Preliminary Analysis of Emerging Visualization and Image Modeling Technologies for Highway Construction Inspection

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1 Introduction

Construction and maintenance projects, such as roadways and bridges, have displayed little productivity growth during the past two decades. Number of factors (e.g., shortage of funding) contributed to this situation. Among these factors, reliance on the convental paper-based management processes is a critical root cause of low efficiency in construction inspection activities. The continued reliance on paper-based processes during project development and delivery impedes innovation whereas the shortage of qualified staff slows down production rates and reduces quality of the final product [1]. Previous studies show that there is a direct correlation between the digitalization rate of construction industry and productivity improvements. For instance, adopting effective practices to infuse the use of e-construction technologies and advanced automation instead of the paper based can increase productivity by 8% on average and result in cost savings up to 5% [1]. The Federal Highway Administration (FHWA) defines e-construction as a paperless construction administration delivery process. This process includes electronic submission of all construction documentation by all stakeholders, electronic document routing and approvals (e-signature), and digital management of all construction documentation in a secure environment [2]. E-inspection is a substantial part of this automated process, including electronic field data collection by inspectors, data analysis, and documentation of inspection results. There are ongoing initiatives to support e-inspection for

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transportation construction projects. For example, the FHWA's Every Day Counts (EDC) initiative focuses on employing technologies readily available to the transportation projects, including digital electronic signatures, electronic communication, secure file sharing, mobile devices, and visualization and Image modeling techniques to improve construction management processes [2].

Previous studies have examined application of different visualization and image-capturing technologies in construction projects. For instance, Okpala et al. [3] examined utilization of emerging technologies such as building information modeling (BIM), augmented reality (AR), virtual reality (VR), and image-based sensors. The study found that these technologies are not applied broadly in construction projects. Yamaura and Muench [4] conducted a study to assess the impact of mobile technology on public transportation project inspection. Results of the study indicated that project inspectors using the mobile technology system experienced higher productivity, collected and shared twice as many observations and inspection images, and improved the timeliness of daily reports. There has been an increasing number of publications concerning the visualization and image modeling technologies in the area of construction projects during the past two decades. However, limited research has focused on providing a systematic review and content analysis of published articles related to applying these technologies to transportation construction projects. Researchers need to identify implementation challenges, the current, and future application trends of these technologies to different construction operations. Further, practitioners need to a useful reference on adopting new technologies in construction inspection.

The objective of this study is to summarize research efforts and practical applications of different types of visualization and Image modeling technologies used in transportation construction inspection. The current and future research trends are elicited from the collected articles. Further, practical information regarding what construction elements to be inspected by these technologies, effectiveness, and the enablers and barriers of technology adoption are also discussed.

2   Construction Inspection

Quality assurance (QA) inspection of construction project is defined as a tool or means by which the owner and contractors ensure that the road or bridge is constructed in accordance with approved plans and specifications by the most economical, efficient, and safe method [5]. When QA programs are well designed, they can provide confidence that project materials and workmanship will be in reasonable conformance with plans and specifications [6]. Typically, QA inspection and acceptance are managed by the means of material certification, visual inspection, or sampling and testing. While the acceptance by certificate is typically for standard and prefabricated materials with non-to-low inspection failure risk, the acceptance by testing and field inspection are often for project-produced materials and workmanship with higher levels of risk. To alleviate this risk, transportation agencies

allocate resources to perform construction materials testing and inspect construction items as a part of their QA programs. Typically, inspection staff is responsible for conducting and verifying the results of the material testing and inspection processes. The inspection process may be on-site such as visual field inspection or off-site such as shop and source inspection [7].

Various indicators showed that the conventional inspection process has reached its limits, and numerous transportation agencies have begun shifting from the conventional testing and inspection to automated process aiming to save time, cost, and inspection workforce. These agencies are using a combination of manual and electronic systems and tools. The emerging e-inspection technologies such as visualization and image modeling enable easier access to real-time information and more accurate data collection. They also give inspectors access to a vast range of options that can help them complete inspection tasks in the field and documents inspection results [2, 8].

