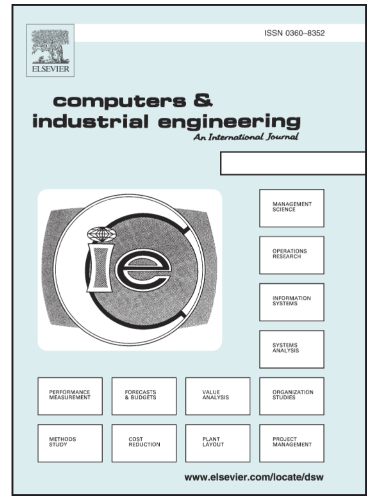

The confirmed realities and myths about the benefits and costs of 3D Visualization and virtual reality in discrete event modeling and simulation: A descriptive meta-analysis of evidence from research and practice

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The confirmed realities and myths about the benefits and costs of 3D Visualization and virtual reality in discrete event modeling and simulation: A descriptive meta-analysis of evidence from research and practice

Abstract

The past seventeen years has witnessed a significant transformation in discrete event modeling and simulation, and the introduction of new modeling methodology based on three-dimensional (3D) visualization and virtual reality (VR) technologies. While several studies demonstrate the benefits and costs of 3D and VR modeling in discrete event simulation (DES) based on empirical evidence, others rely on anecdotal evidence and experience from practice. Further, there are still some unsubstantiated claims about the gains and challenges arising from the application of 3D and VR technologies in DES. This paper synthesizes the realized benefits and costs associated with modeling and simulation in 3D and VR while differentiating the realities from claims (myths). The results show that 3D and VR techniques offer significant benefits in the major modeling and simulation tasks than speculated among practitioners in the simulation community.

Keywords: Discrete event modeling, simulation methodology, three-dimensional display, virtual reality user interfaces, visualization techniques

1. Introduction

The Visual display (VD) in discrete event simulation (DES) has witnessed a significant transformation in nature and sophistication since the introduction of visual interactive simulation/modeling – VIS/VIM (Hurrion, 1980; 1986; Bell & O'keefe, 1995). In the past seventeen years, most DES software and modeling tools implement more advanced state-of-the-art visualization techniques in three-dimension (3D) and virtual reality (VR) (Barnes, 1996; Akpan & Brooks, 2012; Akpan & Brooks, 2014; Turner et al. 2016). The application of 3D display and VR in DES indicate a significant progression from the block diagrams, iconic graphics and rudimentary two-dimensional (2D) animations (Bell, 1991). Some of the simulation software packages that offer desktop-based 3D modeling include AutoMod (Rohrer & McGregor, 2002), Flexsim (Nordgren, 2002; Beaverstock et al. 2012) and WITNESSVR (Waller & Ladbrook, 2002).

VR and DES originated from separate disciplines (Turner et al. 2016). The emergence of the two fields into virtual reality simulation (VRSIM) as coined by Akpan, (2006) and Akpan & Brooks, (2005a), has significantly improved DES practice (Akpan & Brooks, 2005b; 2012; 2014). The 3D display and VR offer advanced visualization capabilities and realistic displays with better interactive experience (Hurion, 1993), and greater dynamic and stereographic depth effects

(Hubona et al. 1999; Waller & Ladbrook, 2000), the features that have greatly enhanced visual simulation (Hurrion, 2000). Other desirable features of the 3D display include the ability to alter the users' viewpoints and being able to "fly through" the system (Waller & Ladbrook, 2002). The 3D visualization and VR also possess 'accurate 3D geometries' which are significant where the physical layouts and processes of the simulated system are crucial, and where some level of physical detail and performance measures is required to make the process design firmer and clearer (Barnes, 1997).

However, there are still some speculative claims about the benefits and costs associated with the 3D visualization and virtual reality in DES. This paper refers to the unproven claims as the 'myths', while the substantiated and proven benefits via empirical or practically demonstrated and functioning benefits are referred to as the 'confirmed realities'. For example, in a survey of simulation practitioners, 35% of non-users perceived that the 3D/VR does not add any significant value to the DES modeling and simulation process (Akpan & Brooks, 2005b). Similarly, 65% of the same respondents tend to exaggerate the costs of 3D modeling and simulation, stating the difficulty or complexity in modeling, and the long learning curve, etc. (Akpan & Brooks, 2012). It is essential therefore to fill this gap in the literature by synthesizing the realized gains and any associated costs based on proven evidence from research and practice.

This paper attempts to fill this gap by synthesizing the realized gains and any associated costs through a descriptive meta-analysis of evidence from research and practice covering the period 2000-2016. The rest of the paper is organized as follows: Section 2 reviews the literature highlighting the various claims about the potential impacts of 3D visualization and VR in DES. Section 3 explains the research methodology. Section 4 presents the results of the study and discusses the findings. Finally, Section 5 concludes the paper and presents a brief discussion of future research.

2. Literature Review and Theoretical Background

This section reviews the key DES activities and the various claims about the impacts of 3D visualization and VR on those tasks, including problem definition, conceptual modeling, and model development. Others are model validation and verification, experimentation and analysis.

2.1 **Problem Definition**

Problem definition or specification is an important first step in the DES process. The primary activities involve analyzing the requirements, developing project objectives and formulating the structure for the simulation project. Specifically, the key tasks and activities include:

i. Creating a list of questions or problems that the simulation should address, define a set of assumptions and decision variables (Law & McComas, 2002).

ii. Determining the project scope, identify specific problems to address, with hindsight on how to use the model during experimentation and analysis phase (Brooks & Tobias, 1996; Banks, Carson II & Barry, 2005).
iii. Developing the scope or boundary of the model, and the level of detail based on the questions that the model seeks to answer and data availability (Brooks & Tobias, 1996; Brooks & Wang, 2015).
iv. Determining a list of measures of performance and meaningful alternatives that can be used to evaluate and compare with the real system (Brooks & Tobias, 2000). These performance measures can provide information and insight into the problem domain (Akpan & Brooks, 2014).

The overall claims about the benefits of 3D/VR on problem specification, many researchers and practitioners posit that there are no perceived or realized benefits of visual display on the problem definition.

2.2 **Conceptual Modeling**

Conceptual modeling is an essential ingredient for successful simulation if developed properly. It entails logical representation of the problem or specification requirements in a way that the model developer and by the client can easily understand. The model can be developed conceptually by way of diagram or pictorial sketches to show process-flow or layout of the system. It is also possible to represent the conceptual model in a textual format or as a supplement to diagrams or pictures (Brooks & Tobias, 2000; Tako & Robinson, 2010).

The use of the visual display for conceptual modeling involves representing the model elements and system's components by way of graphic symbols or sketches (Waisel, Wallace & Willemain, 2008), block diagrams, or graphics supplemented by text (Au & Paul, 1996). The aspects of conceptual modeling include, System description (describes the problem situation and the system), non-software dependent Conceptual model and computer model, which is software specific design and representation of the system (Kotiadis & Robinson, 2008; Robinson, (2008).

2.3 **Model Development**

Model development involves the implementation of the conceptual model (Section 2.2), through a computer program or by drag and drop of graphical elements, and defining parameters using drop-down menus and commands of standard modeling tools and software. Currently, most DES models are developed using software applications (e.g. WITNESS/VR, FLEXSIM, etc.). Using the modeling software enables the building of models without any recourse to extensive programming. While some of the software is general purpose (that is, can be used to model different systems) purpose, others are specific to certain applications (Tako, 2014). Several perceived benefits and claims about 2D and 3D visual displays include the following:

i. Creating simulation model in 3D (from the perspective of the model builder) provides visual details and more accurate model that represents the system (Barnes, 1996; Akpan & Brooks, 2012).

ii. The 3D visualization enhances appropriate insight into the designed system and highlight subtle aspects of data and in some ways manipulates the viewer's perception of information positively (Farooq, et al. 2007; Orady, Osman & Bailo, 1997).
iii. VR helps to reduce the likelihood of overlooking the important details that affect the performance of the system (Barnes, 1996; Waly, & Thabet, 2003).
iv. The 3D simulation models provide the means for generating, representing information about the system in natural and accurate form (Barnes, 1996).
v. The benefit of 3D graphical animation presents realistic display compared to other techniques, e.g. the 2D display type (Farooq, et al. 2007).

The relative costs of modeling in 3D and VR include the following:

i. There is a popular claim that modeling and simulation in the 3D display or VR adds little or no value to the DES process (Akpan & Brooks, 2005b, 2012).
ii. It is time consuming and takes significantly more effort to develop 3D models compared to other methods (Akpan & Brooks, 2005b).

2.4 **Validation and Verification**

Validation is a process of determining whether a simulation model is an accurate representation of the system, for the particular objectives of the study (Law, 2003). The purpose is to identify and correct any errors in the model to ensuring that the simulation model accurately mimics the real-world system accurately from the perspective of its intended uses. Error free models enable managers and users sufficient to use it for decision-making. Kamat & Martinez (2000) emphasize validating models using the visual display to ensure accuracy as demonstrated in an experiment by Akpan & Brooks (2014). Verification, on the other hand, is concerned with determining whether the conceptual model with assumptions correctly translate into a DES model (Sargent, 2013; Robinson, 2008). The common claims about the effects of 3D/VR techniques in DES include the following:

i. It helps the developers in debugging models during the development stage and in verifying that the model accurately represents the modeled system, as the developer understands it (Kamat & Martinez, 2000).
ii. It emphasizes details about the system and enhances better problem detection and problem-solving (Mujber et al. 2004)
iii. It facilitates model verification and validation process, which improves model accuracy (Akpan & Brooks, 2005a, 2005b).
iv. It allows better problem detection (Mesquita, Cunha, Henriques, Grave, Silva, 2000; Akpan & Brooks, 2005a).

v. Providing all relevant details improves model accuracy (Akpan & Brooks, 2012, 2014)
vi. The 3D animation is potent in evaluating model behavior (Akpan & Brooks, 2005a, 2005b).

However, some skeptics also assert that, although 3D models may look convincing, it does not guarantee validity bearing in mind that, the model can only be as valid as the information it represents (Mujber, Szecsi & Hashmi, 2004). The model builder must also be aware that, the appealing visual representation of 3D model cannot be a substitute for the important statistical analysis (Rohrer & McGregor, 2002; Brooks, 1999).

2.5 Model Run, Experimentation and Analysis

Experimentation involves investigating the alternative courses of action, towards arriving at a preferred decision that can improve a system of interest. It involves running the model and observing the behavior of the model. The simulation analyst can alter the running speed of the model and the parameters to examine different alternatives. Other important activities involved in experimentation include collecting output statistics, carry out multiple replications, and the use of statistical and optimization techniques and analysis (Robinson & Pidd, 1998; Brooks & Robinson, 2001; Law, 2003).

