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Digital representation strategies to reveal the cultural significance of Canadian Post-war Architecture

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Abstract

Considering the growing attention on the architecture of the second half of the 20th century and the rising issue of its documentation and interpretation, an operative methodology is presented to support knowledge production activities and conservation. Post-war architectural lexicon materialized spatial narratives from the ’50s up to the present. These spatial narratives can be visualized through analogic or digital drawing to gain in-depth knowledge and support interpretation and analysis.

The proposed documentation strategy emphasizes the opportunities for digital representation in revealing and interpreting the post-war architectural lexicon. The potential advantages of employing digital survey and representation techniques for information visualization and management are being discussed in relation to the Strutt House, designed by Canadian architect James W. Strutt between 1951 and 1957.

The study encompassed a thorough examination of primary and secondary sources, a comprehensive survey, and the experimentation with various modeling approaches in the SCAN to BIM procedure, with the final aim of comprehending the significance, purpose, and cultural value of documented characteristics. The adopted approach exploits the opportunities of geometric 3D modeling to visualize complex structures and semantic enrichment in an HBIM environment to support the knowledge, interpretation, and preservation of this outstanding example of Canadian Post-war architecture.

Keywords: Digital documentation, Visualization, HBIM, Canadian architecture, 3D modeling

1. Introduction

The second half of the 20th century generated unprecedented typologies and an incredible variety of architectural languages. Heterogeneous examples range from the Sydney Opera House by Jørn Utzon to the architectures by Lissoni, Quaroni, Passanti, Giò Ponti, Portoghesi, Rossi, Bottoni in Italy or to the building by Victor A. Lundy, Paolo Soleri, Frank Gehry and several others in the States. However, the role of this architectural production as a representative example of collective memory has only been recognized and studied recently. Its protection poses the question of the values of recent memory whose survival depends on two elements: protection by the law and the sensitivity of the designers called to intervene[1].

Recent policies grounded on an ecological and economic vision put this tangible and intangible heritage even more at risk. These risks include several types of building interventions, such as the loss of constructive details and solutions (once thought consistently with the quality and specificity of the single materials); the adoption of invasive recladding systems that deeply alters facades and their architectural language; the variation of windows’ profile, the replacement of entire facades; the addition of volumes and other kinds of retrofitting intervention (such as the installation of photovoltaic systems) that distort buildings’ image.

Unfortunately, a summary redevelopment and retrofitting of the built heritage, from 1945 until nowadays, has already shown its results. A study conducted in 2018 about the outcomes of the energy requalification process resulting from the low carbon policy showed the reduction of the architectural quality and the negative social implications of this kind of redevelopment [2]. In this framework, several researchers, such as Franz Graf, are looking for new and more adherent models for the redevelopment project of residential buildings in the second half of the 20th century that require accurate knowledge of pre-existing structures.

Considering this common set of problems with a worldwide dimension, the present contribution illustrates an operative methodology to support the understanding and dissemination of the defining features of architecture through digital representation tools. The proposed workflow is further implemented on a representative example of Canadian architecture built in the '50s. The article focuses on the documentation, visual understanding, and interpretation of the house architect James W. Strutt designed, exploiting the opportunities of digital representation and 3D modeling in fostering a coordinated and comprehensive knowledge base of the constructive system. The research opens several application pipelines that are illustrated and debated, paying particular attention to the replicability of the adopted approach.

The research stems from a collaboration between public and private institutions, including the Fondation Strutt Foundation (FSF), the National Capital Commission (NCC), and the Carleton Immersive Media Studio (CIMS) lab.

2. The methodology

The goal of this contribution is to propose a documentation strategy to support the transmission of knowledge about post-war architecture and the nature of its significance. The final aim is to raise awareness about the importance of conserving these architectures, store and transmit knowledge about their evolution and significance to society, and support their preservation. Considering previous concerns, an inductive approach was adopted to ensure that the developed framework is tailored to the particularities of the object under study.

The case study of the Strutt House, built in the '50s by the architect J. Strutt for his family, has been studied. Data collection activities included site visits, *in situ* studies, a literature review, and multiple interviews with a selection of specialists to verify, complete and expand the existing knowledge base. A global framework was established to guide the documentation of the case study and the definition of representation strategies to reveal the fabric's significance [3]. The proposed method can be implemented in other contexts to identify replicable strategies for disseminating knowledge about post-war architecture.

3. The significance of the case study: the Stutt House, an iconic Canadian architecture

The Strutt House is a Recognized Federal Heritage Building and a significant example of Canadian architecture located in the city of Gatineau, in the Canadian province of Québec [4] (Fig. 1). The house is one of the most iconic masterpieces of James Strutt, an influential architect in post-war Canada. One of the most outstanding qualities of this design lies in its modularity, omnipresent in all dimensions [5].

