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THE TRANSFORMATIVE IMPACT OF ADVANCED GRAPHICS TECHNOLOGIES AND COMPUTER-GENERATED IMAGERY IN CIVIL ENGINEERING

Abstract: *The present study explores how modern graphics technology and computer-generated imagery (CGI) are revolutionizing the field of civil engineering. With an emphasis on 3D modelling, the study investigates how virtual reality (VR), augmented reality (AR), and 3D modelling may transform project design and communication. The research explores how these graphic tools improve planning, analysis, and presentation in civil engineering projects through case studies and software innovations. The construction of safer, more creative, and visually striking infrastructure projects is aided by the integration of CGI, which also enhances visualization and makes decision-making more effective. The important developments at the junction of civil engineering and graphics are highlighted in this study.*

Key words: *graphics, virtual reality, augmented reality, 3D modelling, civil engineering.*

1. INTRODUCTION

Civil engineering endeavours, characterized by their complexity and extensive scope, require the adoption of state-of-the-art design, visualization, and communication techniques. The advent of computer-generated imagery (CGI) and advanced graphics technologies has provided engineers with robust tools to tackle these complexities.

The advent of Building Information Modelling (BIM) alongside computer-aided design (CAD) software has brought about a paradigm shift in the visualization and design methodologies within civil engineering. BIM enables the generation of intricate, three-dimensional models, empowering engineers to simulate diverse design scenarios, identify potential clashes, and enhance project outcomes [1]. Incorporating CGI techniques further elevates design accuracy, allowing engineers to create photorealistic renderings that offer stakeholders a comprehensive insight into both the aesthetic and functional facets of the project [2]. Advanced graphics technologies have transformed the dynamics of collaboration and decision-making within civil engineering teams. Virtual reality (VR) and augmented reality (AR) technologies offer immersive environments where multidisciplinary teams can explore design alternatives, evaluate spatial constraints, and optimize construction processes in real-time [3], [4].

The transformative impact of advanced graphics technologies extends beyond project teams, influencing public perception and engagement in civil engineering initiatives. Bryden and Banda highlight the potential of interactive visualizations and multimedia presentations to communicate the societal benefits and environmental implications of proposed projects to diverse stakeholders [5].

This study aims to delve into the comparative advantages and drawbacks of employing scanning technology versus traditional methods in trestle frame roof structure surveys, with the intention of providing insights into optimizing surveying practices for architectural documentation and structural analysis.

2. LITERATURE REVIEW

Recent studies have explored the efficacy of scanning technology in conducting trestle frame roof structure surveys compared to traditional methods, shedding light on the evolving landscape of architectural documentation. Advancements in laser scanning have revolutionized the process of capturing detailed structural information, offering unparaleled speed and accuracy [6]. By employing 3D laser scanners, researchers have been able to swiftly capture intricate details of structure facilitating efficient modelling and analysis [7]. However, the transition from classical surveying techniques to scanning approaches prompts critical inquiries into the reliability and cost-effectiveness of such methodologies [8].

2.1 Traditional surveying techniques

The process of conducting a classic survey typically involves several systematic stages aimed at capturing accurate measurements and structural details. Initially, the survey begins with meticulous planning, wherein the scope and objectives of the survey are defined, and necessary equipment and resources are identified. Subsequently, the fieldwork commences with on-site inspections and measurements conducted by skilled surveyors using traditional tools such as tape measures, levels, and plumb bobs. These measurements encompass various parameters including the lengths, angles, and dimensions of the trestle frame roof components, as well as the spacing and connections between them.

Precision and attention to detail are paramount during this phase to ensure the accuracy of the collected data. Following the data collection process, the recorded measurements are meticulously documented and compiled into detailed drawings or sketches depicting the geometry and configuration of the roof. These drawings serve as valuable reference materials for further analysis and engineering assessments. Finally, the survey concludes with a comprehensive review and validation of the collected data to identify any discrepancies or inconsistencies that may require additional verification or adjustment. Throughout the entire surveying process, adherence to established surveying standards and protocols is essential to ensure the reliability and integrity of the survey results for subsequent engineering and construction activities.