One benefit of using the 3D display for experimentation and analysis is that it enhances ease of analysis and generation of ideas about the modeled system. The rationale for this claimed benefits it that:

i. Running the model in real time using 3D/VR makes it possible to obtain the actual/dynamic positions of entities during the run (Bennaton & Sivayoganathan, 1995).
ii. Model run in the 3D/VR environment can be very slow.
iii. The 3D animation makes it possible to observe the model behavior in real-time in a way that mimics the real life situation at model runtime. It is also possible for the observer to 'walk' or 'fly' through the simulation, and also to modify simulation parameters or examine performance statistics (Waller & Ladbrook, 2002).
iv. With the VR system, it is possible to move around your simulation model as if being inside the process, viewing activities from any angle, and at any size, which improves understanding of the system (Waller & Ladbrook 2002).

The limitation of experimentation in a 3D environment is that running 3D model in real time can be slow. This can limit the strength of 3D simulation modeling (Akpan & Brooks, 2005a, 2005b) and can hinder knowledge elicitation (Robinson, Lee & Edwards, 2012).

2.6 Presentation of Results to the Clients

One of the DES tasks is presenting the outcomes of a simulation project to the stakeholders in a way they can understand, and believe in it. According to Waller & Ladbrook, (2002), the 3D/VR is a valuable tool to convey ideas to senior management, managers and other non-technical personnel who may. The reasons are as follows:

i. The 3D graphics helps to simplify the presentation and interpretation of simulation results to the users, especially to the managers and other decision-makers with little knowledge of statistics and computer simulation (Smith, 1999).
ii. The 3D graphics helps to simplify the presentation of the results for technical engineers as well as for upper management (Kamat & Martinez, 2008).
iii. Realistic 3D simulation can be a very effective medium for communicating to observers from various disciplines and non-technical personnel (Barnes, 1996).
iv. The 3D enhances understanding of the technical details by non-experts, and offers a platform for improved communication between management, model builders, users, and non-technical personnel (Smith, 1999).
v. The 3D/VR offers the ability to visualize system as in real-life and provides a more pragmatic and comprehensible feedback from the simulation models (Kamat & Martinez, 2000).

3. Materials and Method

3.1 Literature Search Methodology

The literature search process, reporting, and analysis of results are structured according to the guidelines offered by the preferred reporting items for systematic reviews and meta-analyses (PRISMA: Runeson, & Höst, 2009). PRISMA defines the steps and processes in identifying, interpreting and evaluating the data.

The articles on visual display, 3D visualization, and virtual reality are quite diverse with records of implementation and application in several disciplines, e.g. computing, engineering, medical sciences, business operations, etc. The literature search was carried out using Google Scholar (https://scholar.google.com), which index articles from all disciplines, and cross-matched with the articles' retrieved through 'Publish or Perish' (Publish or Perish, 2015). In other to avoid omitting any relevant papers, we also searched the bibliographic databases that index computing/information systems, operations research and the management sciences, including the Science Direct, Informs PubsOnline and IEEE Xplore Digital Library. Others were ACM Digital Library, Springer, Wiley (onlinelibrary.wiley.com/advanced/search), Palgrave Macmillan and Emerald Insight/Emerald FullText (emeraldinsight.com). Most of the articles indexed by individual publisher's database and "Published or Perished" also appeared on the Google Scholar.

The search covered the last seventeen (17) years (2000 to 2016), the period that no comprehensive review papers exist that synthesizes the realized benefits and costs and claims about VRSIM. However, Robinson, (2005) examined the advances in DES generally and the visual display from the mid-1990s to the mid-2000, with a brief mention of 3D/VR as the current trend in the early 2000s. Table 1 shows the search terms. The retrieved articles were exported on to EndNote bibliographic software for filtering, screening, and selection.

Table 1. Keywords used in the literature search and Paper Selection Criteria

Search Terms	Concatenate with the following terms
Three-dimensional display or 3D Display	Computer simulation
Three-dimensional visualization or 3D Visualization	Discrete event simulation
Virtual reality or VR	
Visual interactive simulation or visual interactive modeling	
Criteria for Selection and Inclusion of Articles in the Review	
Studies that implement 3D/VR displays and demonstrate the real impacts on DES tasks (Section 2.1-2.6).	
Articles published between 2000 and 2016 (print/online sources).	
Peer reviewed journal article.	
Papers written in English or formerly translated into English.	

3.2 The Filtering, Screening and Selection of Articles

The filtering, screening and selection process followed the PRISMA guidelines (Runeson, & Höst, 2009) as explained in Section 3.1 above. After exporting the identified publications on the Endnote, we employed its search, filtering and querying functionalities to remove the duplicate entries. Further filtering and screening process (Figure 1) reduced the initially retrieved 1884 articles to 67 publications after an eligibility screening. Table 1 lists the criteria used in the screening and selection of the papers.

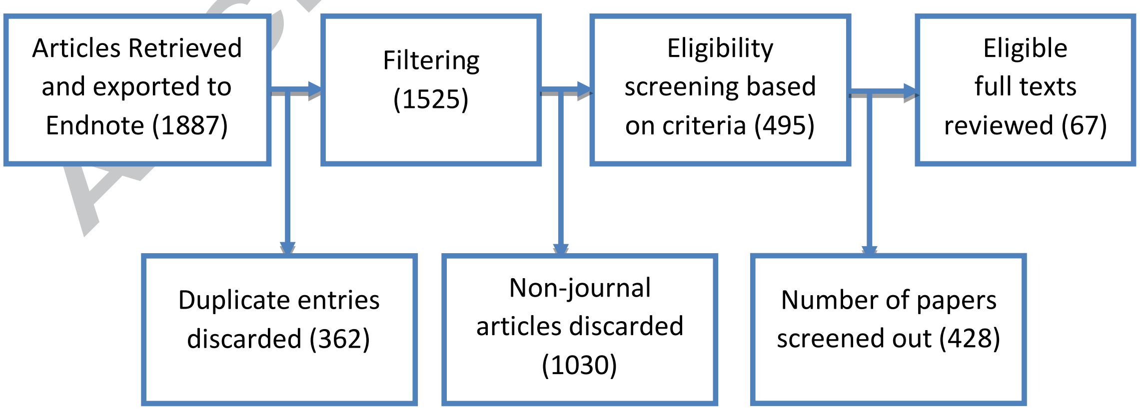

Fig. 1. Filtering, screening and selection process for the articles

Fig. 2. shows the distribution of the 495 papers that were screened for eligibility and the 67 articles included in the review. Each year shows the candidate publications for consideration, and highlight a sustained research on visual display in DES indicating the importance of visualization in DES from 2000-2016. At least one article was selected from each of the 17 years, except in 2009, when 19 articles were screened but none was selected based on the criteria defined in Table 1 in Section 3.1.

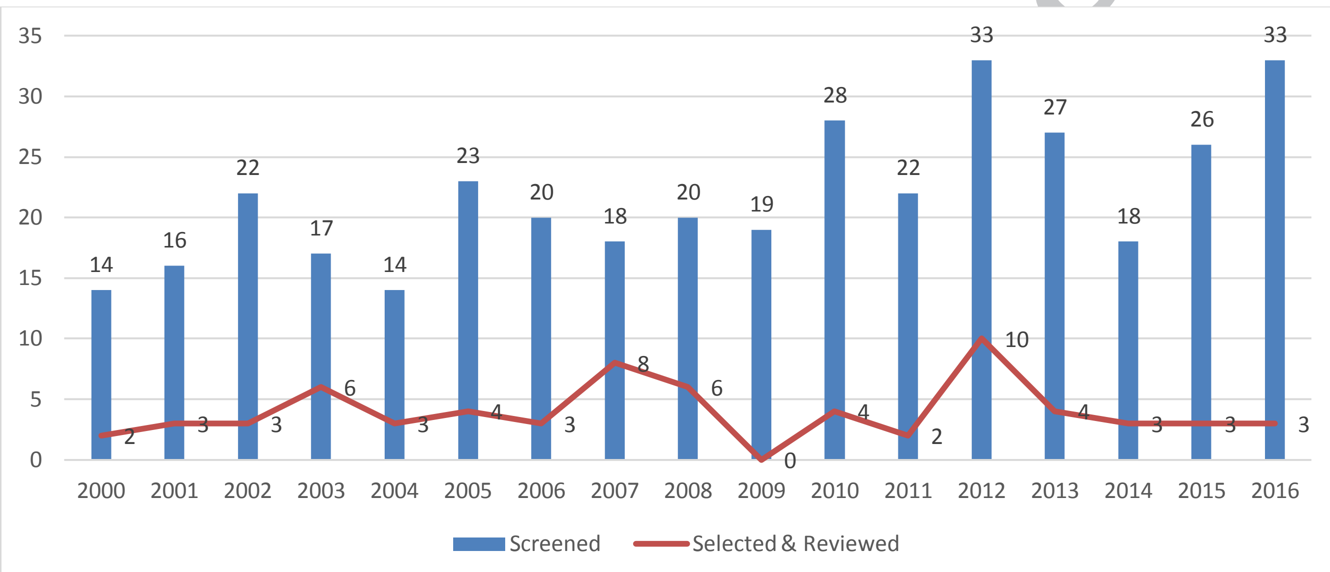

Fig. 2: Screened versus selected and reviewed articles

3.3 Data Analysis Methodology

This study adopts a descriptive meta-analysis to synthesize the findings from peer-reviewed journal publications on the realized benefits and costs of 3D visualization, and VR in DES. A descriptive meta-analysis is considered most suitable given that the reviewed articles differ in some ways including the research method (e.g. surveys, experiments, case studies, or a combination of these methods). The articles also tackled diverse problems in many disciplines and application domains (Table 2), given the multi-disciplinary dimension of computer simulation and information visualization techniques. A confirmatory meta-analysis would not be suitable in this case because the effect size categorization would be inconsistent, or not available for some of the studies. Previous studies have adopted a descriptive meta-analysis successfully for similar reasons (e.g. Bohannon et al. 2006; Toufaily, Ricard, & Perrien, 2013).