The design of the house enhances the building's structural efficiency, spatial organization, and the expression of its aesthetic qualities. Also, the expression of the building's structure through its materiality allows the visitor to perceive the intelligence and rationality of the design from all indoor and outdoor spaces. The use of experimental building materials and assemblies, the integration of technologies, and the implementation of new constructive techniques for the wooden hyperbolic paraboloids are all evidence of the architect's innovative attitude.

Fig. 1 Strutt house location and its relationship with the topography of the surrounding natural context. Processing by authors.

The Strutt House is a representative example of the architect's research on non-orthogonal and naturally structural geometries and weight efficiency ratios. Concerning Strutt's experimental attitude, his research in non-orthogonal geometries was driven by several intentions. On the one hand, he intended to offer spatial qualities that can be found in the natural environment, such as caves. He wanted to create stimulating and inspiring spaces regardless of how he worked with orthogonal compositions. Wide and narrow angles, inclined roofs, Hyperbolic paraboloids, also referred to as hypars, and other features of his Architecture give an organic dimension to his houses indeed. On the other hand, his research in geometry followed functional purposes. For instance, in the Strutt House, the Canadian architect took advantage of every single corner, optimizing the use of space. If the house spaces seem very small when looking at their square meters, the architectural qualities and the functionality of the place give the visitor the impression of a very spacious building (Fig. 2). These explorations allowed him to improve his constructions' cost-effectiveness as it optimized the use of both labor and building materials. Further, the importance of the relief and surrounding nature in the house's design and location demonstrates the architect's sensitivity to the preservation of natural landscapes and the permanent dialogue he establishes between his designs and their context. The perception of the qualities of this architecture is intimately linked to the natural beauty of the site on which it was built (Fig. 3).

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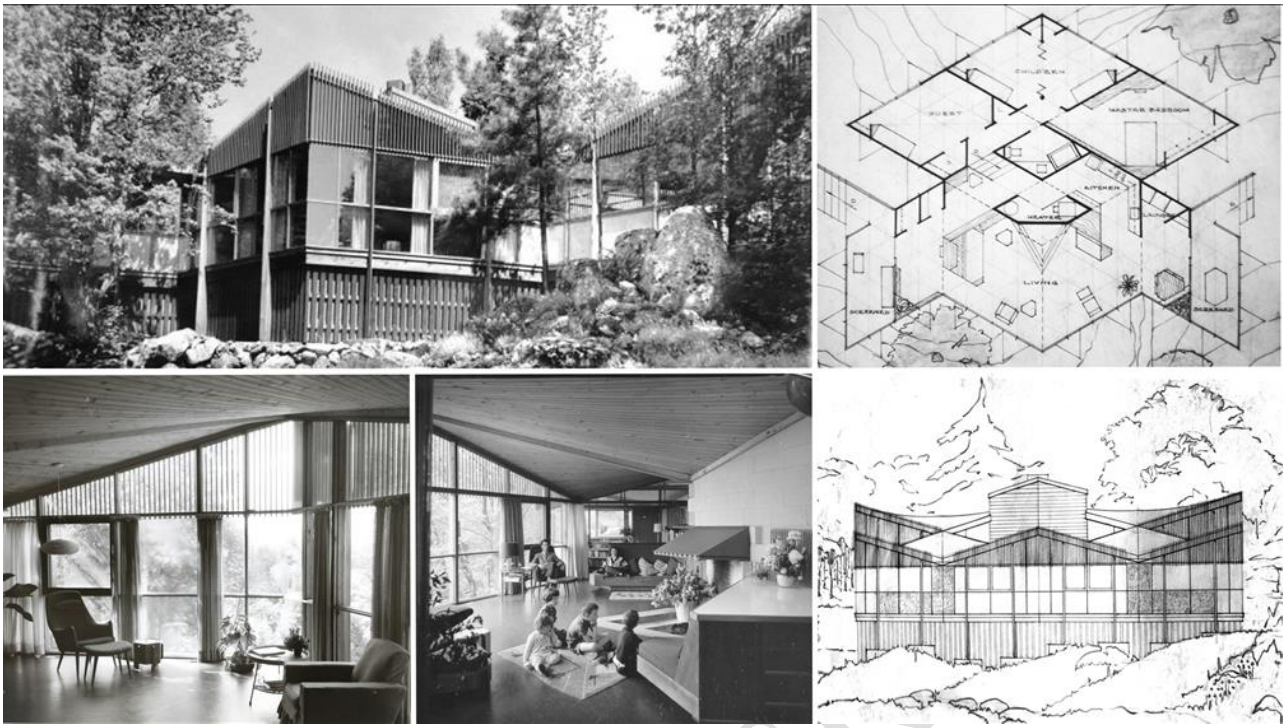

Fig. 2. The original design of the Strutt House. Source: Fondation Strutt Foundation. Image processing by authors.

