of the simulation project. These results match the common perception among the simulation providers. For example, in a survey conducted by Akpan and Brooks (2012), the simulation practitioners expressed the sentiment that it generally takes longer to develop the 3D/VR simulation models compared to the 2D display. Others offer the same reason to support the reluctance in adopting 3D modelling and simulation technique despite acknowledging the numerous benefits to the customers and decision-makers as identified above. Several researches align with this position including Talmaki, Kamat, and Saidi (2015) and Akpan and Brooks (2005a, 2012).

On the other hand, developing 3D/VR visualization capabilities are time-consuming and requires a longer learning curve. The results speak to the reason that many simulation providers continue to use the 2D display despite that it appears dated. The results also speak to the need to improve the current 3D/VR and make it more effective in the creation of simulation models.

5. Discussion

The first sets of results in this study show that the visual display (2D and 3D/VR displays) can influence 94 out of 193 critical SSs, representing approximately 48% of the SSs categorised into five CSFs and fifteen KPIs (Figures 4; Tables 6–10). The result confirms the visual display as a vital dimension that plays a prominent role in the overall success of any simulation project. Given the multifaceted nature of the success factors discussed in this study, the fact that visualization aspect of a simulation project can influence 48% of SSs indicates that stakeholders in any simulation project cannot ignore the importance of the visual display if any simulation project is to succeed. However, visualization alone does not determine simulation project success because there are other essential simulation and project management techniques and strategies that must be applied, which are outside the scope of this study but available elsewhere (e.g., Nordgren, 1995; Robinson & Pidd, 1998). Similarly, no single approach can solve all the problems relating to the challenges that simulation projects face. These results are consistent with research outcomes on usability engineering relating to computer simulation and modelling (e.g.,Akpan & Shanker, 2017, 2018; Robinson, 2002).

The results further showed that the combined visualization techniques of 2D and 3D/VR and simulation models bring benefits to all the 5 CSFs and the 15 KPIs categories (Figure 4). The magnitude of the combined impacts of 2D and 3D/VR displays on the KPIs ranges from 9% on KPI-15: enhancing the organization's knowledge of the problem, to 87% on KPI-7: benefits for the customer/client. The visualization aspect of a simulation project also significantly impacts all KPIs under CSF-4: Involvement of Stakeholders. Full details of the success factors and the statements are available in Tables 6–10. The results indicate that the application of 2D and 3D/VR visualization is essential in a simulation project especially where diverse stakeholder groups are involved in the simulation process as this can help all the parties. Kamat and Martinez (2003) showed an instance where the use of visualization enabled the project owners/managers who are more knowledgeable in the application domain to quickly identify complex errors in the simulation model, which the model developers could not detect. Similarly, Akpan and Shanker (2018) explained instances where 3D/VR visualization helps the non-technical managers/users to understand simulation model, while simulation experts easily demonstrate the technical interactions of the model elements to diverse stakeholders, including those with no experience in simulation. These examples helped to enhance the success of the simulation projects.

When comparing the influence of 3D/VR versus the 2D displays, the results suggest that in most cases (i.e., more than 92%), 3D visualization/VR is preferred to 2D display. This observation holds across different success factors relating to the tasks performed by model developers, clients, as well as other stakeholders including project managers, decision-makers, and domain experts. In fact, the results suggest significant benefits of 3D/VR to the core modelling tasks and activities including model development, experimentation, and analysis, as well as model validation and verification, which ultimately lead to a better simulation solution and the overall success of the simulation project. The results also suggest that utilizing a 3D/VR visualization technique can significantly enhance the potential success of a DES project by improving the accomplishment of the CSFs and associated KPIs. These results, therefore, can help correct the misconception that 3D/VR is merely beneficial to the non-technical managers and decision-makers.

The only and major drawback of the 3D/VR compared to the 2D visualization technique is that it negatively impacts the delivery time of the simulation project (see Figure 6) as it takes longer to create a 3D design compared to using a 2D display. However, according to the results, a 3D/VR visualization still helps in other aspects of the model development such as assisting consultants with little understanding of a particular system to gain insight into such operations by modelling in 3D. Finally, it appears the primary reason that simulation providers continue to use the 2D display is that the 3D/VR modelling tools are time-consuming to develop.

