

## Article

# The Integration of Geospatial Data for the BIM-Based Inventory of a Skatepark—A Case Study

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**Abstract:** Sports facilities encompass diverse spaces tailored to various sports disciplines, each characterized by unique shapes and sizes. Skateparks, renowned for their avant-garde designs, are meticulously crafted to exude distinctiveness, featuring an array of constructions, surfaces, and intricate shapes. Traditional measurement methods often struggle to capture the spatial, structural, and architectural diversity of these facilities. Constructing 3D models, particularly with Building Information Modeling (BIM) technology, faces inherent challenges due to the complex and individualistic nature of skateparks. The crux lies in acquiring credible and comprehensive spatial and construction-related information. Geospatial data emerges as a viable solution, effectively addressing the skatepark's myriad forms while upholding information accuracy and reliability. By gathering, processing, and integrating Terrestrial Laser Scanning and drone-based photogrammetry point cloud data, a precise spatial foundation is established for BIM model generation. Leveraging the integrated point cloud and photographic data aids in identifying elements and construction materials, facilitating the creation of detailed technical documentation and life-like visualizations. This not only supports condition assessment and maintenance planning, but also assists in strategically planning facility expansions, renovations, or component replacements. Moreover, BIM technology streamlines facility information management by preserving vital object-related data in a structured database, enhancing overall efficiency and effectiveness.

**Keywords:** BIM; UAV-based photogrammetry; TLS; data integration; point cloud; inventory of sports facilities



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## 1. Introduction

Sports facilities are spaces or infrastructure designed and intended for various sports disciplines. These are specially equipped areas and complexes where training, competitions, and other sporting events take place. Depending on the type of activity, these facilities can vary in form, size, and structural specificity, tailored to the requirements of a given sport [1].

The inventory of sports facilities is a process of precise measurement and documentation of their geometry and technical condition, which is essential for the management, modernization, and maintenance of infrastructure. It enables the assessment of structural stability, the detection of deviations from design standards, and the planning of maintenance actions. The collected data are used to generate detailed technical documentation, enable the digital archiving of facilities, and support decision-making regarding their operation and development [2]. The inventory of sports facilities can be enhanced by modern

digital technologies, such as virtual reality (VR) and 3D reconstruction, which allow for the accurate representation of spaces and sports infrastructure elements. The use of digital reconstruction methods enables detailed documentation of both historical and contemporary sports facilities, preserving their architectural and functional features. Virtual models allow for the interactive exploration of spaces, supporting technical analyses, maintenance processes, and modernization planning. These technologies enable not only the archiving of sports facilities but also their presentation and promotion for educational and marketing purposes [3].

While traditional sports facilities, such as football fields or athletics tracks, are characterized by a repetitive and standardized layout, skateparks stand out with their unique and unconventional designs. Skateparks are specially designed spaces for enthusiasts of extreme sports, such as skateboarding, rollerblading, and BMX biking. Their construction is based on non-standard shapes and various curvatures of obstacles, making each facility distinctive. Unlike traditional sports venues, where maintaining a uniform structure ensures consistent training conditions, skateparks provide diverse technical challenges and a creative space for skill development. A typical skatepark consists of elements such as funboxes, ramps, miniramps, bowls, and handrails. They can be constructed from various materials, most commonly wood or concrete (Figure 1), which affects their durability, surface properties, and overall riding experience [4].

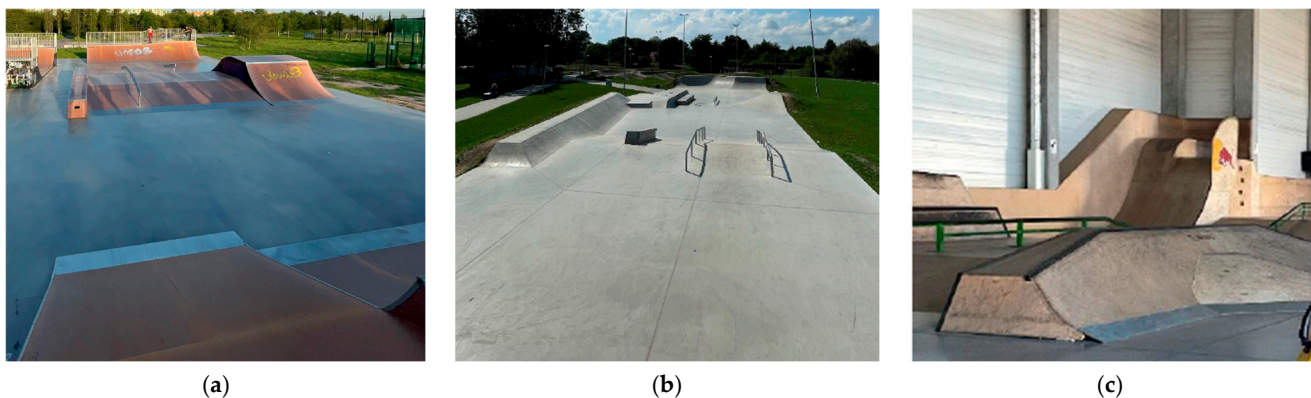


**Figure 1.** Skateparks: (a) Outdoor wooden (Poland, Wrocław), (b) outdoor concrete (Poland, Chojnow), (c) indoor wooden (Poland, Kraków); photos by Małek M.

Building Information Modeling (BIM) is an advanced method for managing spatial data, utilized not only in design and construction phases but also in operation and facility management processes [5–7]. Despite its growing popularity in the construction industry, the application of BIM in Asset and Facilities Management is still under development. BIM technology enables the creation of a digital model of an object, incorporating detailed information on its components, materials, installation systems, and operational parameters. In the context of infrastructure management, this technology allows for the monitoring of the building's lifecycle, efficient maintenance planning, and integration with data management systems [8]. Consequently, property owners and facility managers can continuously monitor the technical condition of the building and optimize its maintenance and operation [9].

Although various data sources are used to create 3D models in BIM technology, including CAD technical documentation [10], field measurement data of existing structures [11], and GIS tools and data [12], modern technologies are playing an increasingly significant role. These include the Internet of Things (IoT), using open standards [13]; Unmanned Aerial Vehicles (UAVs) [14]; and laser scanning [15].

In recent years, Scan-to-BIM technology has become an increasingly recognized and effective approach for the digital documentation of buildings [16]. The primary data sources in this process include Unmanned Aerial Vehicles (UAVs) and Terrestrial Laser Scanning (TLS). UAVs are widely utilized in geodetic and cartographic surveys and forestry engineering, as well as in technical, environmental, and industrial measurement applications [17,18]. Due to their versatility, UAVs have become one of the most frequently used data sources in BIM model generation [19]. Terrestrial Laser Scanning is a high-precision measurement method applied in inventorying and monitoring structures with complex geometries. For large-scale objects with irregular shapes, traditional techniques such as tachymetry or photogrammetry often do not provide sufficient accuracy. TLS enables rapid and precise data acquisition, allowing for the detection of structural deformations, surface displacements, and deviations from the intended design [20]. The dense point cloud obtained through TLS accurately represents the actual state of the object to an accuracy of a few millimeters. These data can then be processed into detailed numerical models, facilitating spatial and geometric analyses [21–23].