Fig. 3. The relationship of the Strutt house with the surrounding context. Source: photo 3 was shot by Kristen Balogh, photo 2 by "L'Institut royal d'architecture du Canada"; image editing by the authors.

3.1 Understanding and interpreting James W. Strutt's architectural lexicon

For an in-depth understanding of the architectural language adopted in the Strutt house, a brief introduction to the personality of James W. Strutt is needed. Indeed, apart from his studies in Architecture, his experience as a pilot of the Royal Canadian Air Force during WWII strongly influenced his design. The influences of his education and training as a pilot are evident in the structure and the parsimonious quality of the aircraft frame of the Strutt House.

Additionally, during his fifty-six years of work, James W. Strutt showed particular interest and attention in exploring different aspects of architectural design such as weight-efficiency, wooden hypars, the relation between the built and surrounding nature, non-orthogonal geometries, use of wider angles than 90° and a meticulous balance between form and function [6]. He did not limit his Architecture to a single vocabulary, style, or expression. Rather, he always explored different materials and spatial configurations.

In the elaboration of the project of the house (and more generally in most of his works), James W. Strutt defined his concept from the intrinsic qualities and values of the site on one side and the requirements of a project on the other. Then, he gradually applied the most appropriate geometries that would be naturally structural, allowing economical and rational use of materials.

Concerning the influences on his architectural language, the architect was amazed by Frank Lloyd Wright's work and the architectural qualities of the Prairie Style, by Buckminster Fuller for weight-efficiency structure, and by Eduardo Catalano's experimental "Hypars". As reported by Truesdale, «*James W. Strutt […] has looked to the master architects of his time and studied what has come before to create a synthesis with, and of, his own understanding of the world around him.*» [6].

Aware of this layered and cultured architectural language, digital 2D and 3D representations supported the analysis and interpretation of the drawn and built project of James W. Strutt, outlining some of the key features of his work, including but not limited to structural concept, hyperbolic paraboloid, modularity and geometry, the latter observable, for instance, in the rhombus grid and the façade walls (Fig. 4).

