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# CREATION OF DIGITAL TWIN MODELS FOR RENOVATION: AN INTEGRATIVE LITERATURE REVIEW

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## Abstract

In the European Green Deal context, around 75% of European buildings need to be renovated within the next 30 years (European Commission, 2020). The generation of digital models of existing buildings is part of industrialised renovation processes. This paper aims to create new knowledge on the generation of the digital twin models of existing structures for the industrialised renovation of buildings by analysing, criticising and synthesising literature using an integrative literature review method. Finally, the paper proposes research on a new hybrid workflow with related topics for integrating the generation of the digital twin of existing structures into renovation processes.

## Introduction

There is much research where methods and workflows for digitalising existing structures are proposed and presented (e.g. (Pan et al., 2022; Truong-Hong and Lindenbergh, 2022; Xiong et al., 2013)). For some reason, these solutions are not widely used or integrated into renovation processes. For example, projects such as LIFE IP BUILDEST ("LIFE 3.0 - LIFE Project Public Page," 2021) have been established to study and solve issues related to the digitalisation of the renovation process. This leads to the question, what are the state-of-the-art concepts, processes and methods for automating the creation of digital twin models of existing structures?

The integrative literature review (Torraco, 2005) aims to get an overview of the latest developments in the field and attempts to identify the problems of existing workflows and methods as the base for new perspectives. This paper defines the general process from input to output as "workflow," the underlying principle of processing techniques as an "approach", and procedures to implement workflow parts as "methods." Other equipment, such as instruments, hardware and software, are defined as "tools".

The background section begins with a brief introduction of the subject's relevance. Next, an overview of the construction digital twin system to position the digitalisation of existing structures is presented. Also, the reality capture and the role of point clouds are described. The background ends with the framework synthesis used to analyse, criticise and synthesise approaches and methods for creating digital twin models. Then the review method is described. After this, the paper continues with the description, analysis, and comparison of relevant research. Critical analysis in discussion is used to identify practices, possible limitations and future perspectives. Finally, conclusions are presented.

## Background

Opposed to the site-based renovation approach, European Commission promotes industrialised renovation and digitalisation to scale and advance the deep renovation of buildings (Pikas et al., 2021). However, for installing fine-fitting prefabricated façade and roof elements, each building needs to be carefully and manually measured to design and manufacture parts. The measurement and study of an existing building to create the digital twin model is the first step in designing, engineering and producing industrialised elements. An example of a typical building in Estonia that needs to be renovated is shown in Figure 1.

*Figure 1: A typical apartment building in Estonia (picture on the left and point cloud on the right) that need to be renovated by using industrialised and digitalised renovation processes*

A resource-efficient and effectively scalable digital process should be developed to reduce the overall lead time of renovation projects and processes (Daniotti et al., 2021).

### Digital twin and renovation of buildings

Many attempts to define the digital twin have been made. However, most of these studies have focused on the building operations phase. Boje et al. (2020) and Sacks et al. (2020) developed the conceptualisation of digital twin information systems for construction project delivery. Specifically on how digital twin systems transform the construction production management from reactive to proactive through continuous monitoring of the current status and extensive use of analytics and simulations to predict and evaluate outcomes of alternative design and management decisions. The complementary works by Boje et al. (2020) and Sacks et al. (2020) together form a comprehensive digital twin paradigm for the delivery of new structures.

However, renovation projects have peculiarities different from the delivery of new structures. The first noticeable peculiarity is that something already exists (entire or part of a structure or service system), and often it is in use/operation (Kemmer and Koskela, 2020). Both of these often constrain the renovation solutions and processes. Stemming from these peculiarities and based on the Transformation-Flow-Value theory of lean construction, Kemmer (2018) proposed a management method for renovation, which consists of the conceptual model, the characterisation of reconstruction projects, and the best practice guidelines for improving the reconstruction processes. Kemmer (2018), however, did not address industrialised practices and digitisation of renovation processes.

Many studies on BIM for renovation have been published (Gökgür, 2015; Joblot et al., 2017), while less has been alleged about the digital twin for renovation. An exception is a study by Daniotti et al. (2022). They define building information modelling in the context of the renovation as “a modelling technology and associated set of processes to produce, communicate, and analyse building models. The outputs of BIM processes are building models or BIM models”. BIM is considered a means for constructing digital twin models.