Conducting a classic survey entails both advantages and disadvantages. One advantage lies in the familiarity and simplicity of traditional surveying methods, which often require basic tools such as tape measures and levels, making them accessible and cost-effective. Additionally, these methods offer a hands-on approach, allowing surveyors to visually inspect and assess the structure's condition, identifying potential issues or anomalies in real-time. However, classic surveys may also present limitations, notably in terms of accuracy and efficiency. Manual measurements are susceptible to human error and may result in inconsistencies or inaccuracies, particularly in complex or irregular structures. Moreover, these surveys tend to be time-consuming, requiring considerable manpower and resources to complete, which can impact project timelines and costs. Furthermore, traditional methods may be challenging to implement in inaccessible or hazardous environments, limiting their applicability in certain scenarios. Despite these drawbacks, classic surveys remain a viable option for capturing basic structural information and can complement more advanced surveying techniques in comprehensive engineering assessments.

2.2 Scanning technology

The process of scanning involves several systematic stages to capture detailed and accurate data of the structure. Initially, meticulous planning is undertaken to define the objectives of the survey, identify the areas of interest, and determine the scanning parameters. Once the planning phase is complete, the actual scanning process begins, wherein 3D laser scanners or LiDAR-equipped drones are deployed to capture point cloud data of the entire roof system (Figure 1). This stage involves systematically scanning the roof structure from multiple vantage points to ensure comprehensive coverage and capture of all structural elements. Following data acquisition, the collected point cloud data is processed using specialized software to generate highly detailed digital models of the roof.

(a) (b)

Figure 1 The equipment used for 3D scanning: (a)LIDAR drone; (b) Laser 3D scanner (Source: [9]; [10]).

The final stage of the process involves analysing and interpreting the digital models to extract relevant information about the trestle frame roof's dimensions, configuration, and structural integrity. This may include identifying any anomalies, discrepancies, or areas of concern that require further investigation or analysis. Throughout the entire process, attention to detail, accuracy, and adherence to established scanning protocols are essential to ensure the reliability and usefulness of the survey data for engineering and construction purposes.

Utilizing scanning technology for conducting surveys offers numerous advantages alongside some inherent limitations. One of the primary advantages is the high level of precision and accuracy that scanning provides. Laser scanners and LiDAR-equipped drones capture detailed point cloud data, enabling the creation of comprehensive and highly accurate digital models of structures such as trestle frame roof. Additionally, scanning technology allows for rapid data acquisition, significantly reducing the time and manpower required compared to traditional surveying methods. Moreover, scanning enables remote data collection, making it suitable for accessing hard-to-reach or hazardous areas. Despite these advantages, scanning also presents certain drawbacks. The initial investment in scanning equipment and software can be substantial, making it cost-prohibitive for some projects. Additionally, scanning requires specialized training and expertise to operate effectively, which may pose a barrier to entry for some surveying teams. Furthermore, processing and analysing the vast amounts of data generated by scanning can be time-consuming and resource-intensive. Lastly, scanning technology may struggle with capturing certain materials or surfaces accurately, leading to potential inaccuracies in the resulting models. Despite these limitations, scanning remains a valuable tool in modern surveying practices, offering unparalleled accuracy and efficiency in capturing detailed structural information.

3. CASE STUDIES

The present paper investigates the application of scanning technology in conducting trestle frame roof surveys compared to traditional surveying methods. The study revealed that utilizing scanning techniques, such as Leica BLK360, offers several advantages over conventional approaches. Firstly, scanning technology allows for the rapid and precise capture of detailed point cloud data of the entire trestle frame roof structure. This data can be processed to generate highly accurate digital models, facilitating comprehensive analysis and assessment of the trestle frame roof system's condition, dimensions, and potential structural issues. In contrast, traditional surveying methods often involve manual measurements and visual assessments, which are more time-consuming, prone to human error, and may result in incomplete or inaccurate representations of the roof geometry. The study concluded that embracing scanning technologies enhances the efficiency, accuracy, and reliability of trestle frame roof surveys, enabling engineers to make informed decisions and implement proactive maintenance strategies for ensuring optimal structural integrity and safety.