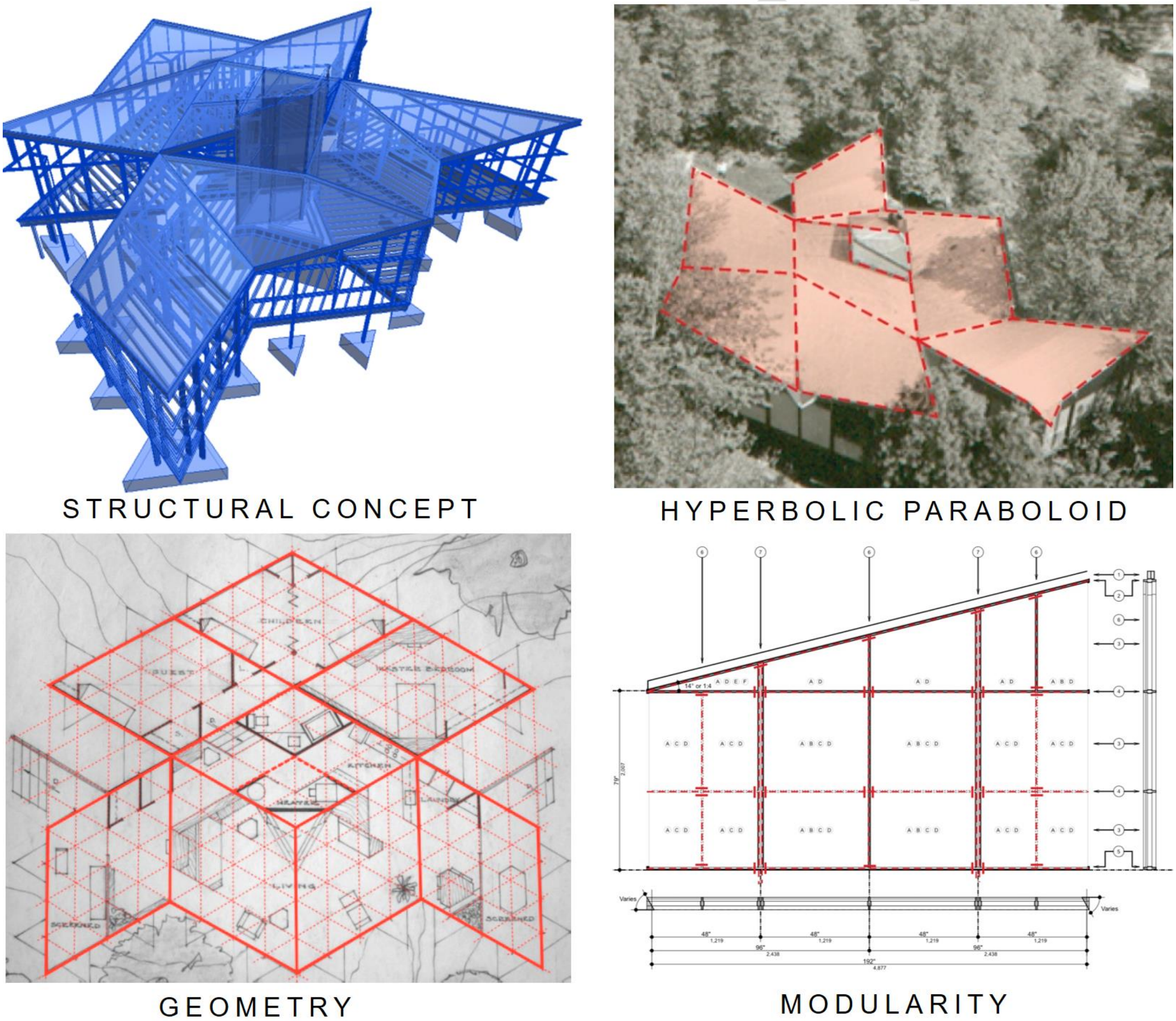

Fig. 4. Key identified features of the design of the Strutt house that have been interpreted and analyzed using digital 2D and 3D representations. Image editing by the authors.

4. Digital documentation workflows for the knowledge and interpretation of Post-war architecture: the case of Strutt house

Before elaborating on the documentation strategy, significant information about the Strutt House was first collected, analyzed, and interpreted [7]. Several types of sources were mobilized to enrich the knowledge base related to the case study [8]. The following sections describe the adopted documentation workflow (Fig. 5), including the geometric and semantic information modeling in the BIM environment [9]. Finally, a reflection on the opportunities offered by the adopted approach in terms of knowledge transmission and virtual representation is also provided [10].

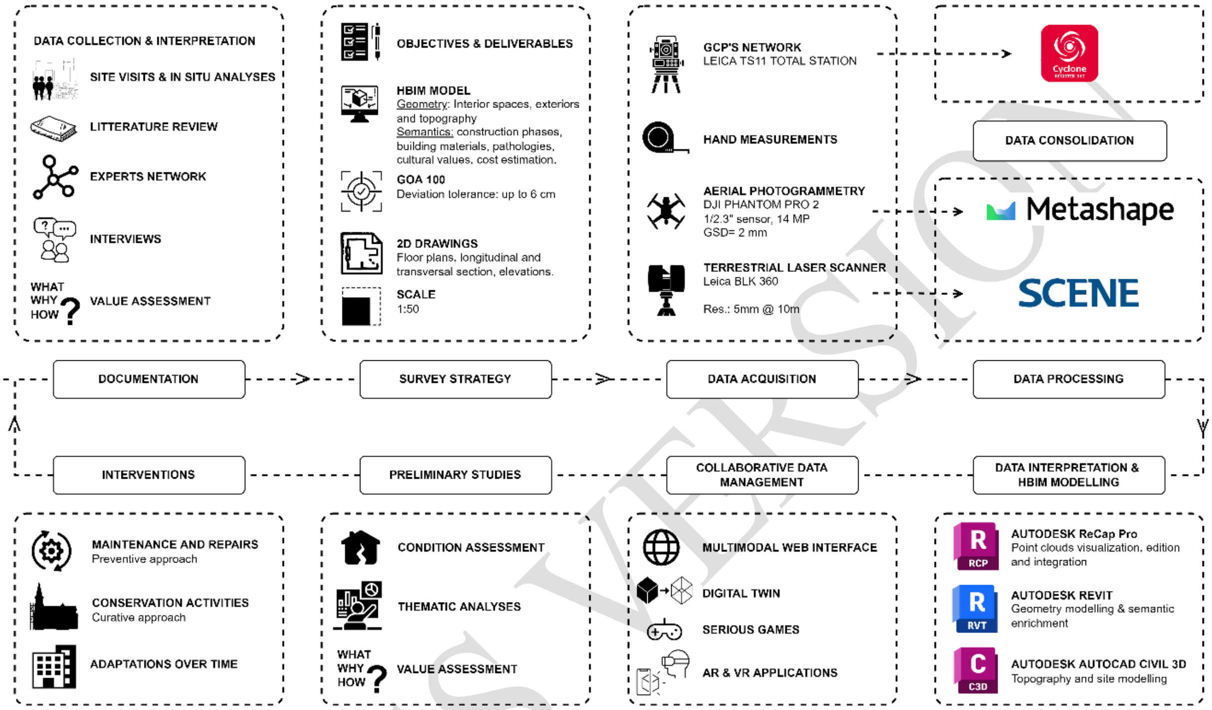

Fig. 5 The diagram displays the comprehensive method for recording, modeling, and managing data related to the case study. The survey strategy is based on key findings of the documentation phase and particularly on the most important cultural values associated with the site. The figure also depicts the documentation techniques and technology used to capture the 3D point cloud and the software to combine and consolidate individual datasets in a common coordinate system. The following step illustrates the Scan to BIM process, the collaborative management of heritage information, and the dissemination of related knowledge based on the generated HBIM models and other deliverables. Image source: authors.

