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3D SCANNING FOR BUILDING DOCUMENTATION AND PRELIMINARY REUSE PLANNING: A CASE STUDY ON AN INDUSTRIAL HALL

Andreea Diana CLEPE, Viktor SZALAI

Politehnica University Timisoara, Faculty of Civil Engineering, Street Traian Lalescu, nr. 2,
Timișoara 300223, Romania
Corresponding author: Viktor SZALAI, E-mail: viktor.szalai@upt.ro

Abstract. The rapid progress in 3D scanning technologies, along with the adoption of advanced digital modelling techniques in the construction industry, has led to a new application: creating 3D models from point clouds for buildings that are set to be assessed with the purpose of deconstruction and reuse. This paper highlights the importance of integrating 3D scanning and point cloud processing into digital modelling for the evaluation of buildings intended for reuse, serving as a decisive factor in enhancing sustainability in the construction industry. In this case study, a methodology is implemented and evaluated, focusing on the analysis of essential data for planning the sustainable reuse of a storage facility. Initially, conventional measurement and 3D scanning instruments, such as total stations and LiDAR devices, are utilized to acquire data from an active deconstruction site. The collected point cloud data is subsequently processed and analysed to generate a precise 3D model. The results are then assessed based on model accuracy, structural element inventory, as-built documentation, and other relevant technical parameters. The use of 3D scanning in deconstruction and reuse has the potential to reduce construction and demolition waste, conserving natural resources needed for new materials, and can support built heritage preservation.

***Keywords**:* 3D scanning, deconstruction, reuse, point cloud, LiDAR, circular economy.

1. INTRODUCTION

In the current context of technological advancement, digitalization, and resource efficiency, advanced three-dimensional scanning methods can play a crucial role in managing and reusing existing structures. This paper explores a case study on the use of 3D LiDAR scanning for planning deconstruction and reuse of an industrial facility. By capturing detailed geometry and the current structural condition in the form of a point cloud and processing it with a specialized advanced software, scanning provides an accurate and essential database for creating digital 3D models. These models enable precise assessment of recoverable structural elements, optimization of deconstruction processes, and effective strategic planning for resource reuse.

The end of a building's service life refers to the stage at which the structure or its components are no longer suitable for their initial intended use without substantial intervention [1]. At present, there are two options that can be considered at the end of a building's service life: rehabilitating or modernizing the structural system and demolishing. Demolition of buildings is one of the largest sources of waste [2]. Consequently, various recycling techniques for construction elements and materials have emerged to reduce waste in this sector. For instance, 56% of the steel produced globally is utilized in the construction industry (approximately 42% for buildings and 14% for infrastructure works) [3–4], and at the end of the service life of steel-framed buildings, over 95% of this material is recycled. However, steel recycling is energy-intensive, and the carbon emissions generated during this process are considerably high. Additionally, steel components are often recycled despite their high quality and good condition, rather than being directly reused. On the other hand, concrete is the primary construction material, with a global annual consumption of 30 gigatons [5]. In Europe, waste generated from concrete accounts for approximately 30% of the total mass of solid waste [6]. Concrete is one of the major contributors to environmental degradation and, to some extent, human health issues. The production of cement, primarily based on clinker, is energy-intensive, and the annual global production of 4 gigatons of cement is responsible for 9% of anthropogenic greenhouse gas emissions [7]. With an ever-increasing demand, concrete production today constitutes a significant portion of atmospheric pollutants [8], and both the extraction of raw materials and the disposal of its waste threaten biodiversity and ecosystems [9].

Deconstruction and reuse of buildings represent an emerging approach that aligns sustainability goals with improvements in environmental safety, and economic circularity by focusing on the recovery and reuse of materials and structural elements [10,]. Consequently, the construction industry can reduce carbon emissions, conserve natural resources, and foster economic growth. However, to fully achieve these benefits, it is essential to address the technical, economic, and regulatory challenges involved in this practice. It is anticipated that, with ongoing research and innovation, deconstruction and reuse could become key components of a more sustainable construction industry.