Table 2 Tasks and Activities in DES, the Problems Tackled and the Research Methods

References	Method Used	Problems Tackled	Problem Definition	Conceptual Modeling	Model Development	Model run	Experimentation	Validation	Verification	Analysis	Presentation
Aigner, et al. (2007)	Case Study	Visual Analytics								X	X
Akpan, & Brooks, (2012)	Survey	Surveyed simulation practitioners and users on diverse DES projects	X		X	X	X		X	X	X
Akpan, and Brooks, (2014)	Experiment	Error detection, understanding and decision-making exp.						X	X		
Alberts, et al. (2012)	Case Study	Diagnoses of inflammatory response syndrome						X		X	
Al-Hussein et al. (2006)	Case Study	Tower crane operations on construction sites			X			X	X		
Whyte, (2003)	Case Study	Construction management									X
Waly, & Thabet, (2003)	Case Study	Engineering construction process planning & design				X					
Bruzzone, et al. (2007)	Case Study	Process mangt for large scale retail store								X	X
Chan, (2003)	Case Study	Process design					X	X	X		
Wenzel, Jessen, (2001)	Case Study	Process planning									X
Chen, & Huang, (2013)	Experiment	Problem formulation (2D vs. 3D) of transport operations in construction		X	X						X
Choi, Park, & Park, (2003)	Case Study	Automated manufacturing systems design			X			X			
Dangelmaier et al. (2005)	Case Study	Simulated digital factory			X	X	X	X	X	X	X
den Hengst, de Vreede, & Maghnouji, (2007)	Experiment	Collaborative Modeling of airport construction & operations			X		X				
Dorozhkin, et al. (2012)	Case Study	Coupling interactive flexible manufacturing operations				X	X			X	
Bailey, Leonardi, & Barley, (2012)	Case Study	Evaluating display types						X			
Farooq, Wainer, & Balya, (2007)	Case Study	Implementation process simulation	X			X	X	X	X	X	
Fishwick, (2004)	Experiment & Survey	Modeling systems using 2D v 3D			X		X				X
Fishwick, Davis, & Douglas, (2005)	Case Study & Survey	Visualization in 2D vs. 3D			X						
Talmaki, Kamat, & Saidi, (2015)	Case Study	Monitoring visibility-constrained construction				X				X	X

Su, & Huang, (2014)	Case Study	Smart building planning			X				X		
Huang, et al. (2007)	Case Study & Survey	System implementation			X	X					
Sun, et al. (2012)	Case Study	Container terminal management			X						
Kamat, & Martinez, (2008)	Case Study	Creating and evaluating software for construction management			X			X	X		
Kamat, & Martinez, (2007)	Experiment	Evaluating speed detecting in 2D v 3D						X	X		
Kamat, (2008)	Case Study	Construction process-level planning						X	X		
Kamat, & Martinez, (2005)	Case Study	Visualization of construction equipment									X
Kamat, & Martinez (2003)	Case Study	Validating complex earth moving construction activities						X	X		X
Kamat, & Martinez, (2001)	Case Study	Construction planning						X		X	
Kamsu-Foguem, et al. (2012)	Case Study	Detection of issues in intensive care patient								X	X
Khoury, Kamat, & Ioannou, (2007)	Case Study	Airside airport construction & operation						X	X		
Kim, Lee, & Fishwick, (2002)	Case Study	Web-based sim									X
Li, et al. (2003)	Experiment	Virtual Construction					X			X	
Lindskog, et al. (2013)	Case Study	Systems Re-design			X						X
Moon, et al. (2006)	Case Study	Simulated body shop design in auto assembly							X		
Mujber, Szecsi, & Hashmi, (2004)	Case Study	Flexible manufacturing process analysis						X	X		
Murphy, & Perera (2002)	Case Study	Process planning		X							
Okulicz, (2004)	Case Study	Process Planning								X	
Otamendi, Pastor, & Garcia, (2008)	Case Study	Software evaluation and selection for airport construction & operations			X						
Quarles, et al. (2010).	Case Study	Analyze interaction among components			X						
Rekapalli, and Martinez, (2011)	Case Study	Process evaluation						X			
Waisel, Wallace & Willemain, (2008)	Experiment	Model formulation by experts	X	X							
Robinson, Lee, & Edwards, (2012)	Experiment	Knowledge elicitation and decision-making in auto engine production				X	X				
Rodriguez, Hilaire, & Koukam, 2007	Case Study	Industrial plants & traffic flow, speed, rate, etc.									X
Qu, et al. (2010)	Experiment	Teleonomic modeling of eggplant								X	X

Rua, & Alvito, (2011)	Case Study	Reconstruction of heritage					X			X	X
Rubio, Sanz, & Sebastián, (2005)	Case Study	Flexible Manufacturing								X	
Smallman, et al. (2001)	Experiment	Evaluation of 2D versus 3D in air traffic control								X	
Son, & Kim, (2012)	Case Study	Visualization of underwater vehicle and effective maneuvering control								X	
Oerter, et al. (2014)	Case Study	VR platform solution for collaborative modeling & simulation			X	X	X				
Hurrion, (2000)	Case Study	3D modeling as DES methodology					X			X	
Dialami, et al. (2015)	Experiment	Material transport and flow in a friction stir welding						X			
Lu, et al. (2015)	Case study	Assembly facility planning operation						X			
Korošec, Bole, & Papa, (2013)	Experiment	Production scheduling and optimization	X								
Khosravi, Nahavandi, & Creighton, (2010)	Experiment	Metamodeling and simulation of baggage handling system.			X						
Chen, Hou, & Wang, (2013)	Case Study	Maintenance and management of existing building facilities			X						
Hajdasz, (2008)	Case Study	Create an intelligent support system and simulate construction process dynamics					X			X	
Somasundaram & Kalaiselvi (2010)	Experiment	Surgical experiment					X	X			
Calabrese, et al. (2012)	Case Study	Shipboard damage control						X			
Li, et al. (2008)	Case Study	Construction planning								X	
Hong, Shi, & Tam, (2002)	Case Study	Construction process planning			X			X	X		
Moghadam, et al. (2012)	Case Study	Building construction scheduling								X	
Nandan, et al. (2006)	Experiment	Material transport and flow in a friction stir welding process						X		X	
Zhou, et al. (2016)	Case Study	Manufacturing process optimization						X		X	
Zhang, et al. (2016)	Case Study	Evaluates the use of 2D and 3D simulation visualization in the planning and performing hepatectomy operations.									X
Van Orden & Broyles, (2000)	Experiment	Altitude and speed judgement (air traffic control)									X
Patel, Dholakia, & Singh, (2016)	Case Study	Disaster, emergency and crisis management									X
		n=130	4	3	19	9	14	23	15	23	20

4. Results and Analysis

4.1 Data Sources

The data used in this study were extracted from the reviewed articles. After a thorough review of the abstracts and the main contents of each publication, sixty-seven (67) articles, published in 38 journals covering diverse fields were selected. All the selected journal papers carried out 130 investigations on the realized impacts of the 3D visualization and VR on DES tasks and activities. Some studies compared the impacts of the 3D/VR against other forms of visual display, e.g. 2D visual interactive simulation. The studies on model validation and analysis had the highest count (23 each: Figure 3) followed by presentation of results to the clients (20) and model usability development (19). The DES activities with the fewest research were conceptual modeling and problem definition (with 3, 4 studies respectively). Some articles investigated more than one DES activities. For example, each of Kamat, & Martinez, (2003) and Akpan & Brooks, (2012) investigated the impacts of 2D, 3D/VR displays on model validation, verification, experimentation, etc.

To find out if the research methods, the application domains/problems tackled had any impacts on the conclusions arrived by the selected authors, we collected relevant data to observe any such pattern. The 67 selected articles adopted five (5) research methods, with case study being the most popular, followed by experiment (Figure 3).

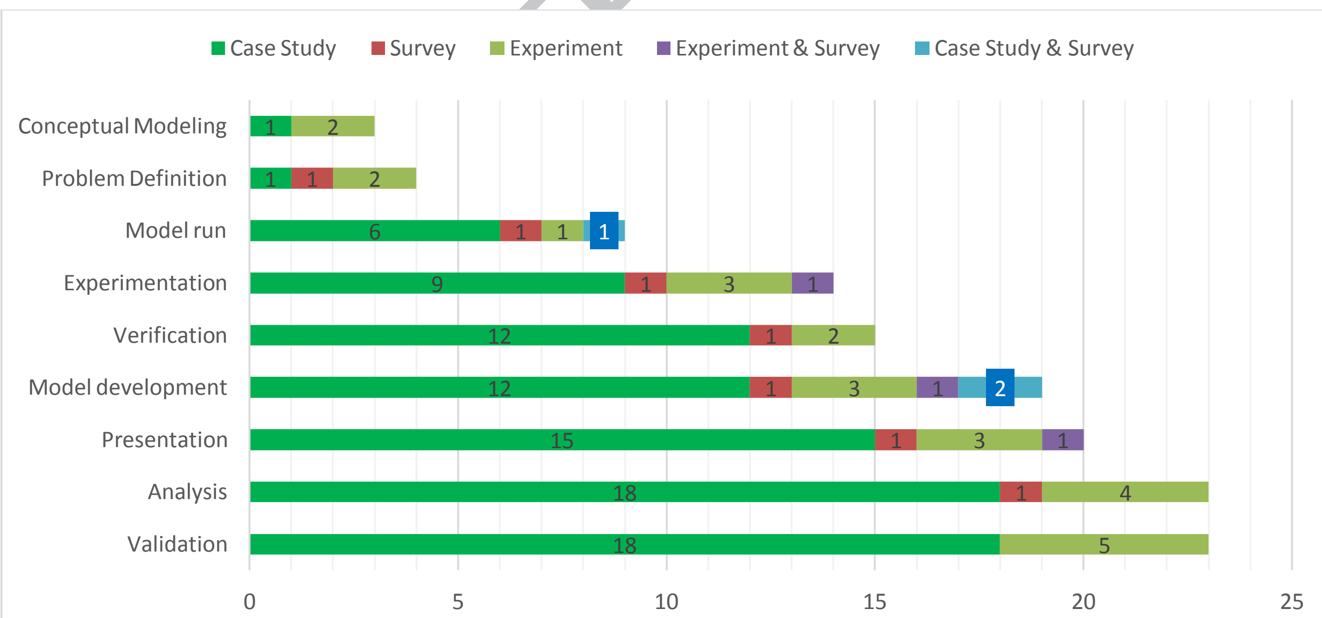

Figure 3. DES Activities and the Research Methods Used by the Selected Articles

On the application domains classification, the reviewed articles covered a broad range of areas. Overall, 38 application domains were covered by the 67 selected publications, with some of the papers evaluating more than one area of application (e.g. Akpan & Brooks, 2014, Kumar & Benbasat, 2004). Civil Engineering, particularly construction was the most popular area with 14%, followed by systems implementation and evaluation, which had 11% (Figure 4). Other major areas of applications include aerospace, production/manufacturing, healthcare/medical services operations and air traffic control. The significance of these categorizations is to ascertain any possible impacts of visualization on the DES activities due to the domain and problems tackled.