3.1 Technical details of the structure studied

The trestle frame roof structure represents a classic architectural design characterized by its sturdy yet elegant construction. The trestle frame roof structure relies on a system of carefully engineered connections. The horizontal beams, known as tie beams, are secured to the vertical posts, or king posts, through mortise and tenon joints, providing robust support while maintaining flexibility to accommodate various roof shapes and loads. Additionally, diagonal braces extend from the king posts to the tie beams, enhancing stability and resisting lateral forces [11].

The selection of timber species and grading standards are paramount considerations to ensure structural integrity and longevity. Moreover, proper detailing of joints, such as scarf joints for extending tie beams or lap joints for connecting rafters, is crucial for achieving seamless integration and load transfer within the framework [12].

The main purpose of this article is to make a comparison regarding the surveying of trestle frame roof (Figure 2), both in a classical manner and using modern technology, namely scanning and interpreting the results in specialized software.

Figure 2 Details of the trestle frame roof studied.

The component parts and technical details of the roof will be briefly presented in the following. Central to the trestle frame is the king post, a vertical timber beam that provides primary support for the roof. Reinforced by diagonal braces extending from the king post to the horizontal tie beams, this arrangement distributes loads effectively and enhances structural stability [13].

Horizontal tie beams, securely fastened to the king post through mortise and tenon joints, form the framework of the roof. These beams span the width of the structure, providing a solid foundation for the roof covering. Traditional joinery techniques, such as scarf joints and lap joints, are employed to ensure durable and secure connections between elements.

3.2. The steps in conducting the classic survey

The first study conducted was the classical surveying of the trestle frame roof, which is an essential task in construction and renovation projects, ensuring structural integrity and precise measurements for effective design implementation. The following will synthetically represent the steps conducting for the survey of this kind:

- *Preparation*: The survey begins with the assembly of essential tools and equipment, including a measuring tape, laser level, plumb bob, ladder, and necessary safety gear.
- *Initial Inspection*: Prior to ascending onto the roof, a thorough visual inspection is conducted from ground level to identify any signs of damage, sagging, or structural anomalies that may impact roof measurements.
- *Safety Measures*: Safety protocols are emphasized throughout the survey, with personnel utilizing appropriate safety attire such as helmets, gloves, and non-slip footwear.
- *Accessing the Roof*: Cautious ascent up the ladder ensures stability and secure positioning against the structure for roof access.
- *Identifying Roof Elements*: The survey commences by pinpointing the location of each element within the roof framework, utilizing visual scrutiny and precise measurements to ascertain their precise positioning.
- *Measuring Structural Frame Spacing*: Horizontal and vertical spacing between adjacent elements is measured using either a measuring tape or laser level. Measurements are validated through verification and consideration of any irregularities in the roof structure.
- *Assessing Roof Angles*: Angles of each element relative to the horizontal plane are determined using a protractor or digital angle finder.
- *Recording Data*: Systematic documentation of all measurements and observations is carried out, generating a detailed sketch or diagram illustrating the roof layout, including the position, spacing, and angles of each element.
- *Documenting Findings*: Structural discrepancies, damages, or deviations from the anticipated roof configuration are documented (photographic or videographic evidence).
- *Final Inspection*: A comprehensive final inspection ensures the integrity and accuracy of the survey data.
- *Reporting and Analysis*: A comprehensive report is compiled, detailing the outcomes of the roof survey, including precise measurements, observations, and recommendations for subsequent actions.

3.3. The steps in conducting the survey using scanning and processing the data in Revit

The second study involved surveying the same roof using the Leica BLK 360 scanning device and interpreting the results obtained by importing the point cloud into the specialized software Revit (Figure 3).