The Scan-to-BIM methodology is also applied in the inventorying of sports facilities, where data acquired primarily from TLS and UAV-based photogrammetry is converted into precise 3D models. This approach facilitates efficient data collection, reduces measurement errors, and improves the overall quality of inventory data [24]. A multi-source data integration approach is increasingly being implemented in inventorying and modeling processes, enabling the generation of comprehensive spatial datasets. The combination of different measurement technologies overcomes the limitations of individual methods and ensures a more accurate representation of an object's geometry and structure [25]. In BIM, the integration of UAV and TLS data is commonly used due to their complementary nature [26]. TLS ensures the accurate representation of building geometry and structural details [27], while UAV photogrammetry provides additional data from difficult-to-access areas, such as roofs and the upper parts of facades [28]. These datasets are processed into a point cloud, which serves as the foundation for creating a digital BIM model of the object. The final outcome of the Scan-to-BIM process is a high-accuracy 3D model, which can be used for geometry analysis, modernization planning, infrastructure management, and technical documentation [24].

In the context of utilizing BIM models for facility (or complex) management, not only the geometry of the model but also the Level of Detail (LOD) and Level of Information (LOI) play a crucial role [29]. Properly defining these levels allows for precise building lifecycle management, the optimization of maintenance processes, and effective integration with data management systems [30]. Research indicates that LOD and LOI are essential in Building Information Modeling, enabling more efficient environmental assessment and better planning of operational activities [31,32].

The objective of this study is to analyze the integration of geospatial data acquired through Terrestrial Laser Scanning and UAV-based photogrammetry for the inventory and management of sports facilities using BIM technology. The main goal is to assess the effectiveness of TLS-UAV data synergy in representing complex and non-standard skatepark structures, which pose challenges for traditional measurement and spatial modeling methods. The research focuses on evaluating the accuracy, completeness, and practical applications of such integration to enhance the reliability and efficiency of 3D model generation in BIM technology. Unlike traditional sports facilities with standardized layouts, skateparks feature highly irregular and non-uniform geometries. This makes them an ideal case for testing the effectiveness of TLS and UAV-based photogrammetry in BIM.

Despite the growing adoption of TLS and UAV-based photogrammetry in BIM, research on sports facility inventorying remains limited. A literature review revealed that

studies focusing on the precise documentation of such objects, particularly those with complex geometries like skateparks, are virtually non-existent. The lack of widely available research on the integration of TLS and UAV data for skatepark inventories within BIM technology highlights a significant gap in the field. This study aims to address this issue by proposing a comprehensive, high-precision methodology for capturing and modeling such unique structures. By addressing this research gap, we provide a replicable methodology that can serve as a reference for future studies and practical applications in documenting and managing non-standard sports facilities with BIM technology.

This article consists of five main sections. The first section presents various methods and sources of geospatial data, such as TLS and UAV photogrammetry, used to create precise and comprehensive databases (point clouds) for the inventory of sports facilities. The next section describes the process of acquiring, processing, and integrating these data, addressing key challenges related to ensuring the consistency and completeness of the information about the objects. The third section discusses 3D model generation methods in BIM technology and the practical application of integrated data for creating, verifying, and updating BIM models of skateparks. The fourth section focuses on analyzing the impact of multi-platform data integration on the quality of inventory and sports facility management. The final section presents our conclusions, emphasizing the importance of integrating data from various sources for future research and the development of BIM technology in inventorying non-standard, unique, and complex sports facility structures.

## 2. Materials and Method

### 2.1. Research Object

The research project was conducted on the “StreetPark” sports complex [33], located in Kraków, at Siwka 28. The complex consists of an industrial hall and a brick building serving as an office space. The hall, which is the largest part of the complex, houses the skatepark (Figure 2).

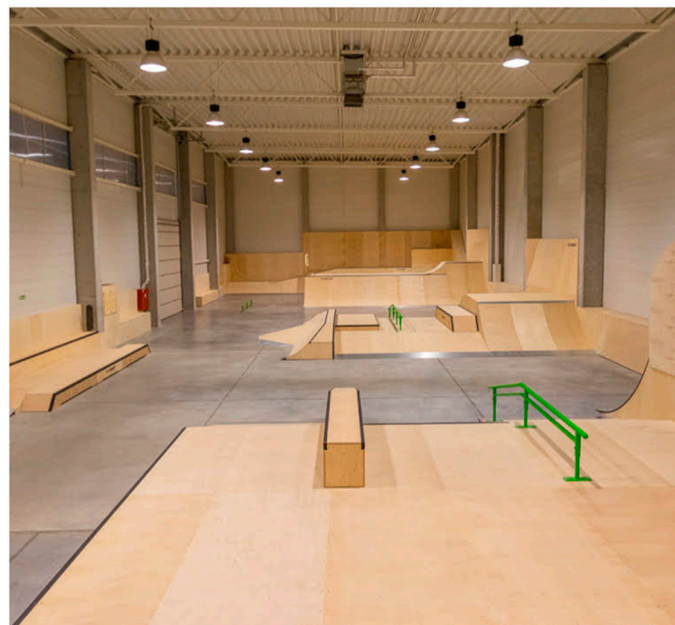


**Figure 2.** Research object—skatepark; source: [www.streetpark.pl](http://www.streetpark.pl) (accessed on 1 February 2025) [33].

A skatepark is a geometrically unconventional space designed for extreme sports such as skateboarding, BMX biking, and rollerblading. This particular skatepark was of a modular type, constructed from wood as its primary material.

The main structure, designed for sports activities, consisted of elements such as a miniramp, funbox, flybox, and pyramid. The total area of the building was approximately 1300 m<sup>2</sup>, while the built-up area of the sports facility inside the building covered around 450 m<sup>2</sup>.

## 2.2. Description of Fieldwork

For the data acquisition process aimed at BIM model development, Terrestrial Laser Scanning and Unmanned Aerial Vehicles were utilized. The TLS technology enabled the capture of spatial data for both the interior and, partially, the exterior of the building complex. The UAV was used to acquire data for hard-to-reach elements, such as the roof, roofing structures, and parts of the windows.

For the TLS measurements, the Leica ScanStation P40, produced by Leica Geosystems, was used. The P40 scanner allowed for high-density point cloud acquisition, characterized by high accuracy and rapid data collection. The scanner is based on the Time-of-Flight (ToF) distance measurement method and further enhanced by phase-based measurement techniques, enabling highly precise point positioning in space ([www.leica-geosystem.com](http://www.leica-geosystem.com) accessed on 1 February 2025) [34].

The TLS survey was conducted from 43 scanning locations. The exterior of the building was scanned from 12 stations, while the interior section, including the skatepark elements, was measured from 31 stations (Figure 3). The scanning resolution for the exterior measurement stations was 4 mm/10 m, while the interior scanning resolution varied, ranging from 4 mm/10 mm to 10 mm/10 m, depending on the distance between the scanner and the object.