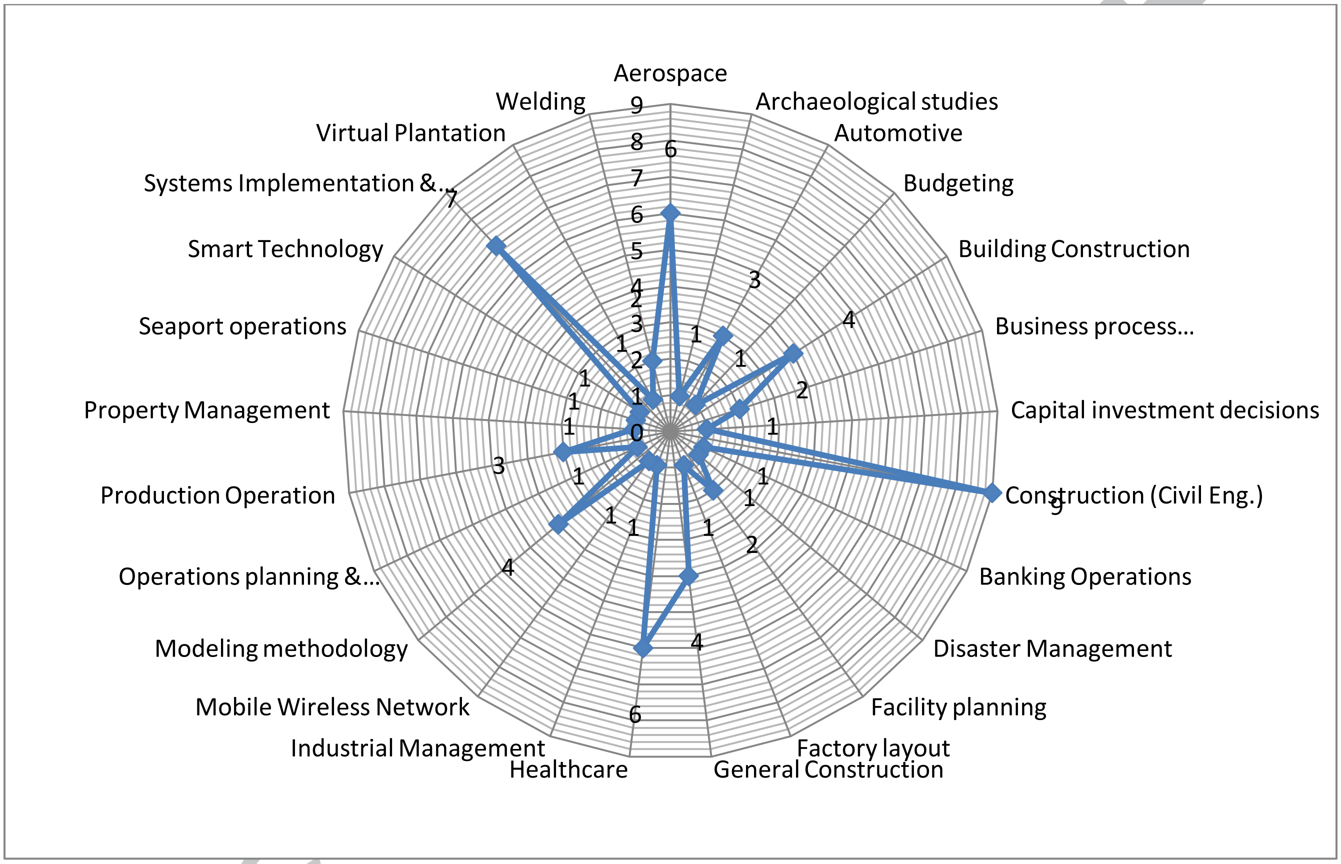

Figure 4. The Application domains covered by the selected articles

Out of the 67 articles selected for the final review, fifteen (15) or 22% were published in the core simulation journals, followed by twelve (12) or 18% in the civil engineering related sources, particularly in construction, while majority of the remaining papers appeared in computing/information systems and decision sciences outlets, including the journal of computers and industrial engineering. The journals in others application areas were healthcare/medical sciences, and archaeological/cultural heritage, etc. (Table 3).

Table 3 List of reviewed articles and the journals sources published (2000-2016)

Journals	References	No	Journals	References	No
	n=67				

Expert Systems with Applications	Robinson, Lee, & Edwards, (2012); Son, & Kim, (2012); Korošec, Bole, & Papa, (2013); Chen, Hou, & Wang, (2013); Khosravi, Nahavandi, & Creighton, (2010); Calabrese et al. (2012)	6	Automation in Construction	Al-Hussein, et al. (2006); Waly, & Thabet, (2003); Chen, & Huang, (2013); Huang et al. (2007); Li, et al. (2003); Hong, Shi, & Tam, (2002); Li et al. (2008)	7
Simulation Modelling Practice & Theory	Bruzzone et al. (2007); Farooq, Wainer, & Balya, (2007); Murphy, & Perera (2002); Otamendi, Pastor, & Garcia, (2008); Rodriguez, Hilaire, & Koukam, (2007); Qu et al. (2010)	6	Simulation	Akpan, & Brooks, (2012); Alberts, et al. (2012); Wenzel, Jessen, (2001); Choi, Park, & Park, (2003); Fishwick, (2004); Khoury, Kamat, & Ioannou, (2007)	6
Journal of the Operational Research Society	den Hengst, de Vreede, & Maghnouji, (2007); Waisel, Wallace & Willemain, (2008), Hurrion, (2000)	3	ACM Transaction on Modelling & Computer Simulation	Fishwick, Davis, & Douglas, (2005); Kim, Lee, & Fishwick, (2002); Quarles, et al. (2010).	3
Journal of Computing in Civil Engineering	Kamat, & Martinez, (2001); Kamat, & Martinez, (2005)	2	International journal of production research	Moon, et al. (2006); Okulicz, (2004)	2
Decision Support Systems	Akpan, & Brooks, (2014); Kamsu-Foguem, et al. (2012)	2	Advances in Engineering Software	Kamat, & Martinez, (2008); Kamat, (2008)	2
Organization Science	Bailey, Leonardi, & Barley, (2012)	1	Engineering with Computers	Talmaki, Kamat, & Saidi, (2015)	1
Computers in Industry	Dangelmaier, et al. (2005)	1	Computers & Graphics	Aigner, et al. (2007)	1
Systems Analysis Modelling Simulation	Kamat, & Martinez (2003)	1	Construction Management and Economics	Whyte, (2003)	1
Assembly Automation	Chan, (2003)	1	Computers in Biology and Medicine	Somasundaram, & Kalaiselvi, (2010)	1
Procedia CIRP	Lindskog, et al. (2013)	1	Journal of Archaeological Science	Rua, & Alvito, (2011)	1
Virtual Reality	Dorozhkin, et al. (2012)	1	Computers & Industrial Engineering	Lu, et al. (2015)	1
Science and Technology of Welding and Joining	Nandan, et al. (2006)	1	International Journal of Computer Integrated Manufacturing	Rubio, Sanz, & Sebastián, (2005)	1
Computer Standards & Interfaces.	Su, & Huang, (2014)	1	Journal of Materials Processing Technology	Mujber, Szecsi, & Hashmi, (2004)	1
International Journal of Material Forming	Dialami, et al. (2015)	1	IEEE Computer Graphics and Applications	Smallman, et al. (2001)	1
Advanced Engineering Informatics	Sun, et al. (2012)	1	Technological and Economic Development of Economy	Hajdasz, (2008)	1

Journal of Information Technology in Construction (ITcon)	Kamat, & Martinez, (2007)	1	Journal of Defense Modeling & Simulation: Applications, Methodology, Technology	Oerter, et al. (2014)	1
Canadian Journal of Civil Engineering	Moghadam, et al. (2012)	1	Journal of Construction Engineering & Management	Rekapalli, & Martinez, (2011)	1
Displays	Van Orden & Broyles, (2000)	1	JOM	Zhou, et al. 2016	1
Geomatics, Natural Hazards and Risk	Patel, Dholakia, & Singh, (2016)	1	Surgical Oncology	Zhang, et al. (2016)	1

4.2 The Confirmed Realities of the Benefits and Costs Associated with 3D Visualization and VR

This section carries out a reality check on the claims (myths) discussed in Section 2 about the benefits and costs associated with the implementation of 3D/VR techniques based on the impacts on the DES tasks. As explained in the earlier section, this study employs a descriptive meta-analysis.

4.2.1 Reality Check #1: Problem Definition

The impacts of 3D visualization and VR on problem definition attracted few studies (4). Waisel et al. (2008), which examined how expert model developers use sentential and diagrammatic sketches at the problem formulation concluded that such modeling strategy enhances an early insight into the problem, leading to the creation of better DES models. The sketches were 2D diagrams, not 3D or VR. Korošec, Bole, & Papa, (2013) in another experiment using the 3D display arrived at a similar conclusion. Although the third paper (Farooq, et al., 2007) also concluded that the 3D visualization could support modeling at this phase, it was unclear about the specific activity that this apply. On the contrary, in a survey by Akpan & Brooks, (2012), a significant majority of simulation practitioners and researchers did not see any benefit of using the visual display at this early stage of modeling. Further details are available in Table 4.

Table 4. The impacts of visualization on problem definition and conceptual modeling

References	Realized Benefits/Costs
Problem Formulation/Definition	
Korošec, Bole, & Papa, (2013)	The 3D display helped to provide a better understanding of the problem-definition process.
Farooq, et al., 2007	The 3D visualization makes modeling easier than when using the 2D display.
Waisel, et al., 2008	Using 2D sketches during problem formulation helps to generate insight about the problem.
Akpan, et al, 2012	94% of the simulation professionals, users, and decision-makers did not see any effect of the 3D or 2D displays on problem definition, both on the clarity and time it takes to complete the task.
Conceptual Modeling	

Waisel et al, 2008	The more complex the more expert model developers tend to use visualization (2D).
Chen et al, 2013	Model development tasks using 3D prototype and other 2D display simulation applications. It is easier to use 2D sketches during conceptual modeling.
Murphy et al, 2002	Evaluated at what stage of the manufacturing processes that 3D visualization could be more useful in a DES process.

4.2.2 Reality Check #2: Conceptual Modeling

Only one of the three articles that investigated the impacts of visual display evaluated the 3D. The study concluded that although visual display can affect performance on conceptual modeling, the 3D visualization does improve the DES activities at this modeling phase. Table 4 provides the detail conclusions from the studies.

4.2.3 Reality Check #3: Model Development

Section 2.3 listed five benefits and positive claims and two costs or negative speculations about modeling and simulation in 3D and VR. Nineteen out of the sixty-seven articles examined the effects of 3D/VR modeling on performance effectiveness and efficiency. The conclusions from the nineteen studies confirms all the benefits as well as one of the costs of 3D modeling, that is, it takes longer to build a 3D model. However, the results invalidate the claim that the implementation of 3D/VR modeling methodology. On the contrary, the 3D visualization and VR (VRSIM) brings several gains and appears to become an established DES method. Table 5 presents details of the realized benefits and costs of 3D/VR in DES.