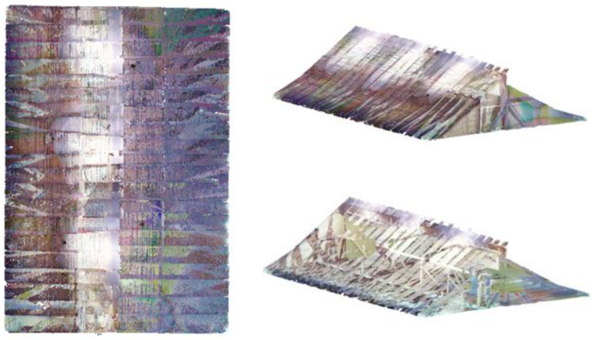
Figure 3 The equipment used Leica BLK360 Imaging Laser Scanner (Source: [14]).

The trestle frame roof surveys play a pivotal role in assessing the structural integrity and condition of roofs. With the advent of scanning technology, conducting these surveys has become more efficient and accurate. Here are the steps involved in performing the roof survey using scanning:

- *Equipment Preparation*: The initiation of the process involves ensuring that the scanning equipment is appropriately prepared, calibrated, and operational. Familiarization with the scanning software is necessary, along with adherence to any specific protocols required for the survey.
- *Safety Protocols*: Emphasis is placed on safety considerations through the conduct of a comprehensive risk assessment of the work environment. All personnel participating in the survey must be equipped with suitable safety gear, including helmets, gloves, and high-visibility vests. Additionally, obtaining the necessary permits and permissions for roof access is essential.
- *Device Setup*: The scanning device is strategically positioned to optimize coverage of the entire roof area effectively. Scanning paths must be unimpeded by obstructions, and the stability and secure mounting of the device must be ensured.
- *Scanning Procedure*: The scanning process is initiated by activating the scanning device. Utilizing laser beams or alternative sensing technologies, detailed 3D images of the roof and adjacent structures are captured.
- *Data Acquisition*: Continuous monitoring of the scanning progress is essential to ensure comprehensive data collection, pre-empting any missed or underrepresented areas.
- *Quality Assurance*: Real-time quality control assessments are conducted to validate the accuracy and completeness of the scanned data. Any encountered issues or anomalies during the scanning process are promptly addressed to maintain data integrity.
- *Post-processing*: Upon completion of scanning, raw scan data is transferred to designated software for subsequent post-processing and analysis. Specialized software tools are utilized to transform raw scans into detailed 3D models of the roof and surrounding structures.

Importing point clouds into Revit involves a series of essential steps that bridge the gap between detailed laser scanning data and the architectural modelling environment. The process begins with the acquisition of point cloud data through laser scanning technologies, which capture precise spatial information of a physical environment [15], [16]. The utilization of imported point cloud data serves as a fundamental basis for the creation of precise 3D models within the Revit environment. This capability empowers engineers, architects, and designers to effectively visualize and analyse existing conditions with a high degree of accuracy and efficiency.

The process of constructing the trestle frame roof structure utilizing point cloud data in Revit encompasses a series of methodical steps tailored to ensure meticulousness and accuracy in documentation. Initially, the intricate details of the roof are captured through point cloud data, which is subsequently imported into Revit as a comprehensive reference (Figure 4). Within the Revit environment, the point cloud data can be manipulated to accurately model the existing roof system, capturing essential dimensions and structural complexities.

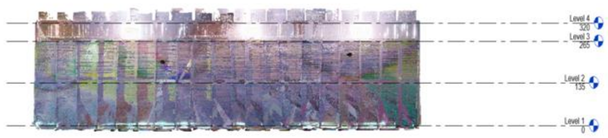


(a) (b)

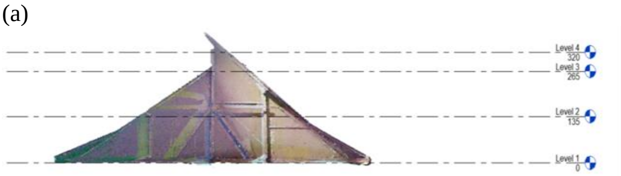
Figure 4 Importing the point cloud in Revit: (a) top view; (b) general view.