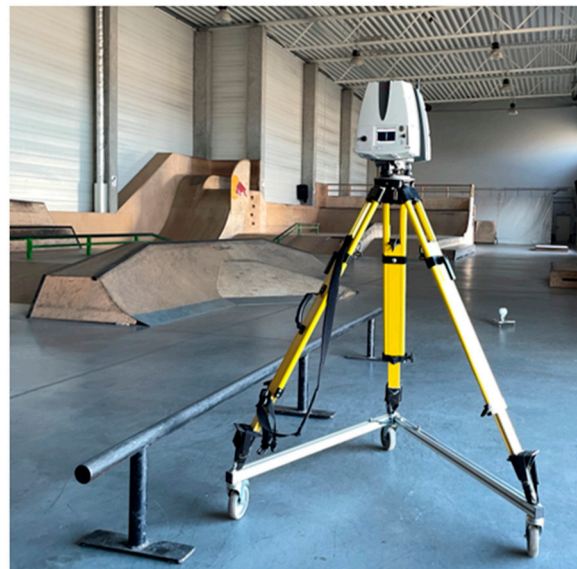


**Figure 3.** Object measurement—terrestrial laser scanner; photo by Małek M.

The photogrammetric survey using an Unmanned Aerial Vehicle was conducted with a DJI Phantom 4 PRO drone. The drone is equipped with a 20-megapixel camera with a 1-inch CMOS sensor, capable of capturing high-quality images and videos. The maximum image resolution is 5472 × 3648 pixels ([www.dji.com](http://www.dji.com) accessed on 1 February 2025) [35].

The UAV survey was carried out to acquire measurement data in the form of digital images, specifically for roof structure elements along with the side roofing sections. To ensure comprehensive data acquisition, the photographs were taken with an 80% overlap, resulting in 69 digital images recorded in RAW format.

For further processing and the subsequent integration of measurement data, reference points in the form of spheres and reference targets were strategically placed during both the TLS and UAV surveys (Figure 4).

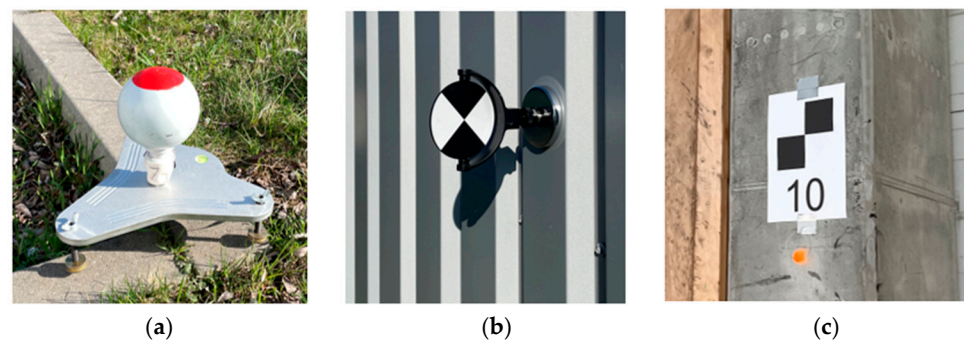


**Figure 4.** Reference points: (a) reference sphere; (b) reference target—Leica HDS; (c) reference target.

As part of the fieldwork, photographic documentation was also conducted as an element of technical material analysis, aimed at verifying and identifying building materials in the context of 3D modeling in BIM technology—serving as non-geometric information about the object. The photographs captured materials such as wood, metal, concrete, and brick (Figure 5), considering their structure, texture, and the technical condition of the facility.

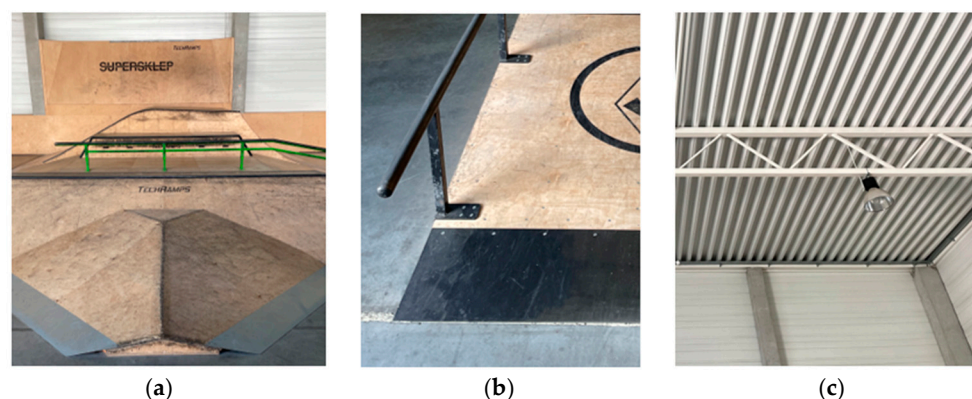


**Figure 5.** Material identification from photographs: (a) wood, (b) wood and steel, (c) metal structure.

### 2.3. Processing of Acquired Spatial Data

The data processing was divided into two stages due to the different types of acquired data. Terrestrial Laser Scanning data, in the form of point clouds, were processed using the Leica Cyclone CORE software. The registration process involved aligning measurement stations based on predefined reference points with assigned identification numbers. The calculated average alignment error for the 43 measurement stations was 0.007 m. The resulting point cloud was generated in a uniform coordinate system (Figure 6a).

The measurement data obtained using the Unmanned Aerial Vehicle, in the form of low-resolution digital images, were processed using Agisoft Metashape Professional. The workflow in Metashape included an aerotriangulation process, which was based on photogrammetric control points. The accuracy of the photogrammetric processing was 0.005 m. The final output of this process was the generation of a point cloud (Figure 6b).

The final stage of data processing involved the integration of TLS and UAV data, resulting in a merged point cloud within a uniform coordinate system (Figure 6c). The average error in data synergy at common points was 0.005 m, while the mean accuracy determined by the control points was 0.025 m.