However, their view is related to utilising the digital twin in the operations phase of renovated buildings rather than how it could be used in renovation project delivery. Research on digital twin models in renovation project preparation, planning, designing, engineering, and construction is still needed. An essential part of this process is the rapid collection, study, assessment, and creation of information on existing conditions.

**Reality capture and point clouds**

Xie et al. (2022) describe reality capture as a process where different technologies are used to create a 3D digital model of a real-world object. This definition might be justified in the construction context, as BIM is widely used in Architecture, Engineering, and Construction (AEC) industry. However, reality capture is broader than just creating a digital 3D model of the existing physical object. For example, object detection based on images or videos could also be considered a reality capture. Xie et al. (2022) state that the key reality capture technologies are photogrammetry, laser scanning and computer vision. The typical output of photogrammetry and laser scanning is a point cloud (Xie et al., 2022), while computer vision is used for object detection and semantic segmentation (Voulodimos et al., 2018).

The renovation of buildings with industrialised elements requires a relatively high level of geometric accuracy of existing structures. According to façade element manufacturers, the expected tolerance should be +/- 5mm (Pikas et al., 2021). This is the critical point in capturing the existing structures for the industrialised renovation of buildings. For example, point clouds are a resource-efficient way to collect vast amounts of accurate data on existing environments. Besides being used in the digitalisation of existing structures, such as bridges (Truong-Hong and Lindenbergh, 2022), laser-scanned point clouds are used for digitalisation in other fields. For example, point cloud data is used for recognising objects in autonomous navigation (Geiger et al., 2012).

**Synthesising (analytical) framework**

The preliminary and exploratory review of selected representative articles (Lu et al., 2019; Pan et al., 2022; Xiong et al., 2013) led to the understanding that articles can be categorised for a more systematic review. The common aspects that emerged from the papers include:

(i) **Problems and needs:** Problems are obstacles observed in the context-specific environment that must be resolved. Needs are prioritised aspects and elements derived from problems in the environment, which are the basis for eliciting requirements for outputs.
(ii) **Input and test objects:** Input is the information used by the workflow for creating output. Test objects are structures or elements used to check the performance of the workflow.
(iii) **Approach:** The underlying principles of information processing techniques. It is used here to categorise workflows.
(iv) **Output and results:** Output is the return of the workflow. Results represent the outcomes or value derived from the workflow.

As there are variations in many aspects, it is assumed that the principal value for new knowledge is hidden in the input data information processing approach. Based on this assumption, the following categorisation into five groups is proposed:

(i) **Design rule-based approach:** This group includes articles where the approach is based on contextual expert knowledge as a fundamental design rule. For example, the wall typically connects to the ceiling, but the door does not, as described by (Xiong et al., 2013).
(ii) **Prior data-based approach:** This includes articles where the approach is based on the known information about the structure (e.g. drawings) (Lu et al., 2020).
(iii) **Object detection-based approach:** The third group includes articles where an object detection-based approach is used to identify elements of a structure. For example (Pan et al., 2022), the transfer learning technique detects objects (e.g. smoke alarms) in images or videos.
(iv) **Space detection-based (voxel) approach:** The fourth group includes articles where the approach is based on detecting first the space between objects (e.g. void-growing in (Pan et al., 2021)).
(v) **Difference detection-based (patterns) approach**: Includes articles where the approach is based on

detecting differences in input data. For example (Maldonado et al., 2022), a difference in light intensity is used to separate wall points from window points.

The proposed categorisation is not final and will be updated in further research. However, it helps to get an overview of the latest developments in the field, highlight the main practices and identify the problems of existing workflows.

## Review method

The integrative literature review method is used as a distinctive form of research. Five goals for integrative literature review have been defined (Torraco, 2016). This study aims to review, critique and synthesise a new perspective on the generation of digital twin models for renovating existing structures. The review was divided into six steps: (i) the preliminary selection of papers; (ii) the development of the review framework; (iii) the selection and collection of articles; (iv) the description of relevant research approaches; (v) critical analysis of literature; and (vi) the synthesis of new knowledge. In the following, the elements of the integrative review are described in more detail.

### Sources of information and search terms

Google Scholar was used as a main source for searching relevant literature. It is a well-known online-accessible database used in scientific research. As reality capture technologies started to evolve rapidly relatively recently, the search period for papers was limited to the last ten years (2013 – 2022).