4.1 The recording strategy

Considering the functional, evidentiary, associative, and sensory aspects of value related to the spatiality, functionality, materiality, and structure of the place, 3D modeling was considered the most suitable for generating virtual representations [11]. A complete point cloud of the house and its setting was captured with a coherent density to enable the 3D modeling of building components in BIM software. Multiple sensors were implemented to capture the entire point cloud. Terrestrial Laser Scanning (TLS) was used for the topography, the façades, and the indoor spaces thanks to the FARO Focus 3D X330 Laser Scanner. Individual scans were registered and combined in Scene software. Considering the importance of the hypars in the overall significance of the building, the point cloud of the roof was captured through aerial photogrammetry with the DJI Phantom 2 pro drone. The data processing was achieved in Metashape. A Ground Control Points network (GCPs) was created to facilitate the registration of individual scans in Scene and to consolidate the datasets in a single coordinate system. The coordinates of the GCPs have been acquired with Refletorless Electronic Distance Measurement (REDM) using the LEICA TS11 Total Station (TS). The result was a consolidated dense 3D point cloud with RGB data (and intensity values for TLS data) of the whole house and the hill's topography.

In addition, hand measurements had to be taken for the accurate documentation of built-in furniture and the survey of key structural elements repeated all over the building (like the 2" by 6" wooden post, for instance). The idea was to enable the comparison of on-site measurements and the captured point cloud with the blueprints of the original design. For the generation of plans, sections, and elevation, we opted for the scale 1:50, considering the absence of interior decoration

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and details. Regarding the level of accuracy of the 3D model, a grade of accuracy GOA100 [12] was adopted (consequently, the representation of geometries has a deviation tolerance of 4-6 cm).

4.2 The Scan-to-BIM process

In the Scan-to-BIM process, several workflows for geometry modeling have been considered, ranging from fully manual to more assisted-automated operations. Based on point cloud data, the manual approach implies the direct modeling of buildings components' geometry in the BIM environment as parametric objects. Repetitive elements can be modeled individually if the deviation exceeds the initial tolerance. If not, the parametric object can simply be snapped, orientated, and scaled onto the point cloud until it fits the exact object size and position. Another method lies in the use of a dedicated plug-in that creates multiple sections, either at regular intervals or targeting key geometric primitives, of a portion of the point cloud to enable more accurate modeling of object deformations [13]. It is a relevant alternative for accurate and fast 3D modeling of components. Besides, the "automated" or "assisted" modeling technique lies in the detection of building elements based on the analysis of point cloud data in third-party software, such as Edgewise, through face detection to identify horizontal (floors, slabs) or vertical (walls, doors, windows) building elements for instance. Although this approach is promising for Scan-to-BIM for very recent constructions with standardized components, modeling unique architectural works and their constitutive elements requires a more cautious approach to interpreting survey data. Indeed, it is very likely that important adaptations occurred over time, and it cannot be assumed that everything is as it seems to the eye. The usefulness of this method in this context is also to be questioned, as building elements and related data are often not documented in available libraries. Finally, another possibility is to create a solid mesh of a particular object from point cloud data in a 3D modeling solution like Rhinoceros 3D, for example, to further import it in the BIM environment and attribute it to the appropriate IFC Class.

Given the aims defined for the Strutt House's 3D model, the fully manual approach (Fig. 6) was chosen as it allowed for reaching a satisfying Level of Accuracy (LOA) while enhancing the modeling process' efficiency (Fig. 7). Regarding the topography, the terrain model was built based on point cloud data in AutoCAD Civil 3D using Kriging interpolation.