Typically, the planning of such projects represents a significant initial challenge, as it requires the prior identification and inventory of the building's structural elements, along with precise measurements of geometric dimensions in the design. The construction drawings developed during the design phase may prove insufficient or even non-existent at this stage, particularly because the operational life of structures can span several decades [11].

In the case of steel constructions, critical barriers to the reuse of structures are represented by deviations from the ideal shape of structural elements, referred to in the literature as geometric imperfections [12]. These imperfections may arise due to the loads to which the structures were subjected during their previous service life. The imperfections in steel columns and beams can significantly influence the behaviour of the structure, reduce its load-bearing capacity and necessitate quantitative evaluation to ensure accountability in reuse design [13, 14]. Furthermore, inaccessible connections and/or those made by welding between steel structural elements pose a significant impediment to reuse and deconstruction [15].

In contrast, while concrete is more widely used as a material in the construction industry, the potential for reuse in concrete constructions is significantly limited. Viable available options for reuse are just precast concrete structures, whereas in-situ poured concrete structures typically form monolithic elements that are not suitable for reuse. When precast structures are designed appropriately, internal deformations during the service period remain minimal, resulting in a high rate of compliance for reuse in most situations involving such elements. Most deformations can occur in precast concrete elements during the deconstruction or reassembly phases due to improper handling or inadequate detailing of the connections [16].

Early three-dimensional (3D) scanning technologies (1960s) focused primarily on industrial metrology, to measure and inspect manufactured parts. During the 1980s and 1990s, the use of 3D scanning expanded into fields such as cultural heritage preservation. Simultaneously, architectural and civil engineering sectors began adopting 3D scanning to capture as-built conditions of complex structures. Nowadays, 3D scanning is extensively used for structural health monitoring, deformation analysis and digital twin creation for different applications [17]. The use of 3D laser scanning technology for building measurement allows for the creation of a point cloud, which can then be used to generate digital documentation to model the scanned structure. This technology has enormous potential to enhance the level of automation within the Architecture, Engineering, and Construction (AEC) sector and is increasingly becoming standard in many countries [18-19].

Planning and design for deconstruction of a building must include, amongst other, preliminary investigations to assess the building's current condition [20]. This stage includes identifying structural components, inventorying them, evaluating damages and deformations, and preparing a report on the reusability grade of each identified element. Some of the technical requirements that may influence the assessment of reusability include:

a. the logistics related to the measurements required for identifying and inventorying the elements, as well as those concerning the actual deconstruction process.
b. the durability of structural elements, directly influenced by the environmental conditions in which they were used during the previous period of operation;
c. the residual load-bearing capacity of the structure;
d. the structural details and alignment with current requirements of current design and execution standards;

Existing documentation from the design period of the proposed building is the preferred source for gathering information, and reviewing it is the first step in assessing the potential of reusability. However, there is a high probability that the documentation may be partially incomplete or missing entirely.

A visual inspection can be conducted on the structure at the end of its operational life, before deconstruction begins. The aim is to identify and record any damage to the structural components, while also removing any elements with low reuse potential due to significant visible degradation that could affect their usability or structural strength.

However, the severity of damage is not always assessable through visual inspection alone. The need for advanced geometric measurements and qualitative assessments of degradation levels [21] has led to the recent integration of new data collection technologies, such as 3D scanning, into the deconstruction planning and design process. The assessment of degradation levels could be done by evaluating directly on the obtained point cloud, geometric irregularities such as cracks or deflections, compared to the ideal shapes of the structural elements. Also, direct integration of the point cloud data (real geometry) in finite element analysis can ensure a more precise assessment. Furthermore, 3D scanning can be particularly valuable in identifying and cataloguing structural elements in buildings proposed for deconstruction, creating "as-built" drawings, determining element positions, and producing three-dimensional models that serve as the basis for initial data collection. In this case, the 3D models are reconstructed from point cloud data (ideal geometries), without the need to consider deflections and cracks. We consider it important to clearly distinguish between these two applications: (1) the direct use of point cloud data representing the real geometry for finite element analysis or damage and performance assessment, and (2) the reconstruction of idealized geometries for documentation and planning purposes. Both approaches could be essential in the near future for deconstruction and reuse planning, as they can provide complementary information for decision-making.