Table 5. The impacts of 3D/VR on model development and the time taken to develop it

References	Realized Benefits/Costs
Al-Hussein et al, (2006)	3D display enables domain experts who are knowledgeable in given systems, but not familiar with simulation to model an operation easily.
den Hengst et al, (2007)	The 3D visualization offers true-to-scale features that helps to resolve any complexities.
Lindskog et al, (2013)	Creating a 3D model is time consuming and may result in unnecessary over simplification.
Choi et al, (2003)	3D makes it easier for domain experts (manufacturing engineer, not only the simulation expert) to build the model of a target system.
Dangelmaier et al, (2005)	3D is preferred when involving multiple domains experts working in the simulation team with experts and analysts.
Chen et al, (2013)	3D enhances precision in model creation, helps to build model in efficient and effective way, and facilitates accurate positioning of components.
Kamat, & Martinez, (2008)	3D enhances accurate representation of model. It is impossible to model the entire system characteristics accurately in 2D space.
Sun et al, (2012)	3D/VR visualization System helps to reduce modeling effort.
Otamendi et al, (2008)	Developing a 3D model is time consuming.
Quarles et al, (2011)	3D enhances transparent reality and provides users with an interactive and

	dynamically accurate visualization of internal structure and processes.
Su et al, (2014)	It is quicker to build 3D model.
Fishwick et al, (2005)	3D modeling (aesthetic computing) is time consuming compared to 2D.
Huang et al, (2007)	The 3D modeling is tedious and time consuming.
Fishwick et al, (2004)	3D should Supplement the 2D method, not replace it.
Akpan, & Brooks, (2012)	Over 93% of respondents who have used both 3D and 2D displays stated that, it takes significantly longer time to build 3D model compared to 2D.
Oerter, et al., (2014)	The VR environment greatly enhances collaborative learning and modeling without losing the engineering specifications. The higher modeling costs and longer time required for the artistic renderings (of the 3D space) are the major drawbacks of the VR Platform.
Khosravi, Nahavandi, & Creighton, (2010)	Modeling the baggage handling system in 3D enhanced precise representation.
Hong, Shi, & Tam, (2002)	It is true that the 3D model is closer to the real world, but it takes considerable effort and time to develop.
Chen, Hou, & Wang, (2013)	Non-experts can interact with the model and obtain information needed to carry out functions. In this case for example, the facility managers can interact with the 3D model interface to acquire information to support operations and decision, can access the backend database through the 3D model for the managers to view.

4.2.4 Reality Check #4: Module Run

Nine studies investigated the impacts of using 3D/VR during the simulation runtime. All the papers confirmed the claimed benefits as well as adverse impacts of 3D/VR at this phase. While seven authors confirmed the positive gains, two concluded that the choosing this visualization technique causes the model to run very slowly. Table 6 contains further details of these conclusions.

Table 6. The realized Benefits and costs of running DES model in 3D/VR

References	Benefits/ Costs
Huang et al, (2007)	Non-simulation experts can run and optimize the 3D (CVP) model, and evaluate the resource utilization.
Robinson et al, (2012)	Slower run-speed of the 3D display is reducing the collection rate
Waly et al, (2003)	Running model in 3D display makes it slower.
Akpan, & Brooks, (2012)	3D Preferred for evaluating model behavior and checking errors.
Oerter, et al., (2014)	The user can explore the 3D environment from a first-person or third person viewpoint while running the model, providing the users with the capabilities to properly visualize and explore the entire model. These capabilities would greatly improve the visualization and make it simpler to use and decreases the number of man-hours used by the team,

	thereby reduce the cost for the customers.
Dangelmaier, Fischer, et al., (2005)	The 3D visualization helps to overcome the various problems associated with the 2D display such as misinterpretation and errors in the results at runtime.
Dorozhkin, Vance, et al., (2012)	Implementing an immersive virtual reality environment with the simulation, the realistic visualization provided allow users to interact with the model as in real-life during the runtime.
Farooq, Wainer, et al., (2007)	The implemented 3D-based DEVs enhanced easy visualization of the operation and observing the realistic interactions at runtime and visualizing the results.
Talmaki, Kamat & Saidi, (2015)	The 3D visualization system integrated with PROTOCOL platform can receive sensor input from the real world, and providing audio-visual warning feedback for accident avoidance at runtime.

4.2.5 Reality Check #5: Model Validation

An investigation into the impacts of 3D visualization and VR on model validation is one of the DES tasks that attracted the most attention (23). In the studies that span several application areas employing different research methods and tackled various problems (Table 2), all concluded by confirming all the benefits of using 3D/VR for model validation listed in Section 2.4, and much more (Table 7). The results show that validating the model in 3D/VR environment does not have any negative effects but contributes significantly to improving the overall quality of the DES model, which can enhance credibility of stakeholders in the process.

Table 7. Realized Benefits of validating DES model using 3D visual display and VR.

References	Explanations/Reasons
Mujber et al, 2004)	3D/VR helps to verify the model logic, and matching model behavior with real-world behavior, which is an important factor in verifying and validating a simulation model.
Akpan, & Brooks, (2014)	Easier to spot errors (logic, routing and wrong components combination) and reduces the time taken to spot the errors.
Al-Hussein et al, (2006)	Utilizing 3D visualization enhances better understanding construction operations, which is particularly helpful for simulation verification and validation.
Akpan, & Brooks, (2012)	3D makes it easier and takes shorter time to identify errors in the model during validation.
Bailey et al, (2012)	The 3D makes it easier for engineers and non-simulation experts to validate the DES models against the actual components and the processes.
Khoury et al, (2007)	3D enhances model validation irrespective of the application domain.
Rekapalli et al, (2011)	The interaction capability of 3D helps to detect any abnormal behavior in the model.
Alberts et al, (2012)	Using 3D in debugging model is very effective.
Choi, (2003)	Domain expert can use it to validate model easily.
Dangelmaier et al, (2005).	3D/VR makes it easier to find errors in the model (overcoming error-prone modeling of complex simulation models) in less time.
Farooq et al, (2007)	The 3D makes it easier to visualize each step in the simulation and enhances easy

	validation and debugging of the model and improvement of various tested protocols.
Kamat, & Martinez, (2001)	Helps domain experts to identify errors that model developers may not be able to spot.
Kamat, & Martinez, (2008)	The 3D visualization makes it possible to involve domain experts who can observe the behavior of simulation model, then compare with the real-life operation, thus helping to identify errors quickly.
Kamat, & Martinez, (2003)	3D helps in spotting inaccurate data and logic error.
Chan, (2003)	3D enables managers and engineers to have a clearer and more reliable picture of any impacts of changes on the system. This makes it easier to validate the model and sequence for assembling components in few minutes.
Kamat, & Martinez, (2007)	3D helps to determine the motion path in an accurate fashion.
Kamat, (2008)	3D provides the spatial information about construction workspaces and geometric details of the erected facility components that are captured into simulation models, which enhance validation.
Lu, Zhen, Mi, & Huang, (2015)	By displaying the results of the assembly components, subassembly sequences and production operation in 3D, the user are able to correct the obvious errors to ensure the finally assembly sequence is feasible.
Hong, Shi, & Tam, (2002)	It is agreeable that validation of model is not an easy task for users, which the 3D can simplify. Rather than using the 3D model animation that is complex to develop, 2D could serve the purpose.
Nandan, et al. (2006)	Presenting a detailed numerical analysis and the experimentally measured values of the 3D simulation of the flow and heat transfer during a friction stir welding of stainless steel, the 3D model was more accurate. According to the authors, this fact indicates the need for 3D models.
Dialami, et al. (2015)	When validating the numerically computed results with the experimentally measured values, both the 2D and 3D simulations results were "remarkably good".
Somasundaram & Kalaiselvi (2010)	Using the 3D based surgical simulation compared to the 2D, leads to significantly better performance in identifying the correct areas to carrying out the surgical operation and related activities.

4.2.6 Reality Check #6: Model Verification

Similar to the case of validation, model verification is another DES activity that benefits most from 3D visualization. Here, twelve studies investigated the relative impacts of the 3D display over 2D (Figure 8). All the surveyed papers concluded that the 3D makes it easier to verify DES model using the 3D display than any other method. Some of the studies explained that in situations where domain are experts are involved in the modeling process, the 3D makes it easier to understand the model and the operations and become very useful and helpful. In the case investigated by Kamat, & Martinez, (2003), the domain experts were able to detect severe mistakes caused by the model developers who used incorrect data, then went on to certify the DES model as correct. The domain experts were able to spot the errors. The studies confirmed all the benefits of using 3D/VR for verification as stated in Section 2.4, and did not identify any associated costs.

Table 8. The realized benefits of verifying DES model with 3D visualization and VR

References	The Realized Benefits
Mujber et al, (2004).	VR helps to verify the model logic and behavior and provides a visual trace of events, and aids the people who have not built the model to verify it.
Al-Hussein et al, (2006)	Utilizing 3D visualization enhances better understanding of construction operations, which is particularly helpful for simulation verification.
Kamat, et al. (2007)	3D helps to correct any discrepancy that may exist in the simulation model as intended by the simulation expert and the real-system.
Khoury et al, (2007)	3D visualization was effective when used to check that code was free of errors.
Dangelmaier et al, (2005).	Using 3D display for verification saves time and costs.
Farooq et al, (2007)	The 3D, which helps to verify the correctness of the results easily.
Su et al, (2014)	Quicker to verify 3D models: Applications with 3D animated models can be rapidly constructed and verified.
Kamat, & Martinez, (2008)	The ability to see a 3D animation of processes enhances verification.
Kamat, & Martinez, (2003)	3D visualization reveals all the logic errors in the model “in a few minutes” and helps the domain experts to detect errors caused by the use of bad data by simulation expert, the errors that the experts may never detect.
Chan, (2003)	3D helps to detect bottlenecks easily and accurate determination of buffer size.
Akpan, & Brooks, (2014)	Using the 3D visualization for the verification tasks reduced the time it takes significantly.
Akpan, & Brooks, (2012)	Over 73% of surveyed respondents who used both 3D and 2D displays said that the time spent for model validation and verification is shorter with 3D display than with 2D display.
Moon et al, (2006)	The 3D display is very effective in verifying automotive assembly simulation.
Kamat, (2008)	3D provides the spatial information about construction workspaces and geometric details of facility components, which enhance verification.
Hong, Shi, & Tam, (2002)	It is agreeable that model verification is not an easy task for users. Although the 3D display can simplify this, it is rather complex to create the 3D animation. Thus, the 2D could serve the purpose.

4.2.7 Reality Check #7: Model Experimentation

This section examines the benefits and costs associated with undertaking model experimentation with the 3D display/VR. The results of the studies reviewed confirmed all the claimed benefits listed in Section 2.5. Also, the studies concluded that the 3D/VR saves the time spent on the undertaking tasks. Table 9 provides details of the conclusions arrived by the fifteen papers that investigated this task.