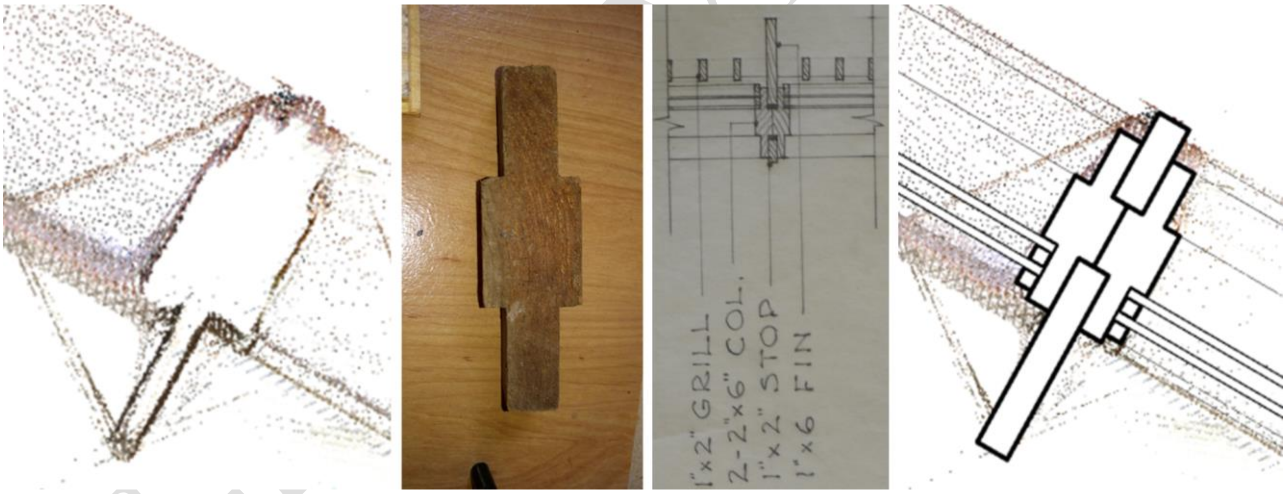

Fig. 6 Parametric objects have been created as Revit families (right) based on a comparison between hand measurements (center left), point cloud data (left), and archival documents (center right, Canada's National Archives). The significant amount of missing data for complex wooden assemblies led to using the point cloud as a base to locate, orient, and scale parametric objects. The deformations of building features were not represented as they felt under the defined deviation tolerance (4-6 cm). Image edited by the authors.

Fig. 7 This image illustrates the modeling workflow with the mapping of parametric objects onto the point cloud and the superposition of the point cloud with the HBIM model of the house (left); an overview of the final model with a section perspective showing the lower and upper level of the house (right). Image source: authors.

The semantic enrichment of the Strutt House HBIM model was achieved in the BIM environment using the object's attributes [14]. Data about the construction period of components, the pathologies, the associated cultural values, the cost estimation for conservation actions, the order of assembly and dismantling, as well as building materials have been integrated to enable performing condition assessment, thematic mapping on the 3D model, cost estimation for interventions and to evaluate the ability of the model to assist stakeholders in the execution of conservation activities.

4.3 *The opportunities of the HBIM model for interpretation and analysis*

This section explores the possibilities semantically enriched HBIM models offer to support documentation and knowledge. Among the topics explored, the ability of HBIM models to constitute a knowledge base for the archival and transmission of heritage information and to centralize diverse sources of information is questioned. Then, the potential of this approach to facilitate the understanding and interpretation of multiple aspects of post-war architecture in Canada is analyzed.

4.3.1 *HBIM as a Knowledge base*

HBIM models allow storing and classifying geometric data about features of the built heritage and related semantics and, therefore, offer the opportunity to create a digital archive for posterity [15]. In the case of the Strutt House, some information collected during the preliminary study has been associated with objects of the HBIM models. For instance, all building materials used in the construction of this building were inventoried and added to the software library with basic properties. Some experimental materials, such as the asbestos-cement panels used for the façades, no longer meet the requirements of certain standards in the construction industry. In the event of their complete or partial replacement, HBIM models preserve and centralize the necessary data to inform future stakeholders about past states of existence and give them a rapid insight into the site's evolution over time. Although the management of multiple temporal states of an object in Revit is thought to support the planning of construction sites for new buildings, this application can also be used to represent past states and, therefore, inform about the most important development phases along an object's lifecycle.

4.3.2 *Understanding & Interpretation*

Initially, the aim of implementing HBIM in the documentation approach was to create a comprehensive 3D model of the building components and their assemblies to facilitate the understanding and interpretation of complex and irregular elements. The case study of the Strutt House demonstrates HBIM's capacity to enhance the communication of architectural details, concepts, and structural designs. The combined use of 2D orthographic projections & 3D views allows the user to adapt data visualization according to his digital models and drawings expertise. Exploded views of the model in Autodesk Revit were particularly useful for explaining details of and components' assemblies (Fig. 8).

The reverse engineering process of modeling the different building features and their interrelationships in BIM software appears as a virtual construction site that enhances users' understanding of many characterizing aspects of the house contributing to its uniqueness and originality. Among other things, the implementation of this workflow allowed to reveal the functionality and role of all building assemblies, understand, and illustrate the implemented structural principles, highlight the modularity and compositional grammar of this architecture in the three dimensions, and the constant quest of the architect for rationality in all aspects despite the apparent complexity of its iconic geometric expression (Fig. 9). In addition, modeling the geometry based on point cloud data allows to highlight inconsistencies with the original design. In this case, the survey revealed an adaptation made by the architect quickly after the construction. Water infiltration issues at the house's southern side against the central core led the architect to add two trapezoidal hypars above the original roof to redirect rainwater towards the lower points of the facades' edges (Fig. 10).