Currently, a considerable number of directives, regulations, and standards concerning the deconstruction and reuse of buildings are being developed and implemented in the European Union. This signals a growing importance of sustainability and economic circularity within the construction industry. One of the most recent developments is the draft version of the prEN 15978-1 standard on the sustainability of deconstruction works – Assessing the potential for the sustainable reuse of buildings [22]. This standard is currently under approval by EU member states as of late 2023 and is expected to become a key reference for the sustainable reuse of buildings. Digital models obtained from 3D scanning could enhance element inventories, precise dimensions, and condition data – which directly address the documentation and quantification needs outlined in prEN 15978-1. Future research will focus on addressing data gaps, connecting to BIM software, and expanding applications to deconstruction and reuse project planning [23–25].

In the following sections we introduce the details of how we acquired a 3D digital model of an industrial building based on 3D scanning measurements with the purpose of gaining structural element inventory and as-built documentation. The obtained 3D model was further checked if desired accuracy levels are achieved and then integrated into a reuse project, addressing a gap in research dominated by cultural heritage projects, new construction projects or studies that stop at producing as-built models with direct relevance for civil and surveying engineers.

2. REFERENCE STRUCTURE AND 3D SCANNING MEASUREMENTS

The proposed structure for this case study is an old industrial hall located in Arad municipality, Romania, and was erected in 1985. Initially designed as a production and storage facility for the agricultural sector, the building consists of a reinforced concrete and precast frame structure, with non-load-bearing masonry walls and a corrugated metal roof. It is a two-storey building with approximately 61 meters in length, 13 meters in width, and 14 meters in height. During its operational peak, the hall was used for agricultural production processes and seed storage. The location (Fig. 1) has undergone in past several maintenance processes, but it was no longer used for the initial purpose.

The use of 3D LiDAR scanning for the detailed capture of the geometry and structural condition of the hall was important for obtaining precise data that allows for an accurate assessment of structural integrity, identification of potential damages, and optimization of the deconstruction or reuse planning process. This technology also helped save time and resources by providing an as-built documentation of the building in a fast and efficient manner.

Fig. 1 – Overview of the investigated building.

The main measurement instruments used were the Leica Flexline TS 06 Plus total station and the Trimble TX8 3D scanner, each playing distinct yet crucial roles in ensuring the precise and thorough acquisition of the data necessary to successfully complete the project. The Trimble TX8 3D scanner uses a scanning method based on LiDAR technology, which involves emitting a laser beam and measuring the time it takes for the beam to reflect from objects in the surrounding environment. Due to the relatively large height of the hall, a DJI Matrice 300 RTK drone equipped with LiDAR was also used to obtain a 360° scan.

The total station was set up at six station points located both outside and inside the hall, ensuring thorough and even coverage of the entire structure. These ground control points were used as reference markers to define precise coordinates within the final 3D model. To achieve accurate georeferencing, four reflective targets were strategically placed outside the scanned object, optimizing the distribution of reference points. This contributed to enhancing the precision of the 3D model and aligning it with real-world coordinates. Once the reference points were collected, the scanning process began using the terrestrial laser scanner. The scanner was positioned at 84 station points and employed to capture detailed data of the hall, including both exterior and interior contours, as well as structural and architectural features, resulting a dense monochrome point cloud.

By integrating the data obtained from the total station, the terrestrial laser scanner and LiDAR drone, a complete 3D model of the hall was obtained.

Next, a post-processing of the collected data was conducted, converting the raw point cloud into an accurate and usable digital 3D model of the scanned structure. Within the Trimble RealWorks software, measurements from each scanning station were first aligned automatically, using the coordinates of the reference points measured with the total station (Fig. 2).