3   Research Approach

This study aims at identifying emerging areas, applications, and predictions of future research directions of visualization and image modeling technologies in transportation projects by conducting a systematic literature review on relevant articles published from 2000 to 2021. Transportation construction and maintenance related articles from construction, electrical and electronic engineering, and computer science journals domains were included in the review. As shown in Fig. 1, three
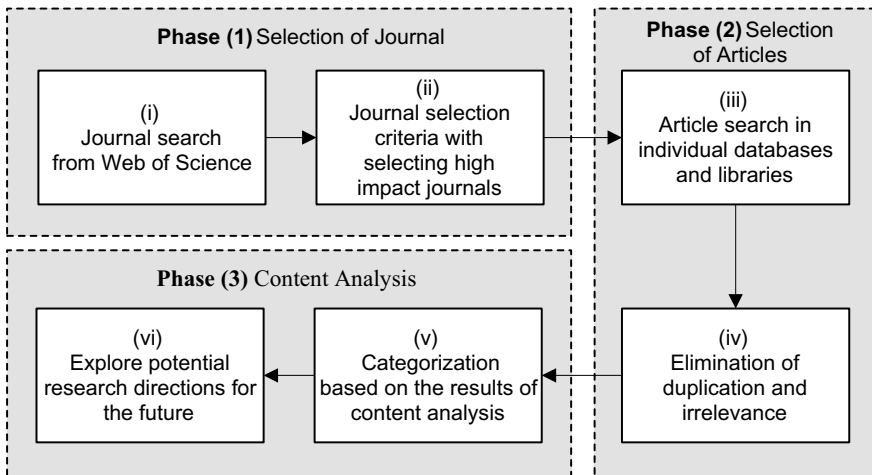

Fig. 1 Research methodology for acquiring up-to-date and high-quality articles

phases have been applied in this study to acquire up-to-date and high-quality articles. In Phase 1, journals that have an important impact and prominent position in the research community were selected. For a double authentication, two criteria have been assigned for journals selection, including a) the literature to be drawn from the top quality journals listed in the 2019 Scimago Journal & Country Rank (SJR) list, and b) the 2019 Scopus journal metrics (CiteScore) on the ranking of construction management journals were referred to when choosing the journals. Journals that have a CiteScore of 1.0 and above based on the 2019 Scopus journal metrics were considered [9]. In Phase 2, advanced search for relevant articles was conducted using Science Direct, Scopus (Elsevier's abstract and citation database), Google Scholar, and American Society of Civil Engineers (ASCE) library, Taylor and Francis Online, and Wiley Online Library. To consider publication from other fields pertained to construction inspection technology, Electrical and Electronics Engineers (IEEE) Xplore and Association of Computing Machinery (AMC) library databases were searched. A keyword search for "construction e-inspection", "highway inspection", "electronic construction inspection", "visualization technology", "image modeling "pavement testing" and "bridge testing", which are frequently used in transportation construction papers. In Phase 3, 93 searching results in the selected journals and databases from Phases 1 and 2 were analyzed (Table 1). By synthesizing articles' abstracts, highlights and key scope, 64 articles were outside the visualization and image modeling in construction project e-inspection domain. This screening process

Table 1 Number of articles pertaining to construction e-inspection of transportation projects

No	Journal			No. of article	
	Name	Cite-score	SJR	Total searching	Reviewed
1	Journal of construction engineering and management (JCEM)	5.8	1.03	11	4
2	Journal of computing in civil engineering (JCCE)	7.6	0.95	14	3
3	Journal of infrastructure systems (JIS)	3.4	0.64	7	2
4	Journal of management in Engineering (JME)	6.7	1.25	6	1
5	Automation in construction (AC)	9.5	1.41	22	10
6	Journal of structural engineering (JSTE)	5.7	1.64	5	1
7	Journal of surveying engineering (JSE)	3.9	0.88	4	1
8	Advanced engineering informatics (AEI)	6.9	0.94	5	2
9	Advances in engineering software (AES)	9.5	1.24	5	1
10	IEEE Instrumentation and measurement magazine (IEEE)	2.3	0.32	3	1
11	Journal of bridge engineering (JBE)	4.6	1.32	11	3
Total				93	29

reduced the number to 29 articles from 11 journals after duplicated and irrelevant articles were eliminated. In addition to these articles, six relevant academic reports were also selected for this research because they discuss these technologies.