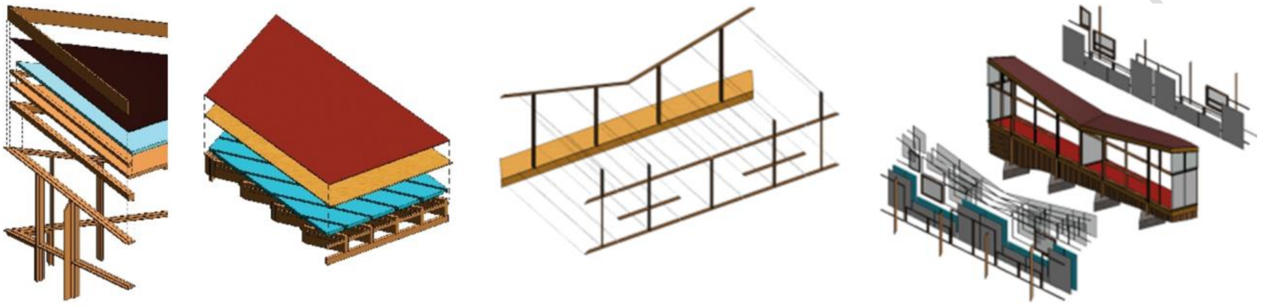

Fig. 8 Exploded views of the 3D model used to visualize building assemblies and the interplay between building components and materials. Image edited by the authors.

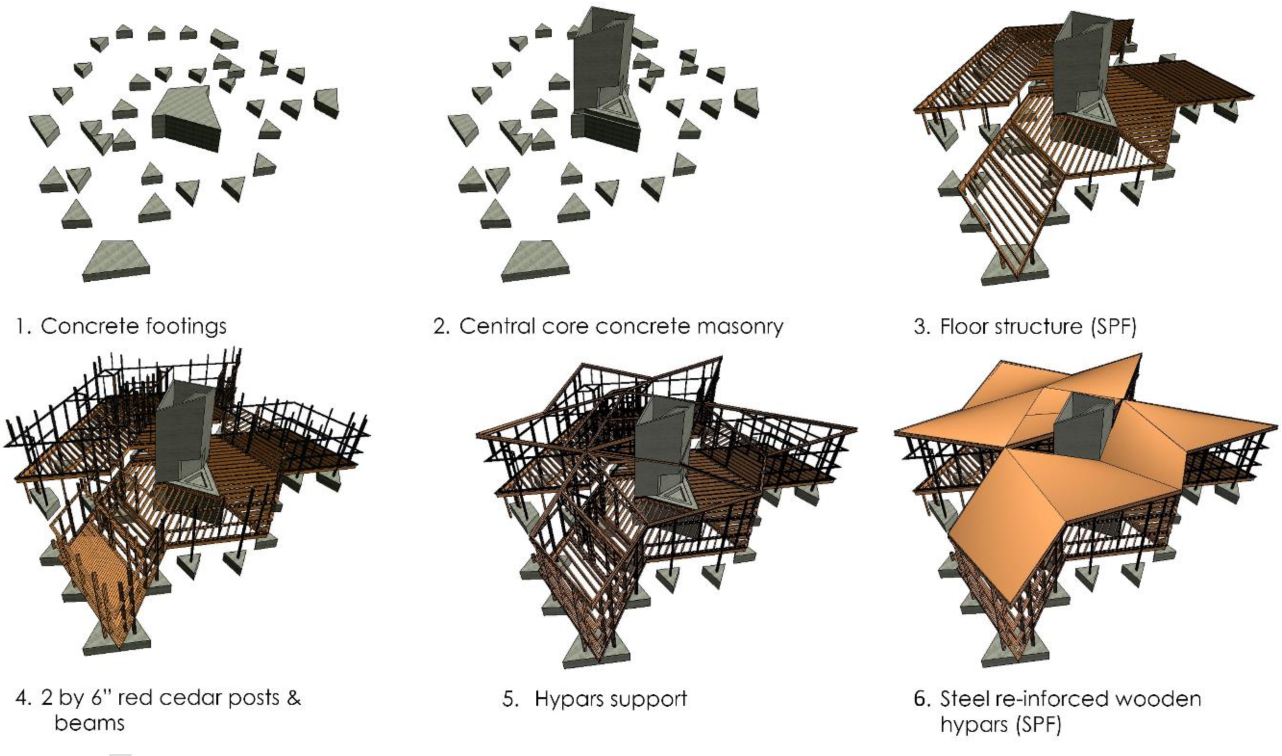

Fig. 9 This set of perspectives shows the structural concepts behind the construction of the house and the rational principles implemented by the architect to optimize the weight-efficiency ratio and, therefore, the construction's cost-effectiveness. Source: authors.