Search targets were topic-related papers that describe the digital twin model generation processes for existing structures. To find topic-related literature as a starting point, the following search terms were used: “point cloud segmentation bridges”, “geometric digital twins of buildings”, and “semantically rich 3D models of existing buildings”. More literature was identified by studying the references of the selected research articles.

### Selection criteria employed

Not all papers found were included in the review. Papers published recently were in focus; therefore, literature published before 2013 was addressed if those articles were referred to in papers under review. Only English-written papers were included. The most cited papers and most cited authors were included in the review. In the digitalisation of existing structures, as the same approaches for information processing are used, articles on digitalising existing bridges and buildings were included. The authors also took the liberty to add papers to the sample if a novel and unique idea was presented. It was ensured that at least three articles in each group were included, except in the “difference detection-based approach” group. In total, 13 articles were included.

### Framework implementation rules

An approach-focused framework is proposed for the integrative literature review. First, articles are grouped and described by the underlying information processing logic to highlight the peculiarities of different approaches. If there appeared hybrid approaches containing elements from the other five and sometimes beyond, in such cases, authors sort articles by their best understanding, which approach has the leading role in the workflow. Secondly, papers in each group are reviewed and critically analysed based on the following aspects: (i) problems and needs; (ii) input and test objects; (iii) approach; and (iv) output and results.

## Descriptions of approches

Articles selected for more detailed review have been thoroughly read based on the established framework. The essence of each approach is described and illustrated with a brief example of how the approach is used in relevant works.

### Design rule-based approach

The underlying principle in the design rule-based approaches is using expert knowledge as a design rule for information processing (Lu et al., 2019; Truong-Hong and Lindenbergh, 2022; Xiong et al., 2013). Design rules can be described as fundamental knowledge about structures (Lu et al., 2019; Truong-Hong and Lindenbergh, 2022) or contextual relations between structural (e.g. beams and columns) or non-structural components (e.g. furniture such as tables and closets) (Xiong et al., 2013).

Truong-Hong et al. (2022) and Lu et al. (2020) use slicing to divide laser-scanned point clouds into sub-clouds and extract point clusters of bridge components with the support of fundamental design rules (e.g. expected dimensions and placement of bridge components). In work (Xiong et al., 2013), labelled surfaces of the room's walls, floors and ceilings from point cloud data are created by context-based modelling. The context-based algorithm considers contextual relations between patches of elements (e.g. orthogonal, parallel, adjacent, and coplanar relations) (Xiong et al., 2013).

### Prior data-based approach

Prior data-based approaches use available information, which can exist in many forms (Lu et al., 2020, 2019; Xue et al., 2018). For example, the 2D drawings of the specific structure (Lu et al., 2020) or the broader conception of the structure (e.g. topology) (Xue et al., 2018).

The approach of (Lu et al., 2020) is based on using prior data in the form of existing data (e.g. drawings, explanatory letters, etc.) as a central idea to identify objects under observation. Lu et al. (2020) use the benefits of the data available on drawings and the data from the actual situation (e.g. images) to overcome challenges related to digitalisation (e.g. hidden structural components such as pipes or beams are identified from the drawings). Xue et al. (2018) use library-based components (e.g. walls, windows, and doors) to build up semantically rich BIM. Measurements to fit parts are derived from 2D images. The fitting is led by architectural (e.g. building styles) and topological (e.g. order of components) constraints. Lu et al. (2019) use a template-matching method that finds the girder type from existing bridge beam catalogues. The beam is chosen from the catalogue by beam dimensions (e.g. width of the beam bottom flange). Beam dimensions are measured from point cloud projection histograms.

**Object detection-based approach**

Object detection-based approaches use knowledge of object visual parameters (e.g. shape, colour, etc.) to identify and mask the object. Machine learning often has a central role in those approaches (Babacan et al., 2017; Pan et al., 2022).

The approach of (Pan et al., 2022) is based on using a transfer learning technique for mapping objects from images. Pan et al. (2022) use a text recognition network model (Li et al., 2019) to detect and recognise text information (e.g. a door sign) from images. Babacan et al. (2017) use Convolutional Neural Networks (CNN) to segment point clouds to components such as walls, floors, etc. Zhao et al. (2020) use CNN to recognise structural components of buildings (e.g. columns and beams) from scanned 2D drawings.