Table 9. The realized benefits and costs of using the 3D visual displays / VR for model experimentation

References	The Realized Benefits and Costs
Dorozhkin et al, (2012)	Users can interactively change model inputs at model runtime in a dynamic way.
Rua et al, (2011)	3D is better suited to real-time manipulation, while technicians can visualize and experiment with different theories and hypotheses for reconstruction.
Dangelmaier et al, (2005)	3D/VR enhances optimization of production system.
Robinson, Lee & Edwards, (2012)	Slower run-speed of the 3D display is reducing the collection rate but it is easier to identify model inaccuracies in a 2D representation.
Farooq et al, (2007)	Cell-DEVS permitted us to develop new experiments easily.
Chan, (2003)	The use of 3D graphics and color scheme helps to analyze the system interactively highlights collisions, violation and near misses throughout the process.
Li et al, (2003)	3D makes it easier to experiment different construction methods in a what-if analysis.
den Hengst et al, (2007)	3D highlights model behavior during experimentation especially when involving stakeholders in the modeling activities.
Fishwick, (2004)	3D visualization (aesthetic computing) was far superior to conventional 2D display in its ability to illustrate the effects of changes in variables.
Somasundaram & Kalaiselvi (2010)	Experimenting on the 3D v 2D medical surgery simulation by the medical experts, the results on 20 MRI data showed that using the 2D display misled the performers to a wrong location to undertake brain surgery, while the 3D visualization enhanced accurate location. Where users identified correct areas in the few places using the 2D display, they were unable to extract correct brain portions most of the time compared to the 3D display.
Akpan, & Brooks, (2012)	3D helps in spotting errors in the model during experimentation, validation or verification.
Hajdasz, (2008)	The simulation and 3D visualization platform of the intelligent support system enhanced the what-if analysis of the construction process.
Oerter, et al., (2014)	The user has the ability to explore the 3D environment from a first-person or third person viewpoint while running the model, providing the users with the capabilities to properly visualize and explore the entire model. These capabilities would greatly improve the visualization and make it simpler to use and decreases the number of man-hours used by the team, thereby reduce the cost for the customers.
Hurrion, (2000)	With the 3D animation algorithm, it is possible to display, rotate and view a neural network simulation response surfaces from different positions.

4.2.8 Reality Check #8: Analysis of Simulation Results

The effectiveness of using 3D/VR to analyze the results of a simulation study was one of the most popular studies. As was the case with model validation, all the twenty-three investigations confirmed all the claimed benefits of 3D/VR in DES. Table 10 provides further details of the conclusions from the twenty-three studies.

Table 10. The impacts of 3D visualization on analysis of simulation results

References	Realized Benefits/Costs
Aigner et al, (2007)	3D encodes further information that is useful for analysis.
Dorozhkin et al, (2012)	3D helps users to understand the modeling environment in 3D and interactively change the inputs to the simulation at runtime.
Kamsu-Foguem et al, (2012).	3D provides new, powerful means for the visual analysis of time-oriented data. The analysis Specifics: Segmentation, clustering, detection of events.
Rua et al. (2011)	3D models and Virtual Reality programs allow different experiments and the analysis of the space on a human scale.
Rubio et al, (2005)	3D is a low cost and fast analysis tool
Talmaki et al, 2015	3D offers better analysis but takes longer time to perform.
Alberts et al, (2012)	This enables analysis of behaviors of this type of system at realistic scales for the first time on desktop computers
Bruzzone et al, (2009)	The 3D display helps in "analyzing store layout modifications" and provide feedback directly to domain experts involved in layout analysis".
Dangelmaier et al, (2005)	3D saves time for analyzing results, especially when involving multi-disciplinary team.
Farooq et al, (2007)	The 3D environment makes it easier to analyze the simulation results.
Wainer et al, (2009)	3D display provides the general users with a variety of easy-to-use environments to facilitate the model analysis process.
Li et al, (2003)	3D helps to experiment different construction methods in what-if analysis.
Qu et al, (2010)	The 3D graphic and status output modules acting as user interface for parameters control as well as data analysis.
Smallman et al, (2001)	2D enhances analysis of details than 3D
Akpan, & Brooks, (2012)	Participants in the experiment who analyzed the effectiveness and efficiency of the bank customer services were able to analyze simulation results quicker.
Son, & Kim, (2012)	3D visualization enhanced the performance analysis of underwater vehicle using discrete event simulation (DEVS model).
Moghadam, et al. (2012)	The visualization utilizing the 3D studio Max was more effective in analyzing the construction methods and complete the project in fewer days.
Kamat, & Martinez, (2001)	Developed and utilized a general-purpose 3D driven visualization system named dynamic construction visualizer (DCV) that enables construction planners to obtain more realistic feedback from simulation analysis.
Huang, et. al. (2007)	The 3D-based system that integrates visualization and simulation allows project teams to check constructability through visualized 3D models of projects. However, the process of collecting input data for this VP system is a time consuming process.
Li, et al, (2008)	Implement a 3D-based system that integrates visualization and simulation allows project teams to check constructability through visualized 3D models of projects easily.
Hajdasz, (2008)	The simulation and 3D visualization platform of the intelligent support system enhanced the analysis of workflow patterns, identification of changes and evaluation of their impact on construction process performance, analysis of variant solutions.
Nandan, Roy, Lienert, & DebRoy, (2006)	Presenting a detailed numerical analysis and experimentally measured values from the simulation of the flow and heat transfer during a friction stir welding of stainless steel, the 3D material was more accurate.
Zhou, et al. (2016)	The 3D/VR makes it easier to examine the system's behavior and adjust the simulation parameters to achieve an optimal solution.

4.2.9 Reality Check #8: Presentation of Simulation Results

Section 2.6 listed several plausible claims of 3D/VR in enhancing the presentation of results to the stakeholders in a given simulation project. As one of the popular areas that attracted the attention of researchers, all the papers confirmed all the claims associated with the use of 3D/VR in DES, with a consensus despite the various problems tackled in different application areas and the study methods used. Table 11 gives further details about the conclusions from the twenty studies.

Table 11 An effectiveness of 3D visualization vs. 2D display on presentation of simulation results

References	The Realized Benefits/Costs
Aigner et al, (2007)	Certain types of data, e.g. volume data require the 3D for expressive data visualization.
Kamsu-Foguem et al, (2012)	3D visualization presents information in symbolic and familiar manner and facilitates the natural and effective representation of information to users.
Qu et al, (2010)	These results of 3D visualization demonstrate that our simulations vividly mimic the appearance and shape of real grown eggplant cultivations.
Lindskog et al, (2013)	Accurate representation of model as in real world.
Fishwick, (2004)	3D Visualization helps in presenting the model to stakeholders.
Rodriguez et al, (2007)	The 3D display offers the user an interface where he can move freely inside the simulation.
Rua et al, (2011)	The 3D models are far more than a simple medium for exhibition and fundamental to archaeological research.
Whyte, (2003)	Simulating building interiors and exteriors in photo realistic 3D display improves presentation of new apartment building units than using 2D.
Talmaki et al, (2015)	The real-time 3D visualization scheme provides realistic graphical views that are not possible through the conventional display.
Bruzzone et al, (2009)	The 3D visualization introduces some significant benefits, such as elaborate presentation.
Dangelmaier et al, (2005)	3D/VR enhances presentation of results to diverse stakeholders.
Kim et al, (2002)	Users considered 3D work engaging.
Kamat, & Martinez, (2005)	The 3D realistic display makes it easier when making presentation to domain experts who are not proficient in simulation and modeling.
Wenzel et al, (2001)	The 3D visualization makes it easier to Illustrate the results for decision-makers / managers.
Chen et al, (2013)	The 3D visualized models and animations are at present still the most intuitive presentation.
Kumar et al, (2004)	The 3D display helps in the presentation of results.
Van Orden et al, (2000)	Generally, 3D display of objects and information often is more appealing to the users
Akpan, & Brooks, (2012)	Simulation experts and decision makers agreed that 3D enhances demo and presentation.
Zhang, et al. (2016)	Surgeons had to transpose the 2D displays into 3D for better understanding and precise performance.
Patel, Dholakia, &	The 3D visualization solutions could simulate disasters from different angles and present

Singh, (2016)	information in ways that that helped users and other decision-makers to comprehend the situation in more detail and plan for appropriate rescue operations.

5. Discussion

The results of this study confirm several benefits of 3D visualization and VR in DES, while also debunked a few but vital claims and speculations in the simulation literature. The modeling and simulation tasks where the 3D display show significant benefits include model development, experimentation, and analysis. Others are model validation and verification, and presentation of results to the stakeholders.

The synthesis of the conclusions from several studies debunks the claim that 3D/VR does not bring any significant to model development. For example, 14 out of 19 papers (74%) that carried out this investigation concluded that the 3D/VR indeed improves model development task significantly, citing several plausible reasons. Some of the reasons advanced by the majority of the studies opined that the 3D visualization supports team modeling, enhances precision, provides clarity, etc. (Table 5). Despite the above positive conclusions, a small majority of the studies still confirmed that a 3D model takes more effort and longer time to create.

Model validation and verification are the other important activities where the 3D visualization has improved tremendously in two ways. First, the simulation experts and other users can quickly spot errors in 3D models due to its advanced display features, which highlights model behavior. Second, the stakeholders' involved as part of the simulation project team are very knowledgeable in the application domains and can identify complex errors in the model during model validation and verification, especially some problems that would take the simulation experts significantly long time to determine, if at all (Kamat & Martinez, 2005). For example, in the situations described by Kamat & Martinez, (2003) and Wenzel & Jessen, (2001), where the simulation experts used wrong source data in a construction operation, then verified and validated the model as error free. The domain experts were able to detect the problem after observing the model in 3D, a situation that brings significant credibility to the modeling process and enhances acceptability, usability, and implementation of the DES outcomes. Thus, 3D brings a significant quality contribution to the DES process, thereby resolving one of the major bottlenecks that had cast doubt in DES as a decision support system for decades (Pidd & Robinson, 1998).

Experimentation is another aspect of the DES process where 3D visualization has brought significant benefits. The activity also attracted meaningful investigations (19) with most articles concluding that the 3D display enhances performance. The various given for this conclusion is available in Table 9. It is important to highlight the fact that, the findings by the different authors largely dependent on the purpose and focus of the experimentation activities. For example, highlighting model behavior, the slow run speed of the model, the time it takes to complete the experimentation tasks, etc. (Table 9).

The question about the need for 3D visualization for analysis is one of the areas that has attracted a huge debate that, the 3D is not essential in analyzing simulation results (Aigner et al., 2007). The attention this draws among the simulation experts perhaps explains why a good number of the reviewed articles investigated this aspect of the DES activities. Out of the 23 articles that examined the impacts of 3D display on analysis of data or results, over 95% concluded that using the 3D display is more potent and leads to better analysis. The studies highlight that the third dimension can be very helpful when evaluating model behavior and undertaking the what-if analysis, which also links to the experimentation activities discussed above (Aigner et al., 2007; Akpan & Brooks, 2012). Similar to the case of experimentation, it was not possible to investigate the impacts of the displays on time taken for analysis due to limited number articles that addressed this problem.

Finally, the study also confirmed the realized benefits of 3D/VR on the presentation of results. The consensus among the researchers that 3D visualization / VR offer significant advantages in this DES task tends to provide an enduring solution to the challenge of presenting simulation results to the stakeholders in a simulation project in a way that decision-makers can easily understand and be convinced.