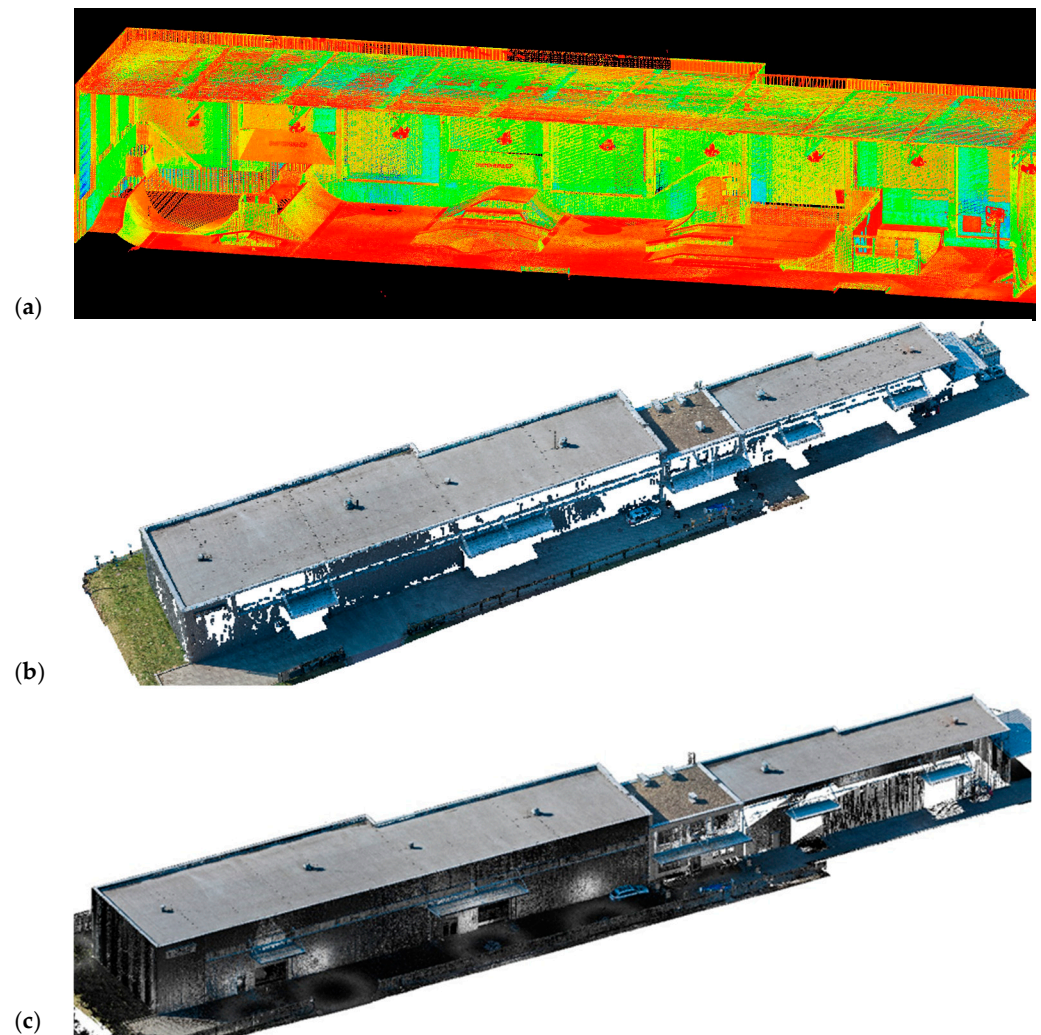


**Figure 6.** Point cloud: (a) from TLS, (b) from UAV, (c) TLS-UAV integration.

#### 2.4. Three-Dimensional Model Generation with BIM Technology

The BIM model generation for the sports complex was carried out using Autodesk Revit 2020. The modeling process in the software is presented through three-dimensional models and the creation of databases containing descriptive information for the BIM model. The workflow is based on parametric modeling, which involves defining parameters for each element.

A significant part of BIM consists of inserting predefined elements with simple geometry, which are stored in appropriate families. A family consists of geometry (shape) and parameters that control dimensions, material properties, and other characteristics of the elements. In the process of BIM model generation, custom elements were also created when necessary. The research object features an external metal covering in a trapezoidal shape (Figure 7). To achieve the most accurate representation of the facility, the cladding was modeled using a custom-built panel family and by creating a wall using a curtain wall system.

One of the stages of modeling was the construction of the load-bearing structure (Figure 8), which is mounted on two opposing structural columns. During the modeling of the structure, BIM beam families were used. The structure consisted of five different beam sizes:  $50 \times 50$  mm,  $80 \times 80$  mm,  $100 \times 100$  mm,  $120 \times 120$  mm, and  $150 \times 150$  mm. The inserted beams were aligned and snapped together, creating an accurate representation of the entire steel structure based on the point cloud.

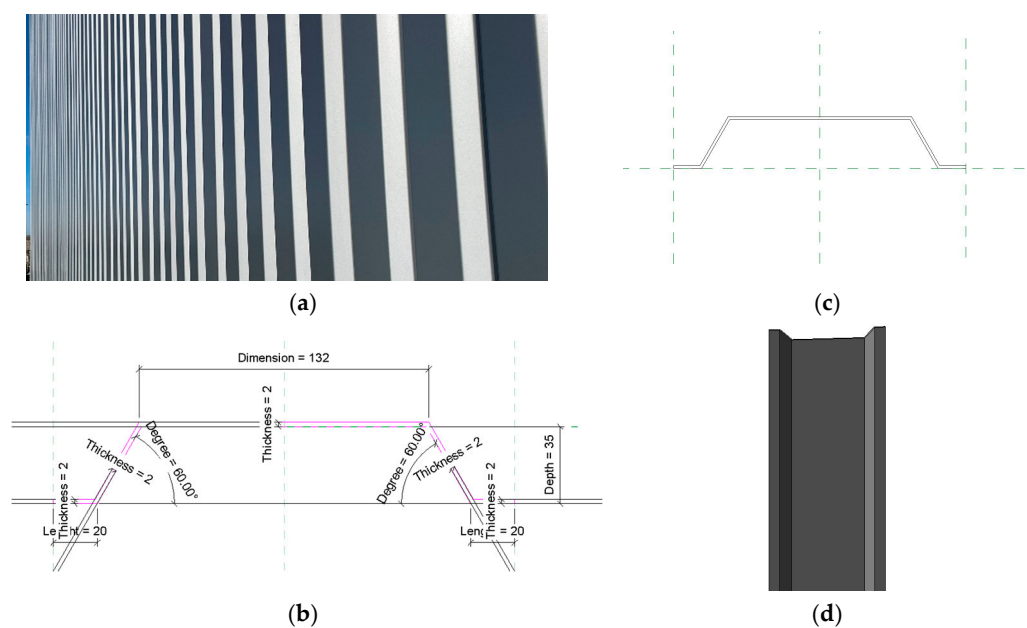


**Figure 7.** BIM family creation for structural element: (a) trapezoidal covering—photograph; (b) object geometry construction; (c) cross-section; (d) BIM model.

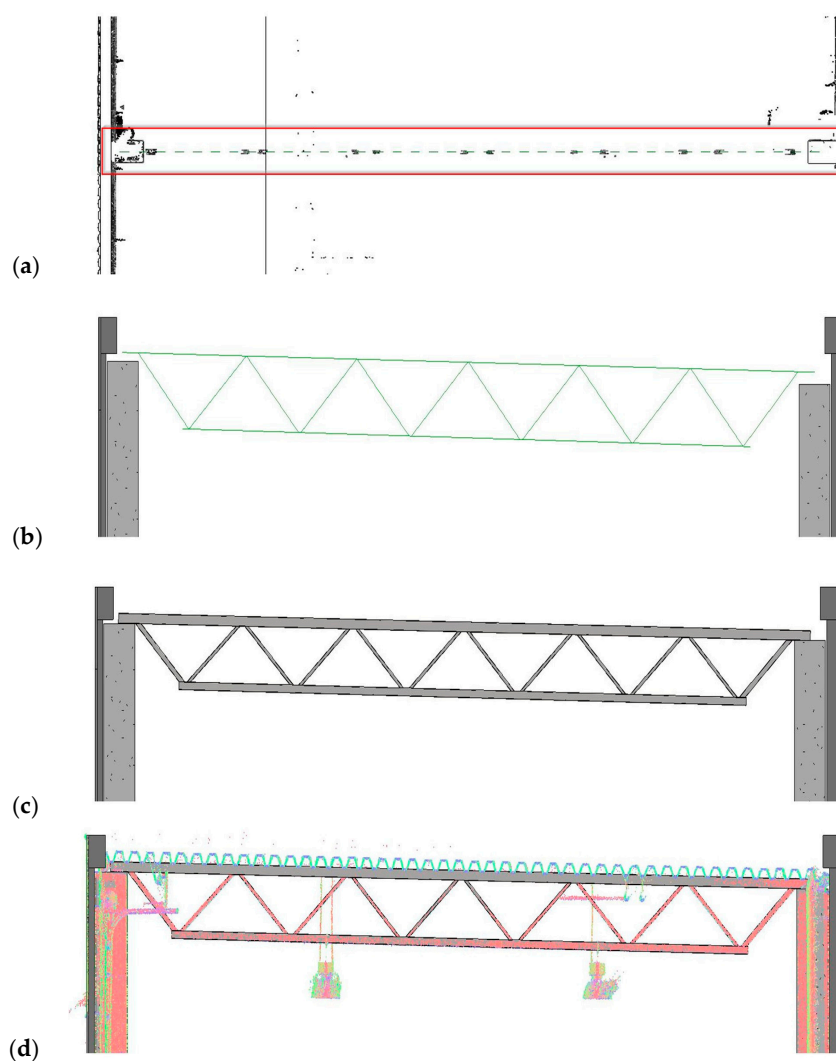


**Figure 8.** Structural modeling: (a) reference plane with location in point cloud, (b) model lines, (c) model with point cloud, (d) BIM model.