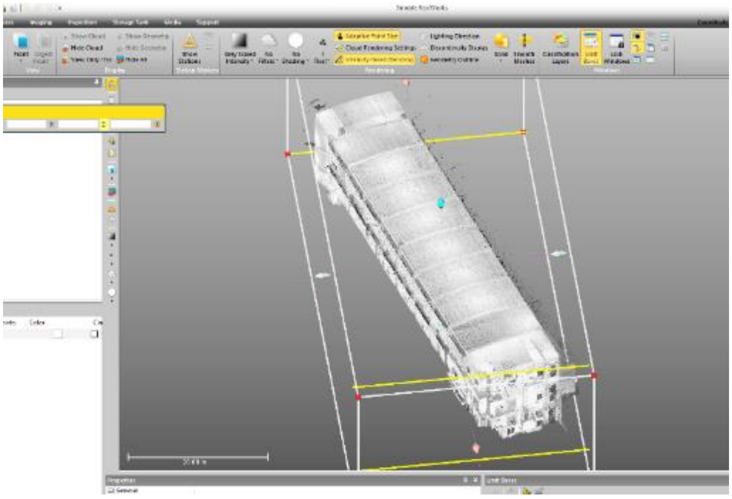

Fig. 2 – Point cloud alignment process using reference points.

It is important to note that although the scanner allows for the collection of colour data through images captured by the integrated camera, colour points were not collected for this scan. The aim of this approach was to record as many points as possible to obtain a denser and more accurate point cloud and highlight important details of the structure (Fig. 3).

Fig. 3 – Monochrome point cloud of the interior of the building.

For further data processing and generating a 3D model from the point cloud, two third-party programmes were selected and tested: ArchiCAD and Autodesk Revit. These programs allow the conversion of the point cloud obtained from scanning into a detailed digital model, which can be applied in various design and construction tasks. Initially, ArchiCAD was developed as a tool for architects, while Revit was created to integrate all stages of the construction planning process, from design and architecture to electrical and plumbing installations. Regarding point cloud processing and 3D modelling, both programs have shown distinct advantages and limitations. Revit, being part of Autodesk, benefited from seamless integration with other programs from the CAD environment but required more intensive procedures for point cloud modelling. On the other hand, ArchiCAD provided an intuitive workflow (Fig. 6) and a more user-friendly interface but had limitations regarding the size of the point cloud it could process, supporting files of up to 4 GB. Given the objectives of this case study and the relatively small size of the point cloud (1.9 GB), it was decided to use ArchiCAD for converting the data.

In terms of workflow for converting point cloud data into a 3D CAD model general steps are presented next. First, the point cloud was imported into ArchiCAD, positioned and aligned with a coordinate system. Afterwards, cross-sections (Fig. 4) were generated by placing section planes within the model, allowing for detailed analysis and documentation and helping refine the model by comparing it to the original point cloud data, ensuring fidelity between the real building and the 3D model.

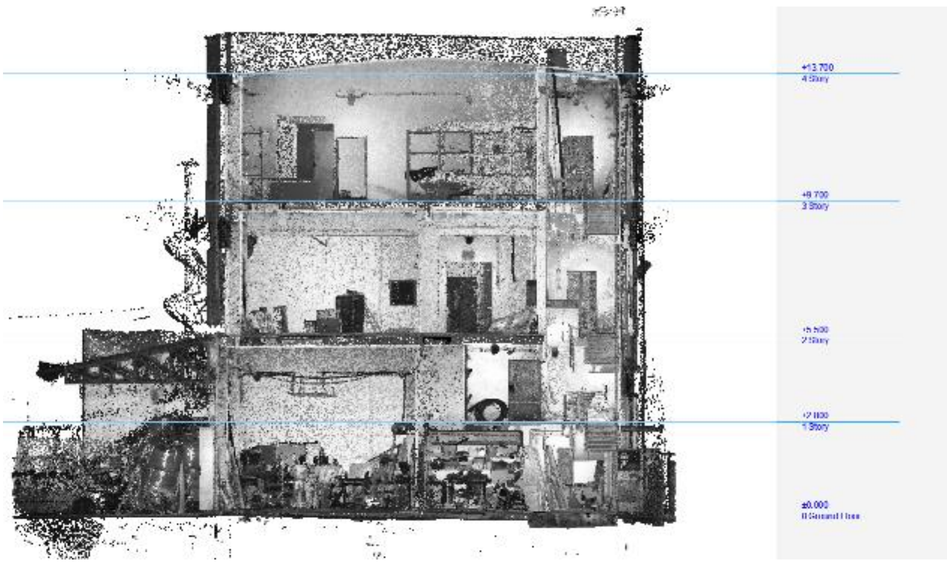

Fig. 4 – Cross-section generation.