In summary, the results of this study first confirmed the significant influence of visualization aspects of a simulation project in defining its success. Consequently, simulation developers should ensure that their products are equipped with effective and appropriate visualization capabilities. This would be even more significant for simulation projects where active involvement of many different stakeholders is required (i.e., CSF 4). In terms of the type of visualizations deployed, the results suggest significant benefits across different success factors when deploying 3D/VR display instead of a 2D display. Subsequently, simulation developers should seriously consider investing in deploying new 3D/VR display capabilities or upgrading their existing 2D display. From the results, it appears the benefits of 3D/VR visualization is specifically highlighted when dealing with more complex simulation scenarios which require more comprehensive visualization methods for effective communication of the final results (i.e., KPI-2), or when active involvement of customers in the simulation project is expected (i.e., KPI-11). On the other hand, 2D display should be adopted by simulation developers if the project is very time-sensitive and involvement from customers is expected to be insignificant throughout the project. Deploying effective 3D/VR visualization solutions has been frequently cited as being more time-consuming. However, as 3D/VR visualizations are becoming more popular, more relevant software libraries and Application Programming Interfaces (APIs) are being developed, which in turn can help reduce the development cycles for 3D/VR visualization capabilities.

6. Conclusions and future work

6.1. Conclusions

This study applies a list of 193 SSs distributed across 5 CSFs and 15 associated KPIs proposed by Jahangirian et al. (2017), to evaluate the influence of visualization techniques (2D display and 3D/VR) on the overall success of simulation projects. The study examines a broad spectrum of application domains considered in past literature. The results of the study illustrate the importance of visualization as a critical dimension that can affect the success of simulation projects significantly. More specifically, the results suggest that the visualization aspects of a simulation project influence 48% of the SSs that define the success of the overall project. According to the results, visualization aspects are specifically relevant to CSF-4: Involvement of Stakeholders and CSF-3: Responsiveness.

Furthermore, when comparing the influence of 3D/VR versus the 2D display, the results suggest that in more than 92% of cases, 3D visualization/VR is preferred to 2D display. According to the results, all stakeholders involved in a simulation project will benefit from capabilities provided by 3D/VR displays compared to 2D displays. For clients, 3D/VR visualizations can significantly improve the understanding and interpretation of the simulation outputs. Similarly, for simulation developers, 3D/VR visualizations can enhance the understanding of the system, especially when they lack specific domain expertise. The study also reveals the following interesting outcomes:

- The study confirms that there are several dimensions to the success of a given simulation project, re-echoing the conclusions by Robinson and Pidd (1998). It establishes the multifaceted dimensions of a given simulation project represented by the SSs, KPIs, and CSFs.
- The study shows that 3D/VR displays significantly enhance the simulation tasks performed by specialist, managers, decision-makers and other stakeholders involved in a simulation project. The results address the misconception that only non-technical users can benefit from capabilities provided by 3D visualization and VR.
- The results of the study suggest that the benefits of 3D/VR visualizations become even more pronounced when dealing with complex simulation projects, and when a high level of customer engagement is anticipated in the simulation project.
- The study shows that 2D display is a more favourable option when there the project delivery is highly time sensitive. This is mainly because developing 3D, and VR visualization capabilities take longer.
- The study provides a guide to simulation practitioners and project managers both before (i.e., project planning phase) and during the simulation development phase of any computer simulation project. To ensure success in any simulation project, the stakeholders can employ the visualization techniques in addition to employing appropriate simulation project management strategies and effective modelling/simulation processes from problem formulation to implementation and change management.

6.2. Limitations and future directions

Currently, few computer simulation projects implement full immersive VR, which is the reason that this study is based on 3D visualization and desktop VR. The future study intends to address the full-immersive, cave-like VR as this practice is somewhat limited currently in the implementation of 3D/VR based computer simulation as a decision support system (Turner, Hutabarat, Oyekan, & Tiwari, 2016).

Disclosure statement

No potential conflict of interest was reported by the authors.

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