All the elements of the facility were modeled following the adopted methodology. For the finishing of the elements, publicly available BIM model families from the BimObject.com platform ([www.bimobject.com](http://www.bimobject.com) accessed on 2 February 2025) [36] were used.

#### Skatepark Model Generation—BIM

One of the most important elements of Building Information Modeling (BIM) inventories is the sports facility itself, specifically the skatepark. The skatepark consists of a diverse and unique structure with complex geometry. Due to the inability to generate a parametric model, solid modeling and the local model insertion technique were used. For each skatepark segment, an individual local model or solid form was created (Figure 9).

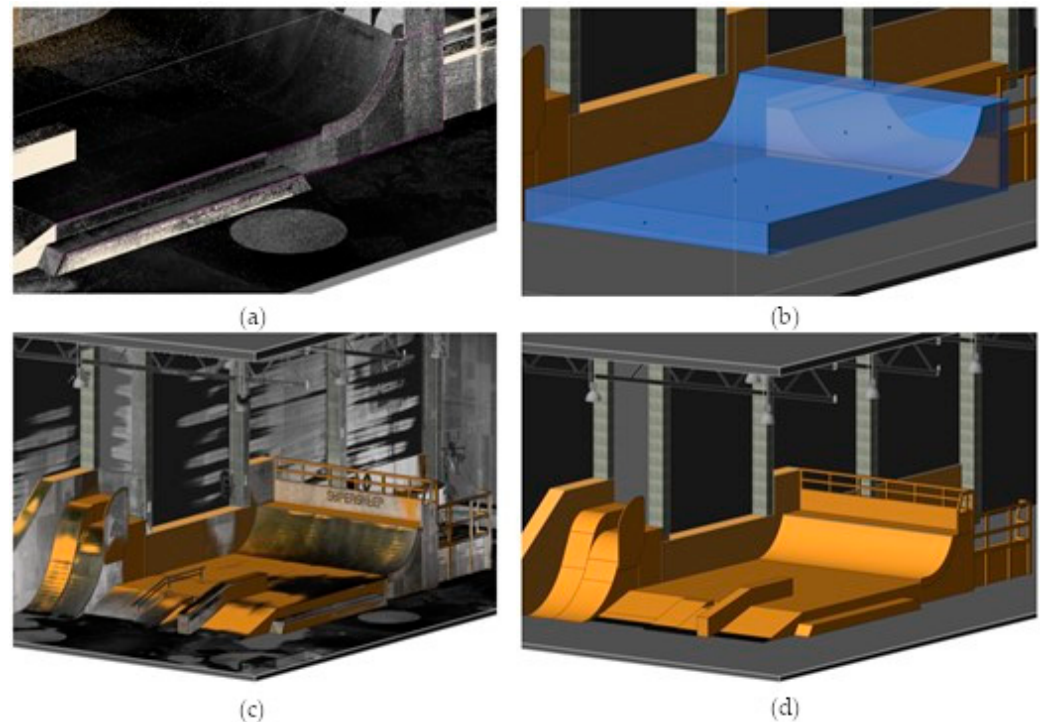


**Figure 9.** Skatepark model generation: (a) profile on point cloud, (b) element extrusion, (c) model with point cloud, (d) BIM model.

During the modeling process, reference plane surfaces were generated to facilitate the creation of individual elements. The resulting solid model demonstrates that it is possible to develop BIM elements with unconventional geometry using a point cloud from TLS as a base.

Sections containing pipe-like elements were modeled using the *Sweep Along Path* tool. This tool works by defining a path along which a pre-prepared profile is extruded. The path can be designated by selecting the edges of created models or by drawing a reference model line that serves as a guide for the extrusion. The profile of the extrusion can be created as any closed shape.

In the generated model, the skatepark's piping elements were modeled with a circular profiles of 50 mm and 40 mm in diameter. The extrusion path was drawn using a model line along the central axis of the pipe (Figure 10).

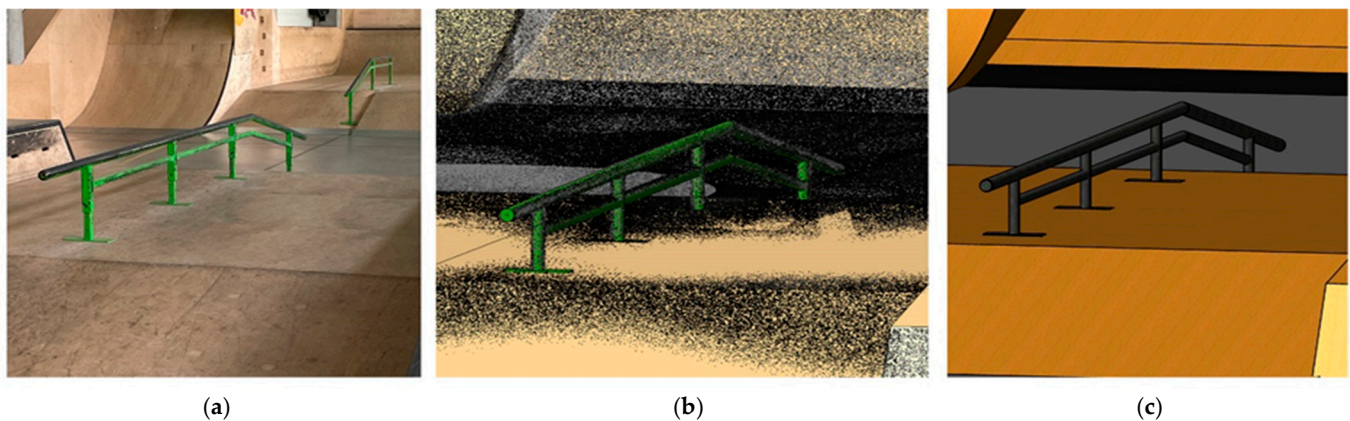


**Figure 10.** Handrail model: (a) object photograph, (b) model with point cloud, (c) BIM model.

The modeling of the sports facility was not conducted through parametric modeling but rather solid modeling, which allowed for the creation of objects with unconventional and unique shapes. The BIM inventory enabled the approximation of the built-up area of skatepark elements, the assessment of the facility's technical condition, and the visual representation of the object (Figure 11).