Redundant data removal such as furniture and other non-structural elements was an important step before tracing key structural elements directly over the point cloud using ArchiCAD modelling tools, such as walls, slabs, and columns, ensuring they conform to the scanned data (Fig. 5). These processing stages required substantial manual intervention, tracing key structural components being the most time-consuming part of the workflow. Looking forward, there is potential to further automate elements of the process, such as automated segmentation and recognition of structural components from the point cloud but taking into consideration the possible variability of geometry across projects (cross-sections, structural systems, architectural styles) can reduce the effectiveness of project-specific coding. On the other hand, machine learning can be trained and improved by collecting large datasets of different building types, representing a promising alternative but still maturing and not yet widely accessible for everyday engineering practice.

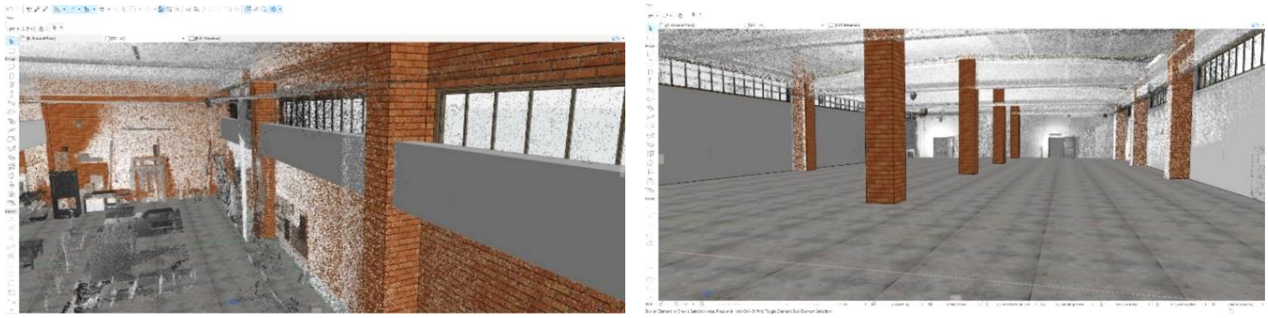

Fig. 5 – Tracing architectural elements over point cloud.

Finally, the completed 3D model was further refined with materials, annotations, and exported for construction drawings or other purposes (Fig. 6).

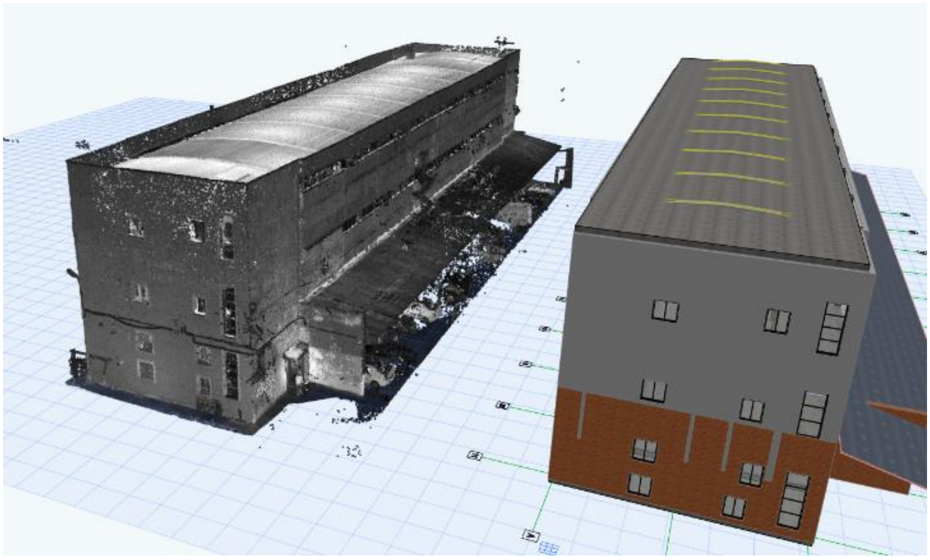

Fig. 6 – Refining and exporting the 3D model.