Once the articles were identified, detailed content analysis was carried out. Content analysis is a research technique for determining major facets of and valid inferences from written, verbal, or visual communication messages [10]. Content analysis (i.e. paper title, abstract, keywords, methodologies, and technology demonstrations, or application areas) was conducted in order to categorize and analyze the reviewed articles.

4 Results

The result of the content analysis is presented in the following subsections. The percentage values indicated in the discussion, figures, and tables were determined based on the number of references over the total number of articles considered in the content analysis (i.e., 29 journal articles).

4.1 Profile of the Reviewed Articles by Journal and Year of Publication

Figure 2 depicts the percentage of the selected articles published in each journal. Approximately one third of the selected articles were published in AC, where the scope of this journal focuses on automation and technologies in construction. Approximately half of the articles were published in the journals of AC and JCEM combined. The remaining percentage of the articles (50%) were published in the other 9 journals. The number of selected articles by journal and year is shown in Fig. 3. The selected articles were published over the period from 2000 to 2021. Among these, 11 articles (38%) were published between the years 2015 and 2019, which is considerably greater than any other publication period. From 210 to 2014, there were nine articles (31%). From 2005 to 2009, there were five articles (17%). Whereas, the number of selected articles published in the span of 2000–2004 is four (13.7%), representing the least number of publications. As seen, the trend in Fig. 3 indicates an increasement in the number of publications and research in the area of visualization and image modeling technologies.

Table 2 a. Summary of multi-dimensional visualization technologies discussed in the selected articles

No	Technology	Description and application area	Related articles [percentage of related articles %]
1	2D vision tracker and sensor	Vision tracking technology used in construction projects for tracking site resources	[13, 14] [6.8%]
2	3-D scan and modeling	The 3-D model provides a virtual representation and visualization of project components. The data of the model can be used to automate construction activities, progress imaging and tracking, review plans, bridge inspection; falsework inspection, tracking construction equipment and materials	[11, 12, 15–24] [41.3%]
3	4-D scan and modeling	4-D model with progress imaging photographs is used in visualization of construction Progress and monitoring with 4D simulation	[25, 26] [6.8%]
4	Virtual reality (VR)	VR superimposes a computer-generated image and provides a composite view. It is used in comparing installed work with drawings and specifications and bridge modeling	[27, 28] [10.3%]
5	Augmented reality (AR)	Similar to VR, AR gives the user a view of the real world and. It is used in comparing installed work with drawings and specifications, bridge modeling, and inspector training	[27] [6.8%]

b. Summary of camera image-based technologies discussed in the selected articles

No	Technology	Description and application area	Related articles [percentage of related articles %]
1	Video camera (VC) and image capture camera	VC is telepresence technology that has the capacity to stream high-quality video images of construction site to members of the project team who are not physically present at the jobsite. It is used in bridge inspection and monitoring construction progress	[29–33] [17.2%]

<div align="right">(continued)</div>

Table 2 (continued)