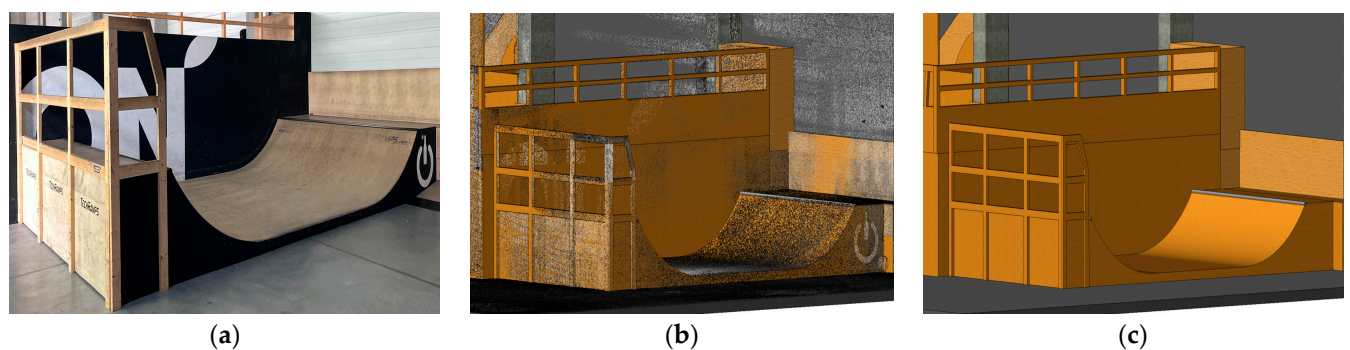


**Figure 11.** Skatepark model: (a) photograph of the object (b) model with point cloud, (c) skatepark model.

### 3. Results

#### 3.1. BIM Model

As part of the conducted research, an advanced BIM model was developed for a sports complex, including a sports hall and a skatepark. The modeling process was adapted to the specificity and complexity of individual facility elements, utilizing various techniques to achieve precise and functional representation. Parametric modeling was applied to elements with regular geometry, such as walls, roofs, load-bearing structures, stairs, and columns. This method allows for defining dependencies and parameters, enabling easy modifications and project optimization in the early design stages. As a result, it was possible to efficiently test different design variants and ensure close collaboration between architects and engineers, which is crucial in modern inventory processes.

For the skatepark, characterized by non-standard and complex geometry, solid modeling and the Model In-Place technique were used. Solid modeling allows for the creation of complex spatial forms that are difficult to achieve using traditional methods. The Model In-Place technique enables the direct creation of unique components within the project environment, making it particularly useful for designing elements with irregular shapes. The developed BIM model integrates all these elements, ensuring a comprehensive and cohesive representation of the entire sports facility (Figure 12). By applying appropriate

modeling methods, this model serves as a reliable foundation for further analyses and the operational use of the facility.

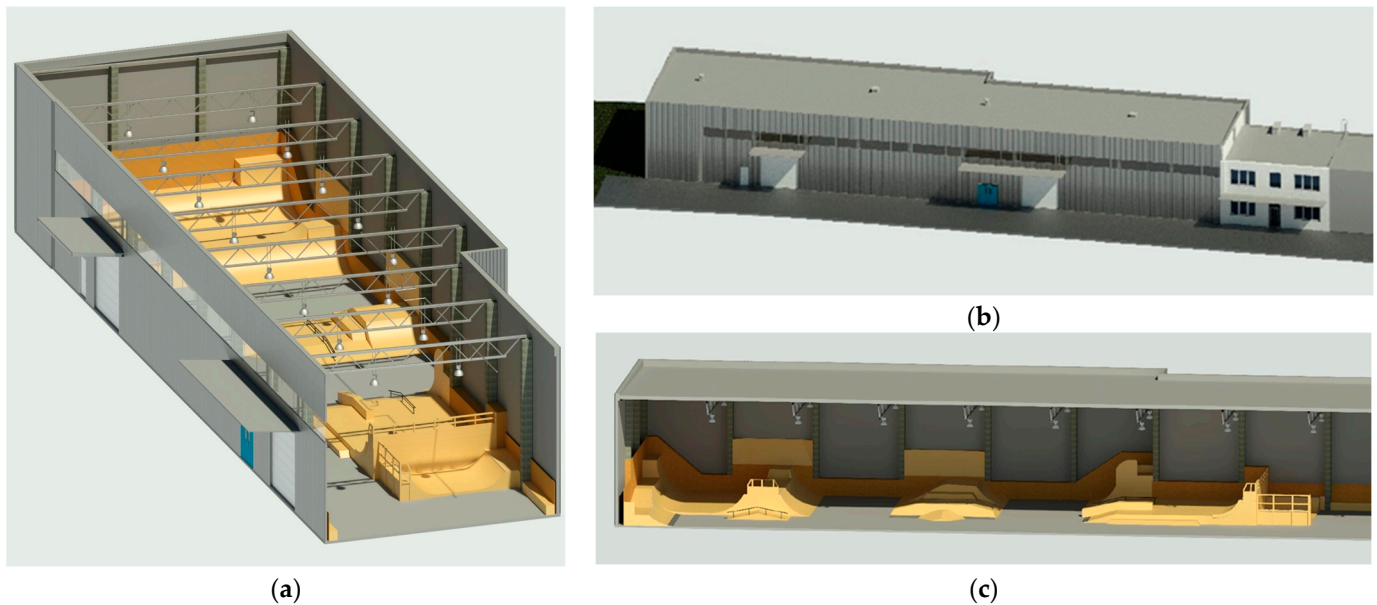


**Figure 12.** BIM model of facility: (a) skatepark view, (b) exterior view, (c) building cross-section.

### 3.2. Documentation Based on the BIM Model

For the sports complex containing a skatepark, documentation based on the BIM model can include a precise representation of the geometry of obstacles, such as ramps, grindboxes, and handrails, along with detailed information on their dimensions, materials, and assembly methods. The BIM model also enables documentation of the skatepark's surface characteristics, including the type of concrete, its texture, and drainage considerations.

Additionally, with an integrated database, the model can store data on dynamic loads that may occur during use, allowing for the structural strength analysis of individual elements. As a result, BIM documentation becomes an indispensable tool not only in the design phase but also in future facility management. The BIM model serves not only as a reliable and comprehensive tool for generating technical documentation but also as a data source for its execution (Figure 13).