Obtaining the 3D model of the building represented just an intermediate stage. For its effective application in reuse planning and deconstruction, an additional phase of data collection and processing, was required, ensuring that relevant information was integrated into the model.

5. RESULTS

The accuracy of the obtained 3D model was verified, which is one of the key aspects of the presented procedure. In this context, real distances measured on field with the total station (treated as reference values), were compared with distances measured afterwards on the point cloud and subsequently the 3D model (Table 1). The results show that the absolute deviation increases with the length of the measured span, ranging from 0.46 mm at 0.50 m to 0.397 m at 60.00 m (Fig. 7), which corresponds to a maximum relative error of approximately 0.66%.

Table 1

Comparison between distances measured with the total station and distances from the point cloud

Reference distance (on field)	Measurement on point cloud (m)	Total station measurement (m)	Absolute difference
0.50 m	0.50953	0.50999	**0.00046**
1.00 m	1.05996	1.06354	**0.00358**
1.50 m	1.50876	1.51209	**0.00333**
2.00 m	2.09992	2.11763	**0.01771**
3.00 m	3.10024	3.14993	**0.04969**
5.00 m	5.14213	5.18842	**0.04629**
10.00 m	10.19999	10.25655	**0.05656**
20.00 m	20.2001	20.31106	**0.11096**
30.00 m	30.24579	30.4951	**0.24931**
40.00 m	40.29885	40.59222	**0.29337**
50.00 m	50.31993	50.66118	**0.34125**
60.00 m	60.35302	60.75044	**0.39742**

At short ranges (< 2 m), the discrepancies remain in the sub-millimetre range, while for larger distances they increase progressively, reaching several centimetres at the largest measured span of the building. The observed accuracy aligns with the 0.5–1% error range indicating that the reconstructed geometry is sufficiently precise for building documentation and reuse assessment.

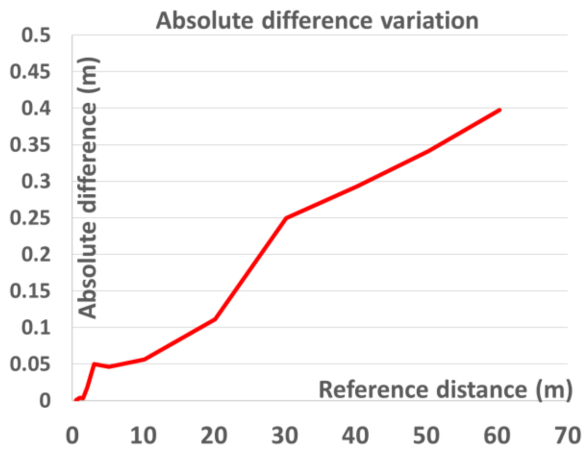

Fig. 7 – Absolute difference variation on reference distance between the two methods.

Cross sections were created for each individual structural element, allowing for a comprehensive analysis of their dimensions and properties. Detailed measurements, such as in-plan dimensions (width and height), surface areas, lengths, and the number of each element, were extracted from the models. These data points provided a clear overview of the building's components, which are crucial for accurately determining the feasibility of reusing specific parts during the transformation process. By organizing this information systematically, it becomes easier to assess which elements can be retained, modified, or replaced as part of the reuse plan for the industrial hall. The identification of structural elements is crucial when proposing interventions that change the usage category of a structure, and this step must be given particular attention. Next, it is necessary to carry out surveys to identify the surfaces for each level and room, as well as to measure the axis-to-axis distances between columns, beams, or walls. Additionally, cross-sections of the entire building can be analysed to check floors thicknesses, ceiling heights, and other relevant dimensions. In terms of measurement accuracy, a comparison was made between real geometry and reconstructed geometry (point cloud) in case of columns and beams (Table 2). The comparison between the field-measured and reconstructed geometries of columns and beams shows mean length differences ranging from 19.5 mm to 43.1 mm and cross-section differences between 10.2 mm and 21.5 mm. Given typical element sizes, these represent relative deviations of approximately 0.5–1.5% in length and 2–5% in cross-section dimensions, enabling reliable identification of elements in reuse planning.