No	Technology	Description and application area	Related articles [percentage of related articles %]
2	Time delayed integration (TDI) camera	TDI is a scan system takes multiple pictures of the same line image and add them up to get an amplified image. It is automated cracking- survey system of pavement surface	[34] [3.4%]
3	High-resolution automated cameras (HRC)	HRC is a remotely operating technology that can provide construction management and other users with imaging feeds of job site activities such as tracking and updating project schedules	[35] [3.4%]
4	Thermal infrared (IR) imaging	IR is remote sensing technology used in assessing bridge deck and superstructure condition	[12] [3.4%]
5	Electro-optical (EO) satellite and airborne imagery	Airborne and remote sensing technology used in assessing condition of infrastructure such as bridges	[12] [3.4%]
6	Dual-light inspection (DLI)	DLI is used to categorize image. It consists of image capture, subtraction, enhancement, and classification. It is used in pavement surface surveying and distress detection	[36] [3.4%]
7	Mobile phone camera	HeadLight mobile technology system and application used in inspection of different construction elements	[4, 37] [6.8%]

c. Summary of other relevant technologies discussed in the selected articles

No	Technology	Description and application area	Related articles [percentage of related articles %]
1	Photogrammetry	The photogrammetry is the practice of extracting precise geometric measurements from photographs. The photographs are typically acquired from airborne platform. It is used in bridge deck and superstructure photographing, progress measurement, and reporting of construction work	[11, 12] [6.8%]

Table 2 (continued)

No	Technology	Description and application area	Related articles [percentage of related articles %]
2	Building information modeling (BIM)	BIM is the process of developing and using a computer-generated 3D/4D geometry model to link and analyze data related to the inspection, evaluation, and compare with the as-planned construction elements such as bridge components. Therefore, the planned state at any time can be derived and compared with the actual construction state	[38] [3.4%]

Fig. 2 Percentage of the selected articles published in each journal
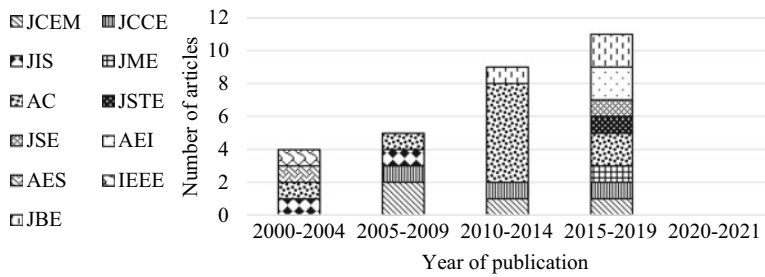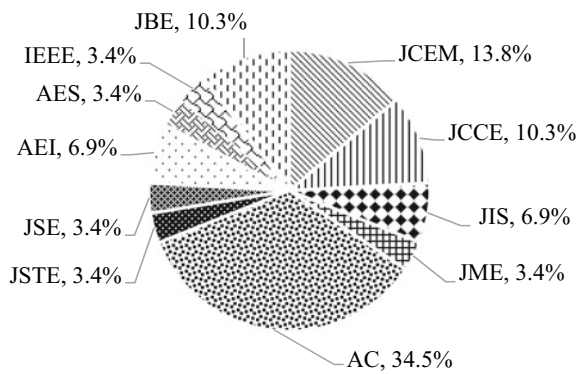

Fig. 3 Number of selected articles by journals and year

4.2 Summary of the Examined Technologies in the Reviewed Articles

One of the objectives of this study is to categorize inspection technologies and identifying the purpose of using each technology, the construction element was inspected by these technologies, and technologies were highly examined by researchers or required less attention. Table 2a–c shows the reviewed types of visualization and image modeling technologies as follows; multi-dimensional visualization technologies, camera image-based technologies, and other technologies such as Photogrammetry and BIM.

As shown in Table 2a–c, 14 construction technologies were used in visualizing and imaging inspection of different construction elements. These technologies may assist construction inspector to check construction progress and quantities, compare installed work with drawings and specifications, and track construction resources such as materials delivery. It can be seen in Table 2a that more than 40% of the reviewed articles have focused on 3-D scan and modeling technology, whereas technologies such as time delayed integration (TDI) camera, high-resolution automated cameras (HRC), dual-light inspection (DLI), thermal infrared (IR) imaging, electro-optical (EO) satellite and airborne imagery, and dual-light inspection (DLI) have less than 4% of the current research trend. Technology such as photogrammetry is a salient example of visualization tool. The photogrammetry extracts precise geometric measurements through photographing of objects, which is typically acquired from airborne platform. Examples of construction elements and activities inspected by the photogrammetry technology are bridge deck, progress tracking, and reporting of construction work [11, 12].