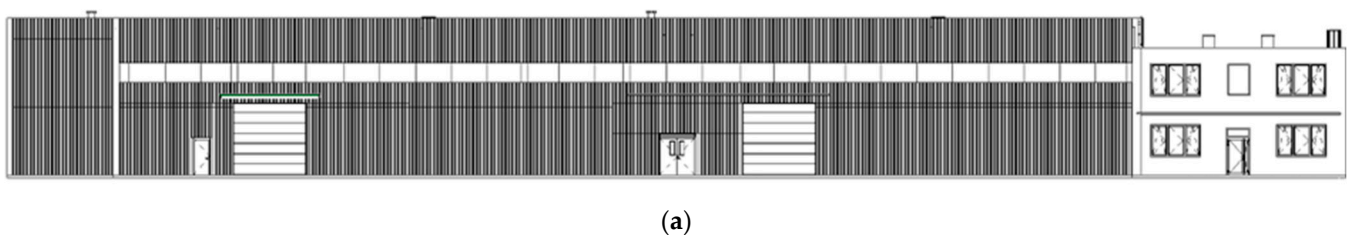


**Figure 13.** Cont.

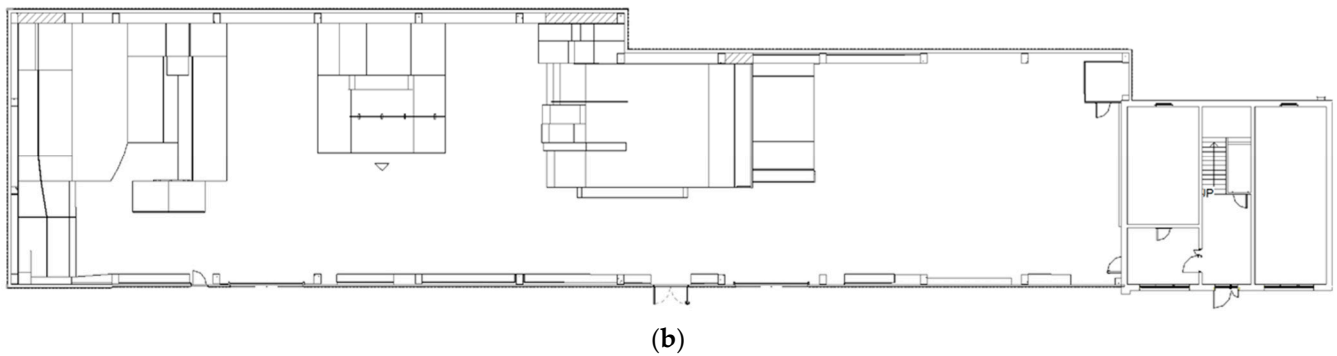


**Figure 13.** Technical documentation: (a) south elevation; (b) ground floor plan.

### 3.3. Object Visualization

The 3D model created with BIM technology serves both a representative and visual function. The visualization of the object was created using Lumion software [<https://lumion.com/>, accessed on 13 April 2025] (Figure 14), which enables the generation of realistic renders and animations of construction projects in a short time. Lumion is a widely used 3D visualization software that integrates directly with BIM models, offering advanced visual features for easy project presentation. Through Lumion, BIM models containing detailed data on structures, materials, and spatial arrangements can be transformed into realistic visualizations, providing an accurate representation of the actual object.

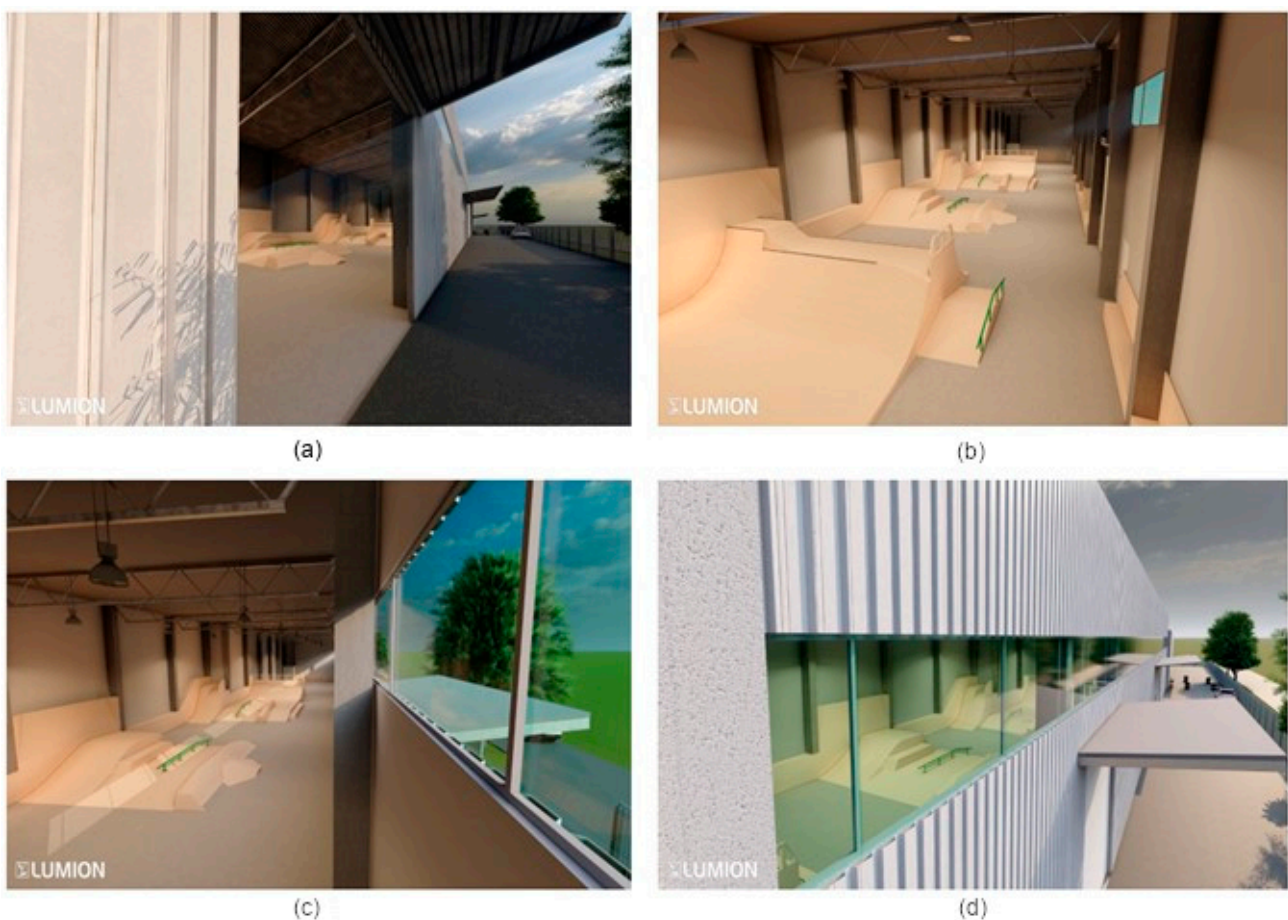


**Figure 14.** Realistic visualizations of the sports complex: (a) a view of the sports hall equipment; (b) a view of the skatepark; (c) the interior of the building; (d) the exterior part of the facility.

The visualization process allows for the detailed representation of elements such as natural and artificial lighting, shadows, surface textures, and environmental components (e.g., greenery, water, roads), significantly enhancing the quality of the project presentation. Visualizations and animations illustrate how users will navigate through the facility, which is particularly valuable for public spaces such as skateparks. These visualizations help stakeholders to better understand the project concept, benefiting both investors and future users of the facility. This presentation method offers a wide range of visual effects, enabling the realistic depiction of various atmospheric conditions, such as rain, snow, fog, and changing times of day. As a result, the visualizations not only showcase the facility's appearance at a specific moment but also simulate its operation under different conditions. These visualizations allow for better project assessment in terms of aesthetics and functionality, which is crucial in decision-making processes.

The results of the visualization process are extremely valuable for communication among project stakeholders. With realistic renders and animations, it is possible to quickly and clearly present the project, supporting concept approval processes and minimizing the risk of misinterpretation. Additionally, BIM visualizations play a significant role in marketing, aiding in project promotion even before its realization ([www.lumion.com](http://www.lumion.com) accessed on 14 December 2024) [37].

#### 4. Discussion

Based on the integrated and comprehensive spatial data in the form of point clouds from TLS and the UAV, a BIM model at LoD level 3 could be generated for the entire facility, including the sports complex/skatepark. Along with the 3D model from the BIM technology, a spatial database for the object was also created. Thanks to this, the complete spatial data, architectural details, structural elements, and intricate components of the skatepark are accurately modeled. Based on the three-dimensional representation of the facility, technical documentation can be created in the form of elevation drawings for each exterior wall, cross-section, and floor plan for the entire sports complex. Additionally, a realistic visualization of the object can be generated using software such as Revit or Lumion.