6. Conclusions and Future Work

The descriptive meta-analysis carried out in this study provide strong evidence of the realized benefits of the application of 3D display and VR in DES can have considerable benefits in many aspects of a DES project and processes. The study highlights significant benefits of 3D/VR on the core modeling tasks and activities including model development, experimentation and analysis, and model validation and verification, which ultimately can lead to an overall success of a simulation project. The strongest and consistent conclusions involved the effects of 3D/VR on model validation, verification, and analysis.

In establishing the realized benefits of 3D/VR, the paper confirms the confluence of thoughts and conclusions about the 3D display as an efficient modeling methodology, and indeed a better model development technique for DES practice in this era of advances in information visualization.

However, the study also confirms that the main drawback of creating 3D models (taking a longer time to complete the model development task) is merely a claim but reality. Although the reviewed articles did not give the specific reasons why creating the model in 3D takes longer, it is an important aspect that simulation software vendors need to pay attention towards improving the modeling tools. Further, the fact that different studies that use different

DES software and tools arrived at slightly different conclusions regarding the difficulty and time it took to complete 3D modeling, one can speculate about the possibility of the causes arising from the particular tools used.

As part of future research, we intend to evaluate the different modeling software and tools to identify any impacts it can have on performance effectiveness and efficiency.

REFERENCES

Aigner, W., Miksch, S., Müller, W., Schumann, H., & Tominski, C. (2007). Visualizing time-oriented data—a systematic view. *Computers & Graphics*, 31(3): 401-409.

Akpan, I. J. (2006). An empirical study of the impacts of virtual reality on discrete-event simulation. Doctoral dissertation, University of Lancaster, UK.

Akpan, I. J., & Brooks, R. J. (2012). Users' perceptions of the relative costs & benefits of 2D & 3D visual displays in discrete-event simulation. *Simulation* 88(4): 464-480.

Akpan, I.J., & Brooks, R.J. (2014). Experimental Evaluation of User Performance on Two-dimensional and Three-dimensional Perspective Displays in Discrete Event Simulation, *Decision Support Systems*, 64(2014), pp14-30.

Akpan, I.J., Brooks, R.J. (2005a). Experimental investigation of the impacts of virtual reality on discrete-event simulation. In Simulation Conference, 2005, IEEE.

Akpan, I.J., Brooks, R.J. (2005b). Practitioners' perception of the impacts of virtual reality on discrete-event simulation. In Simulation Conference, 2005, IEEE.

Alberts, S., Keenan, M. K., D'Souza, R. M., & An, G. (2012). Data-parallel techniques for simulating a mega-scale agent-based model of systemic inflammatory response syndrome on graphics processing units. *Simulation*, *88*(8): 895-907.

Al-Hussein, M., Athar Niaz, M., Yu, H., & Kim, H. (2006). Integrating 3D visualization and simulation for tower crane operations on construction sites. *Automation in Construction*, *15*(5), 554-562.

Au G & Paul RJ (1996). Visual interactive modelling: A pictorial simulation specification system, European Journal of Operational Research, 91(1) (1996) 14–26

Bailey, D.E., Leonardi, P.M., & Barley, S.R. (2012). The lure of the virtual. *Organization Science*, *23*(5), 1485-1504.

Banks, J., Carson II, J. S., & Barry, L. (2005). *Discrete-event system simulation, fourth edition*. Pearson.

Barnes, M. (1996). Virtual reality & simulation. In J. M. Charnes, D. J. Morrice, D. T. Brunner, & J. J. Swain (Eds.), Proceedings of the 1996 winter simulation conference (pp. 101–110).

Beaverstock, M., Greenwood, A., Lavery, E., & Nordgren, W. (2012). Applied Simulation: Modeling & Analysis using Flexsim, 3rd Edition. Flexsim Software Products Inc., Orem, USA.

Bennaton, J. & Sivayoganathan, K (1995). The Usefulness of 3D Discrete Event Simulation. In: Proceedings of the 31st International MATADOR Conference, 20th – 21st April, Manchester, 99 – 103.

Bell PC (1991). Visual interactive modelling: The past, the present, & the prospects, European Journal of Operational Research, 54(3): 274-286.

Bell PC & O'keefe RM (1995). An experimental investigation into the efficacy of visual interactive simulation. Management Science, 41(6): 1018-1038.

Bohannon, R. W., Peolsson, A., Massy-Westropp, N., Desrosiers, J., & Bear-Lehman, J. (2006). Reference values for adult grip strength measured with a Jamar dynamometer: a descriptive meta-analysis. *Physiotherapy*, *92*(1), 11-15.

Brooks, R., Wang, W. (2015). Conceptual modelling and the project process in real simulation projects: a survey of simulation modeller. Journal of the Operational Research Society, 66(10) 1669-1685.

Brooks, R. J., & Tobias, A. M. (1996). Choosing the best model: Level of detail, complexity, and model performance. *Mathematical and computer modelling*, *24*(4), 1-14.

Brooks, R. J., & Tobias, A. M. (2000). Simplification in the simulation of manufacturing systems. *International Journal of Production Research*, *38*(5), 1009-1027.

Brooks, R and Robinson, S (2001). Simulation Operational Research Series, Palgrave.

Brooks, F. P. (1999). What's Real About Virtual Reality? IEEE Computer Graphics and Applications, 19(16-27).

Bruzzone AG, Briano E, Bocca E & Massei M (2007). Evaluation of the impact of different human factor models on industrial & business processes. *Simulation Modelling Practice & Theory*, *15*(2), 199-218.

Calabrese, F.A., Corallo, F., Margherita, A., & Zizzari, A.A. (2012). A knowledge-based decision support system for shipboard damage control. Expert systems with Applications, 39(9), 8204-8211.

Chan, D.S.K., (2003). Simulation modelling in virtual manufacturing analysis for integrated product and process design. Assembly Automation 23 (1) (2003) 69–74.

Chen H.M. & Huang, P.H. (2013). 3D AR-based modeling for discrete-event simulation of transport operations in construction. Automation in Construction, 2013(33), 123-136.

Chen, H.M., Hou, C.C., Wang, Y.H. (2013). A 3D visualized expert system for maintenance and management of existing building facilities using reliability based method. Expert Systems with Applications, 40(1), 287–299.

Choi, B.K., Park, B.C., Park, J.H., (2003). A formal model conversion approach to developing a DEVS-based factory simulator. Simulation, 79(8), (2003) 440-461.

Dangelmaier, W., Fischer, M., Gausemeier, J., Grafe, M., Matysczok, C., Mueck, B., (2005). Virtual and augmented reality support for discrete manufacturing system simulation. Computers in Industry, 56(4), 371-383.

Davies, R., Brailsford, S., Roderick, P., Canning, C., & Crabbe, D. (2000). Using simulation modelling for evaluating screening services for diabetic retinopathy. *Journal of the Operational Research Society*, 476-484.

den Hengst M, de Vreede GJ & Maghnouji R (2007). Using soft OR principles for collaborative simulation: a case study in the Dutch airline industry. *Journal of the Operational Research Society 58*(5): 669-682.

Dialami, M. Chiumenti, M. Cervera, C.A. de Saracibar, J.P. Ponthot, (2015). Material flow visualization in friction stir welding via particle tracing. International Journal of Material Forming, 8(2), 167-181.

Dodgson, M., Gann, D. M., & Salter, A. (2007). In case of fire, please use the elevator: Simulation technology and organization in fire engineering. *Organization Science*, *18*(5), 849-864.

Dorozhkin, D.V., Vance, J.M., Rehn, G.D., Lemessi, M. (2012). Coupling of interactive manufacturing operations simulation & immersive virtual reality. Virtual Reality, 16(1), 15-23.

Fabritius CV, Madsen NL, Clausen J & Larsen J (2006). Finding the best visualization of an ontology. *Journal of the Operational Research Society 57*(12): 1482-1490.

Farooq, U., Wainer, G., & Balya, B. (2007). DEVS modeling of mobile wireless ad hoc networks. *Simulation Modelling Practice & Theory*, *15*(3), 285-314.

Fishwick PA (2004). Toward an integrative multimodeling interface: A human-computer interface approach to interrelating model structures. *Simulation*, *80*(9): 421-432.

Fishwick, P., Davis, T., & Douglas, J., (2005). Model representation with aesthetic computing: Method & empirical study. *ACM Transactions on Modeling & Computer Simulation (TOMACS)*: *15*(3), 254-279.

Hajdasz, M. (2008). Modelling and simulation of monolithic construction processes. Technological and Economic Development of Economy, 14(4), 478–491.

Hoffmann, H., Stefani, O., Patel, H., (2006). Extending the desktop workplace by a portable virtual reality system. International journal of human-computer studies, 64(3), 170-181.

Huang, T., Kong, C.W., Guo, H., Baldwin, A., Li, H., (2007). A virtual prototyping system for simulating construction processes. Automation in Construction, 16(5), 576-585.

Hurrion RD (1986). Visual interactive modelling. *European Journal of Operational Research*, *23*(3), 281-287.

Hurrion, R. D. (1993). Using 3D animation techniques to help with the experimental design & analysis phase of a visual interactive simulation project. *Journal of the Operational Research Society,* 44(7), 693-700.

Hurrion, R. D. (1980). An implementation of visual interactive simulation using a microcomputer. *Omega*, *8*(2), 237-238.

Hurrion, R. D. (2000). A sequential method for the development of visual interactive meta-simulation models using neural networks. *Journal of the Operational Research Society* 51(6): 712-719.

Jain, H. K., Ramamurthy, K., & Sundaram, S. (2006). Effectiveness of visual interactive modeling in the context of multiple-criteria Group decisions. *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on*, *36*(2), 298-318.

John, M. S., Cowen, M. B., Smallman, H. S., & Oonk, H. M. (2001). The use of 2D and 3D displays for shape-understanding versus relative-position tasks. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *43*(1), 79-98.

Kamat, V. R., & Martinez, J. C. (2008). Software mechanisms for extensible and scalable 3D visualization of construction operations. *Advances in Engineering Software*, *39*(8), 659-675.

Kamat, V. R. & Martinez, J. C. (2007). Variable-speed object motion in 3D visualizations of discrete-event construction simulation models. *Journal of Information Technology in Construction* (*ITcon) Vol. 12, 293-303*.

Kamat, V. R. (2008). Logical product models for automated scripting of process-level construction animations. *Advances in engineering software*, *39*(3), 233-241.

Kamat, V. R., & Martinez, J. C. (2005). Dynamic 3D visualization of articulated construction equipment. *Journal of computing in civil engineering*, *19*(4), 356-368.

Kamat, V. R., & J. C. Martinez. (2003). Validating Complex Construction Simulation Models Using 3D Visualization. *Systems Analysis Modelling Simulation*, 43(4), 455–467.

Kamat, V. R., & J. C. Martinez. 2001. Visualizing Simulated Construction Operations in 3D. *Journal of Computing in Civil Engineering*, 15(4), 329–337.

Kamsu-Foguem B, Tchuenté-Foguem G, Allart L, Zennir Y, Vilhelm C, Mehdaoui H....& Ravaux P (2012). User-centered visual analysis using a hybrid reasoning architecture for intensive care units. *Decision Support Systems*, *54*(1): 496-509.