Figure 5 Images with details from inside the structure.

By integrating the point cloud data with Revit's modelling tools, it becomes possible to meticulously analyse the spatial relationships among individual roof components and other elements of the building. This facilitates well-informed decision-making in renovation or retrofitting projects, as demonstrated in Figure 5.



(a)

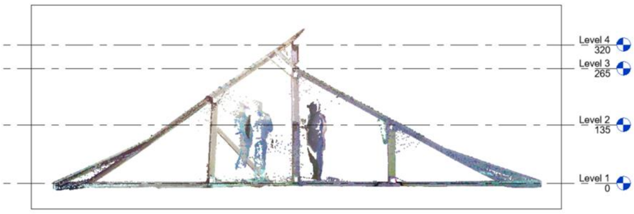


(b)

Figure 6 Establishing the levels: (a) East view; (b) North view.

Furthermore, the utilization of point cloud data within Revit enhances the documentation procedure, facilitating the creation of meticulous plans, elevations, and sections of the roof system with unmatched accuracy. Consequently, the second phase of the program involved determining the vertical levels for the specified structure, thereby enabling the construction of its constituent elements, as illustrated in Figure 6.

The subsequent stage in generating the analysed structure entails drafting sections, facilitating a comprehensive analysis of the structure, its constituent elements, and their spatial arrangement, as illustrated in Figure 7.

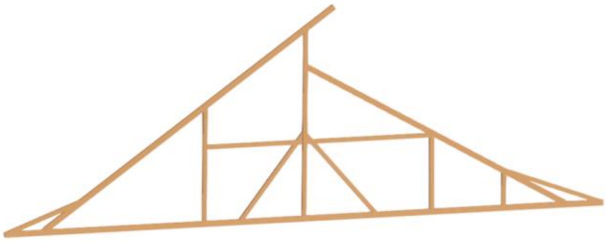


(a)

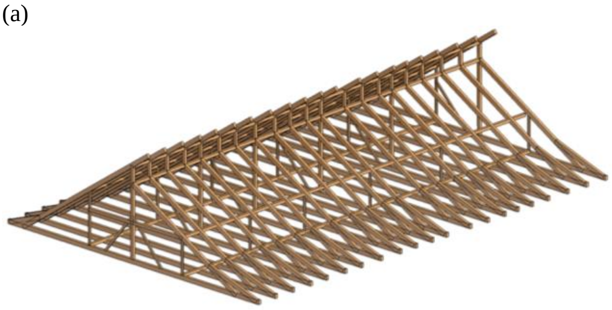
(b)

Figure 7 The sections of the analysed structure: (a) cross-section; (b) longitudinal section.

The final phase in the creation of the structure utilizing the point cloud in Revit encompassed the tangible assembly of the trestle frame roof constituents. In order to streamline the workflow and enhance efficiency, a primary frame was initially generated (as presented in Figure 7.a), subsequently subject to modifications and replication to achieve the entire structure (Figure 8).



(a)



(b)

Figure 8 The trestle frame roof created in Revit: (a) the primary frame; (b) the entire structure.

Through meticulous attention to detail and adherence to established protocols, an accurate representation of the trestle frame roof structure is achieved, facilitating further analysis and design within the Revit environment. The final representation of the scanned structure is presented in Figure 9 and Figure 10. The obtained 3D model can generate technical details, sections, and other necessary information.