**Space detection-based (voxel) approach**

Space detection-based approaches search and define room areas using voxels or void voxels (Pan et al., 2021). Pan et al. (2021) used void voxels to determine the space in rooms inside the point cloud and mark objects, such as walls, floors and ceilings. Hübner et al. (2021) voxelise triangle mesh and use a generated voxels-grid for segmenting rooms into floors, walls and ceilings. Aijazi et al. (2013) used voxels to segment 3D urban point clouds.

**Difference detection-based (patterns) approach**

Difference detection-based approaches use patterns recognised in input data to segment components (Maldonado et al., 2022). The approach of (Maldonado et al., 2022) is based on using patterns in point cloud data as a central idea to identify objects under observation. Maldonado et al. (2022) use the light intensity component, which is included in laser-scanned point cloud data. The light intensity in the point cloud varies in materials, forming a pattern that allows the segmentation of the point cloud into objects.

## Analysis of workflows

Although the selection of articles for review in this paper for critical analysis is not complete, it should represent the state of research and development well, related to the digitalisation of existing structures. It should allow a critical analysis to examine the workflows of each group of papers. The critical analysis aims to find unnoticed knowledge while simultaneously identifying bottlenecks and innovative and promising ideas. The critical analysis follows the aspects described in the framework: (i) problems and needs; (ii) input and test objects; (iii) approach; and (iv) output and results.

**Problems and needs**

Several works point to the problem that manually constructing a 3D model from a point cloud is time-consuming and error-prone, making the process inefficient and resource-intensive (Lu et al., 2019; Maldonado et al., 2022; Pan et al., 2021; Truong-Hong and Lindenbergh, 2022; Xiong et al., 2013). The research for an automated digitalisation process is motivated by the need for 3D models in different construction phases. For example, Truong-Hong et al. (2022) highlight the demand for 3D models of existing bridges in bridge inspection, assessment, and management. The need to update digital models during the operation and maintenance phase, as Lu et al. (2020) pointed out, makes digitalisation a continuous process.

However, the needs often seem apparent, and the problem is described, but precise requirements for the expected results still need to be identified and determined. This should be related to the context in which the outcome is meant to be used. For example, models for preliminary energy calculations or the design of prefabricated elements have different requirements. As a positive example, Kedar et al. (2016) describe the requirements of the bridge information model driven by the need for decision-making in the context of bridge renovation.

Problems that need to be resolved set requirements for the solution so that the solution is applicable in the appropriate environment (e.g. a building renovation process). The proper identification of problems, needs and elicitation of requirements is the first step in the Design Science Research methodology (Brocke et al., 2020).

**Input data and test objects**

Input data can be categorised by the purpose of use and its origin. According to the purpose of use, input data can be divided into four groups: (i) data for training; (ii) data for identification; (iii) data for modelling; and (iv) data for evaluation. This division does not exclude the possibility that one form of data can be used for more than one purpose. By origin, input data can be divided into three groups: (i) prior data (e.g. known data in national databases and archives (Pikas et al., 2021)); (ii) new data (e.g. laser-scanned point clouds); and (iii) user input (e.g. user-defined parameters).

There are examples of the use of combined input data (e.g. existing drawings and images (Lu et al., 2020) or images and point clouds (Pan et al., 2022)). With some exceptions (Lu et al., 2020), all works use laser-scanned point clouds as primary data.

Truong-Hong et al. (2022) and Lu et al. (2019) highlight the importance of input data quality for receiving adequate workflow output. It points to the fact that each part of the workflow should fit the system. This means that each step in the workflow should serve the next until the expected outcome. Besides the data quality, it is essential to determine whether the data is handleable. Aijazi et al. (2013) note that large data sets (e.g. very dense laser-scanned point clouds) should be handled in a simplified way. Otherwise, the computational cost will make it impractical to use.

Proposed workflows are mainly focused on identifying and modelling central structural elements. For example, piers, girders and decks of bridges (Lu et al., 2019; Truong-Hong and Lindenbergh, 2022), and floors, columns, walls, ceilings, windows and door openings of buildings (Lu et al., 2020; Maldonado et al., 2022; Pan et al., 2021; Xiong et al., 2013). The exception is Pan et al. (2022), where small objects such as light switches, emergency switches, lights, smoke alarms, etc., are under review. Tests with small objects (Pan et al., 2022) showed improvement in the identification process when several forms of information (e.g. images and point cloud) were used. This highlights the importance of using a variety of input data for constructing a digital model.