Undoubtedly, Terrestrial Laser Scanning is an effective method for the inventory of sports facilities, enabling the precise reproduction of the facility's geometry. TLS facilitates the detection of structural deviations, the monitoring of technical conditions, and the creation of accurate digital models, significantly improving the management and modernization of sports infrastructure [2]. Another crucial aspect is the ability to capture any shape and geometry of the object using TLS point clouds, which is particularly important for non-standard structural considerations, such as skateparks. Moreover, the integration of TLS and UAV-based photogrammetry enables the creation of detailed and comprehensive spatial information, essential for BIM model development, including sports complexes. The Scan-to-BIM method allows for the accurate representation of the facility's geometry, particularly for complex and irregular structures like skateparks. The combination of TLS and UAV point clouds enhances modeling accuracy, reducing the potential errors arising from the limitations of single-measurement technologies [38]. To improve the accuracy of material and structural element identification, on-site photographs were also utilized to verify and supplement the geometric data. Photographs can assist in the BIM process by identifying the textures and materials of individual elements [15,28]. Additionally, technical documentation in the form of floor plans, cross-sections, and elevations was generated based on the developed BIM model. Such documentation not only serves as a reference for facility management but also supports decision-making processes related to future modifications and maintenance strategies. Kulig et al. (2021) [39] presented a similar application of BIM in modern architectural inventories, demonstrating the ability to generate precise

2D drawings based on 3D models. The obtained results confirm that TLS-UAV integration is an effective tool for the precise inventory of sports facilities, allowing for the accurate reproduction of their geometry and facilitating infrastructure management.

In the cases studied by Haddack (2018) [9], the use of BIM in asset management demonstrated numerous benefits, including reduced operating costs, increased operational efficiency, and improved infrastructure control. This technology also enables better organization and information flow among all stakeholders involved in the facility management process, leading to enhanced decision-making processes. A BIM model can generate diverse documentation that supports the design, construction, and later, management of the facility. In the case of buildings, the BIM model can be used to generate architectural, structural, installation, and execution documentation, containing detailed plans, cross-sections, elevations, and information on the materials, dimensions, and technical properties of individual elements. Furthermore, the model can include data on installation systems (electrical, plumbing, ventilation), facilitating future maintenance and diagnostics [40–42].

The integration of TLS and UAV photogrammetry enables highly precise and comprehensive spatial documentation, which is essential for BIM-based modeling of sports complexes, particularly those with unconventional geometries like skateparks. While TLS is widely used for capturing precise geometries, UAV-based photogrammetry enhances data acquisition for hard-to-reach structural elements, such as roofs, ramps, and overhead components. This combination compensates for the individual limitations of each method and ensures a high level of data accuracy. In this study, additional on-site photographs were also incorporated to further refine material classification and structural analysis, improving the overall accuracy of the BIM model. Despite the increasing adoption of TLS and UAV technologies in architectural and engineering documentation, their application to non-standard sports facilities remains largely unexplored. Unlike conventional buildings with predictable and well-defined structures, skateparks present complex, curved, and highly irregular forms, making their accurate representation in BIM significantly more challenging. A literature review has shown that, while various studies address the use of TLS-UAV for standard infrastructure, there is a major gap in research concerning the precise inventory of geometrically complex sports facilities, such as skateparks, within the BIM framework.

This study directly addresses this research gap by proposing a structured methodology that enables the high-precision, complete, and efficient modeling of non-standard sports structures. The proposed approach not only enhances the accuracy of geometric documentation but also improves workflow efficiency in facility management, safety assessments, and long-term maintenance planning within a BIM-based environment. Our findings suggest that the integration of TLS and UAV data can be standardized as a replicable framework for documenting other geometrically complex structures, beyond skateparks. Compared to the methodologies presented in previously cited studies [1,15,26,38], which often focus on conventional architectural structures or regular sports facilities using either TLS or UAV-based photogrammetry alone, the approach proposed in this study integrates both data sources. This dual-acquisition method enabled full spatial coverage and high geometric fidelity, particularly valuable for capturing the non-standard, curved, and custom-built forms typical of skateparks. While other studies primarily addressed buildings with well-defined geometries, our work demonstrates the feasibility of applying BIM techniques to irregular and complex outdoor facilities, where conventional methods may not ensure sufficient accuracy or completeness. One of the main challenges encountered in this study was the manual processing of point cloud data and its adaptation to BIM. Due to the irregular and non-parametric nature of skatepark elements, the automatic conversion of the TLS-UAV point cloud into BIM components remains a complex task. While solid modeling

and the manual segmentation of the point cloud allowed for the precise representation of curved structures, this process was time-consuming and required significant expert input. Future research could focus on developing and optimizing object detection algorithms and automated modeling techniques to streamline the transformation of point clouds into structured BIM components. This would improve efficiency and enable the application of this methodology to larger datasets and other non-standard sports facilities.

## 5. Conclusions

The generated BIM model and the conducted analysis of results confirmed the feasibility of effectively integrating data obtained from Terrestrial Laser Scanning and Unmanned Aerial Vehicles to create a precise model of a sports facility. The acquired, processed, and integrated point clouds provided comprehensive spatial information essential for modeling the skatepark. The TLS and UAV enabled the detailed inventory of an object with complex and irregular geometry, delivering accurate data on both its structural framework and architectural elements. The development of high-quality BIM spatial models facilitates not only a more efficient inventory process but also supports facility management, modernization planning, and safety analysis. Additionally, BIM technology ensures structured storage of building information, enhancing operational efficiency and optimizing maintenance and development processes.

The integration process demonstrated a high level of accuracy in aligning TLS and UAV point clouds, with a fitting error of 0.005 m and an average point cloud deviation of 0.025 m. These parameters provided a complete and precise spatial dataset, enabling the generation of an accurate 3D representation of the object in BIM technology. The inventory process resulted in a model with an accuracy of 3–4 cm compared to real-world measurements, which directly corresponds to the average accuracy of the integrated TLS-UAV point cloud (the mean accuracy determined by control points was 0.025 m), as presented in Section 2.3 of the manuscript. The obtained data also allowed for the creation of a LOD3-level model, faithfully reproducing both the architectural details and structural elements of the skatepark, according to the guidelines provided by Bednarczyk et al. (2020) [29].

Building Information Modeling (BIM) was used to generate detailed spatial documentation and develop a virtual representation of the object with realistic visualization. The model was constructed using point clouds from TLS and a UAV, supplemented by photographic documentation which was utilized for the material identification and texture mapping of individual elements. Incorporating textures based on photographic data further enhanced the level of detail and realism of the inventoried object.

Future research directions may focus on the automation of TLS-UAV data processing, reducing manual work in point cloud classification and BIM model conversion. Additionally, the implementation of AI-driven object recognition algorithms could further streamline the identification of construction elements within the model. Expanding this methodology to other sports facilities, such as bouldering walls, urban climbing structures, or extreme sports parks, could help validate its adaptability and effectiveness across a broader range of architectural typologies.

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## Abbreviations

The following abbreviations are used in this manuscript:

|     |                               |
|-----|-------------------------------|
| UAV | Unmanned Aerial Vehicle       |
| TLS | Terrestrial Laser Scanning    |
| BIM | Building Information Modeling |
| GCP | Ground Control Point          |

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