Table 2

Comparisons between real geometry measured on field and reconstructed geometry in case of beams and columns

Element type	Number of elements	Mean length difference (mm)	Mean cross section difference (mm)
Ground-floor column	11	39.78654	20.00918
First-floor column	11	43.10029	21.46902
Second-floor column	11	41.99921	19.99954
Ground-floor transverse beams	22	20.02863	12.30099
First-floor transverse beams	22	21.44635	11.01312
Second-floor transverse beams	11	19.51141	10.20524
Ground-floor longitudinal beams	21	27.25765	13.55786
First-floor longitudinal beams	21	34.18989	12.00350
Second-floor longitudinal beams	21	31.00013	11.00800

Based on the initial data collected through 3D scanning and the subsequent modelling of the building, the identified elements inventoried in the previous step, can be investigated also from a structural point of view and proposed for reuse in another building, if quality and safety parameters are fulfilled. In this case study, a solution for the complete reuse of the building was proposed instead of member reuse. Essentially, the category of use was changed based on the 3D model and the surveys. The planning for redevelopment of the building and reuse of the interior spaces will be carried out directly on the model obtained from the LiDAR data. For this reason, the method of quantitative and qualitative evaluation through 3D scanning was chosen. As can be seen from the generated model, the building offers both large storage spaces and offices and other types of rooms.

Starting with characteristics outlined earlier and the results obtained from the LiDAR measurements, a sustainable reuse option was transforming the building into a Business Incubator. The storage areas were reorganized into shared office spaces for various start-up companies (Fig. 8).

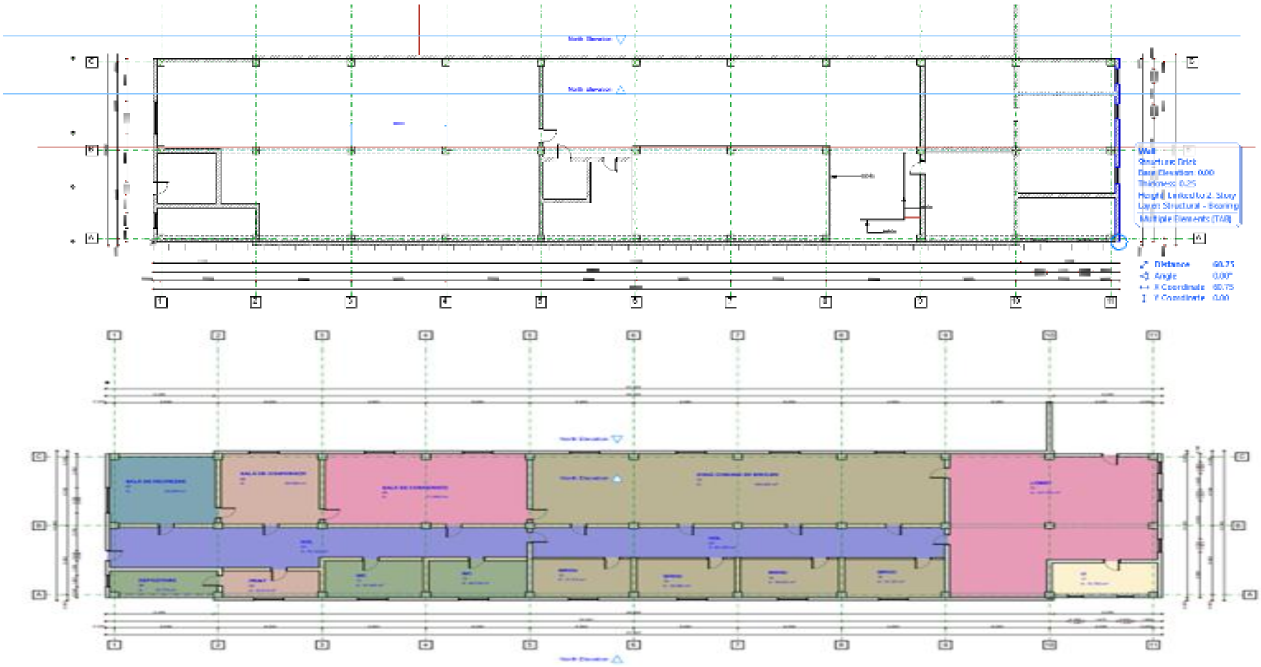

Fig. 8 – Proposal for reuse of the industrial hall.