Khoury, HM, Kamat VR & Ioannou PG (2007). Evaluation of general-purpose construction simulation & visualization tools for modeling & animating airside airport operations. *Simulation*, *83*(9), 663-679.

Khosravi, A., Nahavandi, S., & Creighton, D. (2010). A prediction interval-based approach to determine optimal structures of neural network metamodels. Expert systems with applications, 37(3), 2377-2387.

Kim, J., Hahn, J., & Hahn, H. (2000). How do we understand a system with (so) many diagrams? Cognitive integration processes in diagrammatic reasoning. *Information Systems Research*, *11*(3), 284-303.

Kim T, Lee J & Fishwick P (2002). A two-stage modeling & simulation process for web-based modeling & simulation. *ACM Transactions on Modeling & Computer Simulation (TOMACS)*, *12*(3), 230-248.

Kotiadis, K., & Robinson, S. (2008, December). Conceptual modelling: knowledge acquisition and model abstraction. In *Simulation Conference, 2008. WSC 2008. Winter* (pp. 951-958). IEEE.

Korošec, P., Bole, U., Papa, G. (2013). A multi-objective approach to the application of real-world production scheduling. Expert Systems with Applications, 40(15), 5839-5853.

Law AM (2014). Simulation Modeling and Analysis, 5th edition. McGraw Hill: New York.

Law, A. M., & McComas, M. G. (2002). Simulation optimization: simulation-based optimization In Proceedings of the 34th conference on Winter simulation: exploring new frontiers (pp. 41-44). Winter Simulation Conference.

Li, H., Ma, Z., Shen, Q., Kong, S., (2003). Virtual experiment of innovative construction operations. Automation in Construction, 12(5), (2003) 561-575.

Lindskog, E., Berglund, J., Vallhagen, J., & Johansson, B. (2013). Visualization support for virtual redesign of manufacturing systems. *Procedia CIRP*, *7*, 419-424.

Lu, H. Zhen, H., Mi, W., Huang, Y. (2015). A physically based approach with human–machine cooperation concept to generate assembly sequences. Computers & Industrial Engineering, 89, 213-225.

Moghadam, M. Al-Hussein, M., Al-Jibouri, S., Telyas, A. (2012). Post simulation visualization model for effective scheduling of modular building construction 1 1 This paper is one of a selection of papers in this Special Issue on Construction Engineering and Management. Canadian journal of civil engineering, 39(9) (2012) 1053-1061

Moon, D. H., Cho, H. I., Kim, H. S., Sunwoo, H., & Jung, J. Y. (2006). A case study of the body shop design in an automotive factory using 3D simulation. *International Journal of Production Research*, *44*(18-19), 4121-4135.

Mujber TS, Szecsi T & Hashmi MSJ (2004). Virtual reality applications in manufacturing process simulation. Journal of Materials Processing Technology, 155-156: 1834-1838.

Murphy, C.A., & Perera, T., (2002). The definition of simulation & its role within an aerospace company. *Simulation Practice & Theory*, *9*(6): 273-291.

Nandan, R., Roy, G.G., Lienert, T.J., DebRoy, T. (2006). Numerical modelling of 3D plastic flow and heat transfer during friction stir welding of stainless steel. Science and Technology of Welding and Joining, 11(5), 526-537.

Oerter, J., Suddarth, W., Morhardt, M., Gehringer, J., McGinnis, M.L., Shockley, J., Baysa, A. (2014) A system architecture and simulation environment for building information modeling in virtual worlds. The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology, 11(3), (2014) 205-210.

Okulicz, K. (2004). Virtual reality-based approach to manufacturing process planning. International Journal of Production Research, 42(17).

Orady, E. A., Osman, T. A., & Bailo, C. P. (1997). Virtual reality software for robotics and manufacturing cell simulation. *Computers & industrial engineering*, *33*(1-2), 87-90.

Otamendi, J., Pastor, J.M., & Garcia, A. (2008). Selection of the simulation software for the management of the operations at an international airport. *Simulation Modelling Practice & Theory*, *16*(8), 1103-1112.

Patel, V., Dholakia, M.B., Singh, A.P. (2016). Emergency preparedness in the case of Makran tsunami: a case study on tsunami risk visualization for the western parts of Gujarat, India. Geomatics, Natural Hazards and Risk, 7(2), 826-842.

Publish or Perish (2015). Harzing.com Research in International Management Products & Services for Academics. www.harzing.com/pop.htm [Accessed on Jan 2015].

Qu, H., Q. Zhu, M. Guo, Z. Lu, Simulation of carbon-based model for virtual plants as complex adaptive system. Simulation Modelling Practice and Theory, 18(6), (2010) 677-695.

Quarles J, Fishwick P, Lampotang S, Fischler I & Lok B (2010). A mixed reality approach for interactively blending dynamic models with corresponding physical phenomena, ACM Transaction on Modeling & Computer Simulation, 20(4): 23 pages.

Rekapalli, P., & Martinez, J. (2011). Discrete-Event Simulation-Based Virtual Reality Environments for Construction Operations: Technology Introduction. Journal of Construction Engineering and Management, 137(3), 214-224.

Robinson S (2005). Discrete-event simulation: from the pioneers to the present, what next? *Journal of the Operational Research Society* 56(6): 619–629.

Robinson, S. & Pidd M (1998). Provider & customer expectations of successful simulation projects. *Journal of the Operational Research Society*, 49(3): 200-209.

Robinson, S., Lee, E. P. K., & Edwards, J., S. (2012). Simulation based knowledge elicitation: Effect of visual representation & model parameters. *Expert Systems with Applications, 39*(9): 8479-8489.

Rodriguez, S., Hilaire, V., & Koukam, A., (2007). Towards a holonic multiple aspect analysis & modeling approach for complex systems: Application to the simulation of industrial plants. *Simulation Modelling Practice & Theory*, *15*(5): 521-543.

Rohrer MW & McGregor IW (2002). Simulating reality using automod. In: Yusecan E, Chen CH, Snowdon JL & Charnes JM (eds). *Proceedings of the 2002 Winter Simulation Conference.* San Diego, IEEE, pp 173–181.

Rua, H., & Alvito, P., (2011). Living the past: 3D models, virtual reality and game engines as tools for supporting archaeology and the reconstruction of cultural heritage–the case-study of the Roman villa of Casal de Freiria. Journal of Archaeological Science, 38(12), 3296-3308.

Rubio, E.M., Sanz, A., & Sebastián, M.A., (2005). Virtual reality applications for the next-generation manufacturing. International Journal of Computer Integrated Manufacturing, 18(7), (2005) 601-609.

Sargent, R. G. (2013). Verification and validation of simulation models. *Journal of simulation*, *7*(1), 12-24.

Smallman, H.S., John, M.S., Oonk, H.M., Cowen, M.B., (2001). Information availability in 2D and 3D displays. IEEE Computer Graphics and Applications, 21(5), (2001) 51-57.

Somasundaram, K., Kalaiselvi, T., (2010). Fully automatic brain extraction algorithm for axial T2-weighted magnetic resonance images. Computers in Biology and Medicine, 40(10), (2010) 811–822.

Son, M. J., & Kim, T. W. (2012). Maneuvering control simulation of underwater vehicle based on combined discrete-event and discrete-time modeling. *Expert Systems with Applications*, *39*(17), 12992-13008.

Su, J.M. & Huang, C.F. (2014). An easy-to-use 3D visualization system for planning context-aware applications in smart buildings. *Computer Standards & Interfaces*, *36*(2): 312-326.

Sun, Z., Lee, L.H., Chew, E.P., & Tan, K.C., (2012). MicroPort: A general simulation platform for seaport container terminals. *Advanced Engineering Informatics*, *26*(1), 80-89.

Tako, A. A. (2014). Exploring the model development process in discrete-event simulation: insights from six expert modellers. *Journal of the Operational Research Society*.

Tako, A. A., & Robinson, S. (2010). Model development in discrete-event simulation and system dynamics: An empirical study of expert modellers. *European Journal of Operational Research*, *207*(2), 784-794.

Toufaily, E., Ricard, L., & Perrien, J. (2013). Customer loyalty to a commercial website: Descriptive meta-analysis of the empirical literature and proposal of an integrative model. *Journal of Business Research*, *66*(9), 1436-1447.

Turner, C.J., Hutabarat, W., Oyekan, J., Tiwari, A. (2016). Discrete Event Simulation and Virtual Reality Use in Industry: New Opportunities and Future Trends. IEEE Transactions on Human-Machine Systems, 46(6), 882-894.

Van Orden, K. F., & Broyles, J. W. (2000). Visuospatial task performance as a function of two-and three-dimensional display presentation techniques. *Displays*, *21*(1), 17-24.

Waller AP & Ladbrook J (2002). Experiencing virtual factories of the future. In: Yiicesan E, Chen C-H, Snowden SL & Charnes JM (eds). Proceedings of the 2002 Winter Simulation Conference. IEEE, Piscataway, NJ, pp 513-517.

Wainer, G., & Liu, Q. (2009). Tools for graphical specification & visualization of DEVS models. *Simulation*, *85*(3), 131-158.

Waisel LB, Wallace WA & Willemain TR (2008). Visualization & model formulation: an analysis of the sketches of expert modellers. *Journal of the Operational Research Society 59*(3): 353-361.

Waly, A.F. & Thabet, W.Y. (2003). A Virtual Construction Environment for Preconstruction Planning, Automation in Construction, 12(2), (2003) 139–154

Wenzel S, Jessen U (2001). The integration of 3-D visualization into the simulation-based planning process of logistics systems, *Simulation,* 77(3-4):114-127.

Whyte, J. (2003). Innovation and users: virtual reality in the construction sector, Construction Management and Economics, 21(6), (2003) 565-572.

Zhang, G., Zhou, X.J., Zhu, C.Z., Dong, Q., Su, L. (2016). Usefulness of three-dimensional (3D) simulation software in hepatectomy for pediatric hepatoblastoma. Surgical Oncology, 25(3), L. 236-243.

Zhou, C., Wang, J., Tang, G., Moreland, J., Fu, D., Wu, B. (2016). Integration of Advanced Simulation and Visualization for Manufacturing Process Optimization. JOM, 68(5), 1363-1369.

Zyda M (2005). From visual simulation to virtual reality to games. *Computer*, *38*(9): 25-32.

The confirmed realities and myths about the benefits and costs of 3D Visualization and Virtual Reality in discrete event modeling and simulation: A descriptive meta-analysis of evidence from research and practice

Research Highlights:

- Confirmed realities versus myths of 3D/VR in discrete-event simulation and modeling.
- The 3D/VR improves model quality and contradicts the claims that it adds no value.
- The 3D/VR is highly potent for model validation, verification, and experimentation.
- The 3D/VR is significantly valuable for analysis and presentation of results.
- Creating the 3D/VR model is complex, takes longer, but enhances the project quality.