### Approach

In general, the process of generating a digital model from captured data has the following steps:

(i) **Cleaning of data:** Cleaning of data means a procedure where redundant data (noise) is removed (e.g. ground surface and vegetation (Truong-Hong and Lindenbergh, 2022)).
(ii) **Slicing of data:** The purpose of slicing data is to increase workflow performance by reducing the amount of data that must be handled at a time (Lu et al., 2019).
(iii) **Object pre-identification:** Object pre-identification defines the rough outline of the object.
(iv) **Removing unnecessary data:** Removing unnecessary data prepares the exact data for object digital creation by filtering the object data out in detail (Maldonado et al., 2022).
(v) **Constructing output:** Constructing output is the phase where the inputs are synthesised into outputs based on prepared data. For example, Pan et al. (2022) combine well-prepared data from images and point clouds to synthesise semantically rich digital models.

Depending on the input data, some phases may be missed or rearranged. For example, Pan et al. (2022) start with object identification from images, covering the need for cleaning and slicing data simultaneously. There are situations where data or data processing combinations are used to achieve better results. Pan et al. (2022) point out that photogrammetry has a low performance by identifying flat and texture-poor surfaces (e.g. monochrome walls). Overcoming this issue, Pan et al. (2022) combine photogrammetric point cloud data with laser scan point cloud data by using the better performance of laser scanning on solid surfaces. Truong-Hong et al. (2022) combine contextual knowledge of bridge structures with cell-based and voxel-based region-growing segmentation to identify bridge elements from the point cloud. However, there are limitations to the use of workflows. One of those limitations is that methods or approaches require intensive user input or are usable in idealised problem cases. User assumptions and values of user-set parameters can vary depending on the context. This means that input must be adjusted according to the observed object. Finding the best set for the input of each object can be time-consuming. For example, Pan et al. (2021) have in work several user-defined parameters that can be identified as possible limitations (e.g. room width, length and height limits are estimated and defined by the user, the user-defined limits in dimensions of doors and windows, and doors and windows are estimated to be rectangular). Lu et al. (Lu et al., 2020) analyse existing drawings by using the layout of column grids with the assumption that the centres of grids are located in the centres of grid heads. Often the grid head is moved to the side for better readability, which can cause an assumption error in the approach. Truong-Hong et al. (2022), Hübner et al. (2021), and Pan et al. (2021) pointed out the influence of defined voxel size on results. Aijazi et at. (2013) showed improved results and an increase in computational cost with a smaller voxel size and even observed that at one point, the decrease in voxel size did not produce better results in quality, but the computational cost continued to grow. It is important to note that the user input as such is not the limitation of the approach, but the inflexibility of the parameter or assumption defined by the user can be a limitation.

However, possible limitations are pointed out, but there is a lack of examples of how possible errors can be caught and handled. Lu et al. (2019) described difficulties in girder detection due to the lack of point cloud data. This information is available after the workflow has reached the end but not before the run. This highlights the lack of data evaluation in each workflow phase. Using requirements-based input data in workflow leads to the expected results, while random input data does not. The mismatch in outputs highlights the need for integrating evaluation into each step of generating a digital model.

Even if there seems to be one leading approach in workflow, works (Pan et al., 2022; Truong-Hong and Lindenbergh, 2022) show that combining different techniques in one workflow positively influences results.

### Output and results

The output of the workflows varies from sub-point clouds segmented by the shape of structural elements (Truong-Hong and Lindenbergh, 2022) to semantically rich 3D models of the objects (Pan et al., 2022). In evaluating these outputs, mainly two methods are used: (i) comparing output information with ground truth; (ii) the time of automated workflows versus manual work.

In most works, a manually constructed model or point cloud segmentation as a ground truth was used to compare the workflow output (Lu et al., 2019; Pan et al., 2022, 2021; Truong-Hong and Lindenbergh, 2022; Xiong et al., 2013). Considering output matching with ground truth, proposed workflows almost reach the level of manual users. However, it depends on which form of output is compared. For example, better results are achieved when the output is segmented sub-point clouds (Truong-Hong and Lindenbergh, 2022), compared with results in (Pan et al., 2022), where outputs were 3D models.