The integration of LiDAR scanning and the processing of point clouds into the digital modelling of buildings to be reused will play a key role in enhancing sustainability in the construction industry. Deconstruction and material reuse have significant economic and environmental benefits. Economically, they reduce construction costs by lowering the demand for new materials, create jobs through labour-intensive processes, and generate revenue from salvaged materials while cutting landfill machine disposal fees [26]. Environmentally, these practices reduce waste, lower carbon emissions by decreasing the need for energy-intensive material production, and conserve natural resources like forests and minerals. By integrating reuse into building practices, industries can achieve both cost savings and sustainability, supporting a circular economy and reducing environmental impact.

6. CONCLUSIONS

The rapid development of LiDAR 3D scanning technology and the implementation of innovative concepts in the construction industry have identified a new application: creating 3D models based on point clouds for buildings that are evaluated for deconstruction and reuse. In this study, three types of measurement equipment were successfully used for data collection: total station for measuring control points for georeferencing, drone with LiDAR for scanning inaccessible areas, and terrestrial laser scanner for accessible areas. It can be stated that both the laser scanning technology, and the data processing are very complex techniques, involving multiple stages necessary to obtain the final product: the 3D model.

The model obtained from the point cloud processing has high accuracy due to the high density of the points, ensured by monochromatic scanning and adequate coverage of the scanned area. Regarding processing time, the procedure for creating the 3D model is not yet fully automated, but with continuous improvements in post-processing programs, the efficiency of this technique is expected to significantly increase in the construction industry. Additionally, the choice of ArchiCAD software for data processing was advantageous due to its easy-to-access interface, although the process remains largely manual, as the program was initially developed for use by architects.

Deconstruction and reuse of buildings are key directions for sustainability in construction, being among the most important objectives of the industry. However, there are certain technical barriers that hinder the integration of buildings into a circular economy. These include the need for digitalization of technical data of buildings and the challenges in quantitative and qualitative evaluation of structural elements, especially those previously used. In this context, 3D scanning becomes a useful tool in the deconstruction and reuse planning process.

The case study presented makes significant contributions to identifying the advantages of using 3D scanning on buildings proposed for deconstruction and reuse. Compared to manual measurements or visual inspection, 3D scanning captures the full geometry of surfaces, including complex shapes, curves, and fine details like cracks, deflections or surface textures that are difficult or impossible to record manually. These results can be more detailed and accurate. Small errors in manual input can accumulate, leading to inaccuracies in the final model. Manual measurements are time-consuming, often requiring multiple measurements from different angles, and can take days for complex structures in comparison with 3D scanning which can take just a few hours. 3D scan data can be directly imported into CAD, BIM, or analysis software, speeding up modelling, analysis, and simulation workflows compared to manual-built models which are more labour-intensive.

By obtaining the 3D model, current condition surveys of the building (at the end of its lifecycle) were extracted, cross-sections were made, dimensions were measured, and structural elements were inventoried. Based on this data, a potential change in the building's usage category was proposed. Further research will explore the possibility to use the obtained 3D model in finite element analysis, to investigate information on the distribution of the internal forces, displacements, and damage.

Building reuse is a strategy that has been relatively overlooked, even though past research has begun to highlight its benefits in reducing the negative environmental impact of the construction industry. Future research in the field of geodesy and civil engineering should bring improvements and simplifications to the processing of LiDAR data, so that deconstruction and reuse projects become more efficient, contributing to a significant reduction in waste from building demolitions, extraction of raw materials, and greenhouse gas emissions.

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