5 Discussion

Two areas of discussions have risen during result analysis, including: (1) current implementation and integration of visualization and image modeling technologies to achieve greater synergy and (2) future research directions.

The literature shows that emerging technologies have the potential to revolutionize the future of the construction industry through automated construction operations, and the visualization and image modeling lie among these technologies. Amalgamation of two or more of the e-inspection technologies showed a promising potential to overcome limitations of some of these technologies. For instance, 3D scanning was used to support progress measurement and project control. However, 3D scanning has limitations of the long time required to perform a single scan and the number of scan-positions necessary to acquire accurate information. To address these limitations, 3D scanning was integrated with photogrammetry. The result was enhanced speed and accuracy of data collection from construction site [11]. Another promising e-inspection area is connecting the visualization and image modeling technologies

to project database via internet of things (IoT). Where, the IOT uses the internet connectivity to form a platform that is used to execute any specific function through the network. Connecting the visualization and image modeling devices with everyone in all times and locations of the project using the built-in wireless connection eases the monitoring and control process of project for inspectors [39]. The current trends suggest some possible directions for the future research in the area of integrating e-inspection technologies. In particular, the literature review revealed that some significant problems are still exist on how to transfer data and models from application or device to another [12, 21], which require more investigation.

Emerging technologies continue to evolve, and new technologies are becoming more accessible for a wide range of highway construction applications. Table 2a–c presented description and application of 14 different visualization and image modeling technologies used in construction inspection. This may help transportation agencies identify what and how to inspect by these technologies. Research trend of developing the visualization and image modeling technologies during the past two decades indicated that certain areas of research become more salient, while others require less attention. For instance, the highest focus of research effort is on the technologies of 3-D scan and modeling (>40 of the reviewed articles). In contrast, technologies such as HeadLight mobile application, EO, and DLI have had less attention from researchers (examined in one article or academic report). This can be explained that, compared to the 3-D modeling, these are recent-new technologies, still under evaluation, and have had limited deployment in transportation construction inspection [4, 40]. However, technology such as TDI is exist for more than a decade and still has less research development [34, 35]. In the future, researchers may need to explore why some possible technologies that are existed for a long time have not been applied widely. Additionally, practitioners may identify why these technologies have not been utilized more frequently in practice, and how to avail the construction industry better of the possible benefits of these technologies.

6   Conclusion

The three-phase research approach has been performed in this study to conduct content analysis of literature on the visualization and image modeling technologies used in construction inspection. First, construction engineering and management related journals that have an important CiteScore and SJR impacts were selected. Second, advanced search for e-inspection relevant articles between 2000 and 2021 in these journals has been conducted. Finally, by analyzing articles, the search resulted in 29 articles from 11 journals. Additionally, six academic reports were also reviewed.

The result of analyzing these articles showed increased number of publications and research effort in the area of visualization and image modeling during the last two decades. 14 technologies shown in Table 2a–c were employed in variant construction inspection and testing processes. The current research and application directions of merging two or more of the e-inspection technologies showed promising potentials to

overcome limitations of some of these technologies. While some of the e-inspection technologies have proven their feasibility, there are a considerable number of other technologies are still under evaluation and have had limited deployment in highway construction inspection. Overall, although these technologies are still in an innovation or seed phase, it can be expected that with continued effort put into research and development, they may soon approach the growth phase and encounter adoption by transportation agencies on a larger scale.

This study suggests future research directions. For integration purpose, there is a need for approaches that transfer data between the different e-inspection technologies. Researchers and practitioners need to explore why some e-inspection technologies that existed for a long time have been utilized less frequently in practice. The findings of this study are of value to researchers and industry practitioners seeking a useful reference on adopting new technologies in highway construction inspection.

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