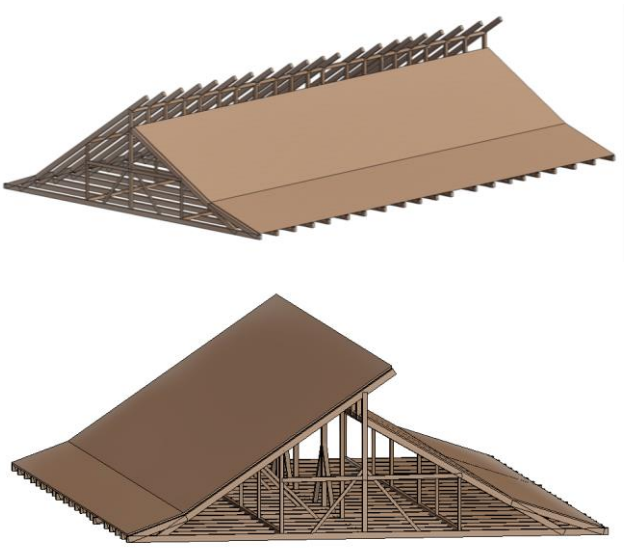


Figure 9 The trestle frame roof created in Revit.

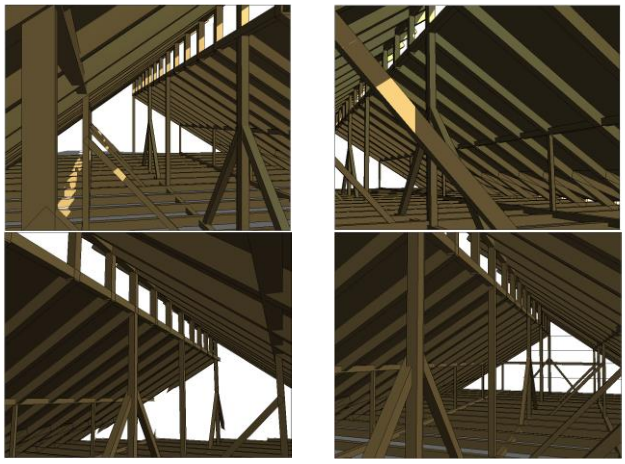


Figure 10 Images with details from inside the structure created in Revit.

Through this methodology, Revit becomes a powerful tool for civil engineers to conduct comprehensive surveys of roof, ensuring that design interventions align seamlessly with existing structural conditions while maintaining accuracy and efficiency throughout the project lifecycle.

4. CONCLUSIONS

Taking into account the two studies conducted and the analysis presented in this article, the table 1 briefly outline the advantages and disadvantages of the two methods of conducting a survey of a structure.

Table 1
Advantages and disadvantages of both methods of survey.

Traditional Survey	***Scanning Survey***
Advantages	
✓ *Accuracy* in capturing details or irregularities. ✓ *Flexibility*: adapt to various environments and conditions. ✓ *Personalization*: clarifications and adjustments based on real-time observations. ✓ *Control over the process*, enabling them to ensure the quality of data collected.	✓ *Efficiency*: rapid data capture, reducing survey time. ✓ *Accuracy*: highly accurate three-dimensional representations of structures. ✓ *Visualization*: Revit allows for the creation of detailed and immersive digital models, facilitating better visualization and analysis. ✓ *Collaboration*: digital models easily shared.
Disadvantages	
✓ *Time-consuming*: manual measurement processes can be labor-intensive and time-consuming. ✓ *Cost*: expensive due to the need for skilled labor, equipment, and extended project durations. ✓ *Error-prone*: human error, inconsistent measurements. ✓ *Limited accessibility*: certain areas may be difficult or unsafe.	✓ *Initial Cost*: acquiring scanning equipment and Revit software can be expensive. ✓ *Learning Curve*: mastery of scanning technology and Revit software requires training and experience. ✓ *Data Processing* can be time-consuming and require specialized skills. ✓ *Equipment Limitations*: scanning technology may have limitations.

These conclusions provide a clear overview of the trade-offs between traditional surveys and scanning with Leica BLK360 and processing the data in Revit, allowing to make informed decisions based on project requirements, budget constraints, and desired outcomes.

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