Automated and semi-automated workflows reduce work time compared to manual modelling (Lu et al., 2019). Unfortunately, the background of manually generating models is typically not described in these studies. The manual construction of a digital model of the existing structure is described as time-consuming and error-prone (Maldonado et al., 2022; Pan et al., 2021; Truong-Hong and Lindenbergh, 2022; Xiong et al., 2013). Despite this, manually constructed reference objects are used for evaluating the results (Lu et al., 2019; Pan et al., 2021; Truong-Hong and Lindenbergh, 2022; Xiong et al., 2013). This comparison can explain how well the proposed (semi-)automated workflow works compared to manual workflow. However, evaluation regarding how problems are solved and needs and requirements are met is often not described. Significant variations in workflow outputs and lack of context-based requirements lead to the understanding that the research in a digitalising existing structure in a renovation context is not as systematically developed as it could.

## Discussion of Results

New knowledge generated by the integrative literature review is summarised and presented as new perspectives and further research. New perspectives describe the potential research areas in generating digital twin models for renovation purposes. Further research highlights the topics that should be considered by handling these areas. At the end of the discussion, possible limitations of this short integrative literature review are presented.

### New perspectives

Based on the critical review in this short integrative literature review, the potential research areas of the generation of digital twin models in the renovation context are: (i) a shared understanding of the problems and needs as the basis for eliciting output requirements that should be resolved and satisfied in the relevant context; (ii) a better understanding of available data gathering and synthesising methods to overcome the gaps in data; (iii) selective and targeted data collection and processing to reduce resources needed for digitalising existing structures; (iv) the use of machine learning-based methods to increase workflow flexibility; (v) development of the framework for resolving problems related to the digitalisation of existing structure.

### Further research

Further research focuses on developing a hybrid workflow combining the strengths of different approaches, including using prior data in the form of building typologies and new data in the form of the laser-scanned and photogrammetrical point clouds. The central idea is to use building typology to construct the skeleton of the building, and the point cloud data is used for calibrating the typology-based building template. An option is to identify existing tolerances by building elements (e.g. wall elements), generate typical building elements shaped by the presumed tolerances, and use them to build up digital twin models of typical buildings instead of measuring each specific building. Further research aadresses, among other things, the following topics: (i) identification of context-based problems and needs to set requirements for outputs; (ii) an overview of the context-based knowledge base focusing on existing tools and their capabilities; (iii) an emerging need for quality training data for AI-based methods leads to the proposal of an international database where research groups can upload or download prepared training data; (iv) what methods from other fields can be integrated into creating digital twin models from existing structures?; (v) how to set up a proper testing environment for comparing the outcome of the workflow with the requirements, and how to evaluate the satisfaction level of the needs?

### Limitations of the integrative literature review

Only English-written papers based on the Google Scholar search are included. Articles in other languages and from databases should also be used for a complete overview. Used search terms might have missed some relevant papers. A rich selection of relevant search terms might improve a selection of papers. Many articles with low citation numbers compared with other papers are included. A low number of citations can be explained by the late publishing date and the specificity of the topic. More articles should be analysed in the proposed framework allows for confirming or rejecting the new knowledge generated by the integrative literature review.

## Conclusion

The preliminary and exploratory review of selected articles led to categorising articles by the underlying principle of information processing techniques. Five groups of papers were proposed: (i) design rule-based based approach; (ii) prior data-based approach; (iii) object detection-based approach; (iv) space detection-based (voxel) approach; and (v) difference detection-based (patterns) approach. Through the review, four common denominators of workflows emerged, which were used to study and analyse selected articles: (i) problems and needs; (ii) input and test objects; (iii) approach; (iv) output and results.

The most important observations in the critical analysis were: (i) while problems and needs are typically described, requirements are often not identified in the renovation context; (ii) a variety of input data are essential for constructing a digital model; (iii) combining different techniques in one workflow positively influences results; (iv) evaluation regarding how problems are solved and needs and requirements are met is missing; and (v) the research in a digitalising existing structures in renovation context is not as systematically developed as it could.

These observations led to a proposal of new research topics, considered in further research of the introduced hybrid workflow. This paper showed the need and importance of a detailed review, which leads to a better understanding of existing obstacles for integrating developed workflows into the digitalised renovation process and helps improve solutions through new perspectives and highlighted topics that should be considered in future research.

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