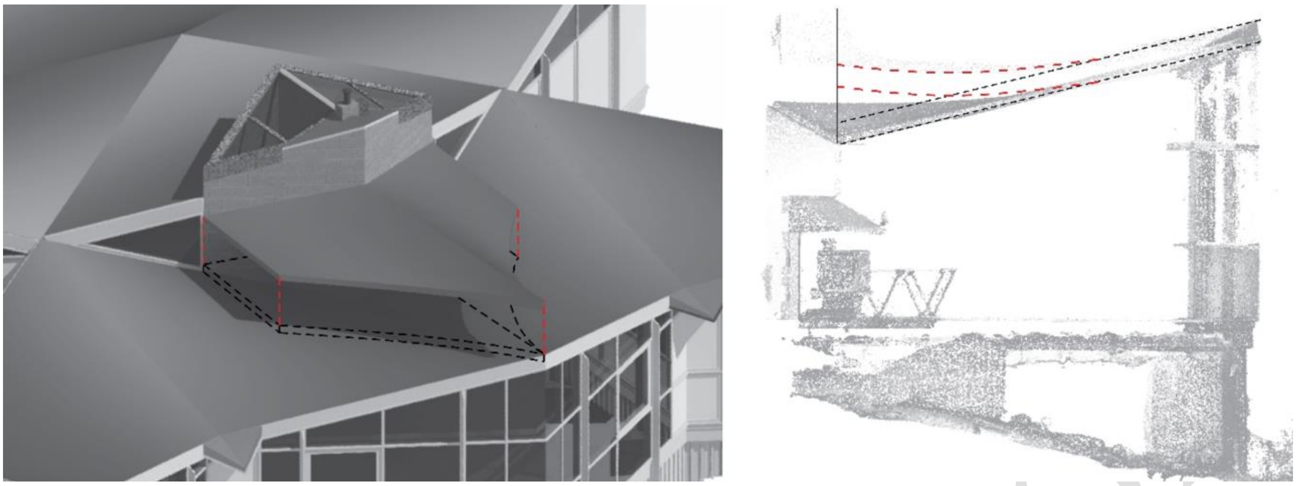

Fig. 10 The use of the point cloud in identifying changes made to the original design, here with the two additional hypars built on the top of the southern hypars network against the central core. Source: authors.

4.3.3 *Supporting conservation activities*

The HBIM of the Strutt House illustrates the opportunities to integrate geometric and semantic information about the condition and cultural significance assessments by mapping cultural values and pathologies on the geometry of associated features. Considering the specificities of the case study, the model was also used to inform about the order of dismantling of façade walls in the event of a restoration.

Finally, the model supports the communication of the different systems integrated into the building and tracks their evolution along their lifecycle.

4.4 *Discussions*

Even though this research demonstrated the Suitability of the HBIM approach to support documentation and conservation activities related to post-war wooden architecture in Canada, its replicability must be evaluated by implementing this framework in other contexts. Besides, some limitations have been observed in the data modeling process.

Regarding the modeling of objects' geometry, the manual method was found unsuitable for modeling the non-orthogonal and irregular shape of hypars, considering the objectives defined in terms of accuracy. The deviations of 3D objects' geometry exceed the defined threshold at many places. Applying the Nurbs-based modeling approach [16] would allow respecting the deviation tolerance defined according to the adopted LoA [17].

Concerning the integration of semantics in the HBIM model, a dedicated workflow should be defined to enhance the interoperability of the database with other standards in the field of cultural heritage conservation. As indicated by [18], using data standards allows operators to «*ensure that information is created in a consistent and valid way over time even through the contributions of a range of individuals who may have varying interests, expertise, and experience*». The appropriate standards, controlled vocabulary, and thesaurus must be identified depending on the project goals and the particularities of the case study. A concept mapping should then be achieved to ensure interoperability amongst ontologies and data models from multiple disciplines. For instance, a workflow was proposed to associate knowledge with parametric objects in HBIM models by retrieving data from an ontology-based system [19]. The data conversion and connection between both environments were achieved in Dynamo, the visual programming interface of Revit. Another aspect that requires further attention is the integration of cultural significance data in HBIM models. The latter is particularly challenging as Cultural values are not necessarily positive, "not intrinsic; mutable, not static; multiple and often incommensurable or in conflict" [20] as they depend on the observed object, the observing subject and the context of their interaction [21]. As indicated in previous research [22], communicating such knowledge requires the adoption of a dedicated taxonomy to contextualize and enable multiple representations of the collected data.

Finally, many other benefits can be derived from the information stored in HBIM models in terms of knowledge dissemination and collaborative management of data along the conservation process. The semantically enriched model can be integrated into multimodal web interfaces to enhance its accessibility and usability by a wide range of stakeholders. Such platforms can also be used as digital twins to support preventive conservation approaches [23].

HBIM models integrated into serious games and AR/VR applications can finally help awareness about inaccessible places of significance and transmit associated knowledge [24].

6. Conclusions: outcomes and further research perspectives

The present study illustrates the role of survey and digital representation to document, understand, interpret, and manage the built architecture of the second half of the 20th century. Through the representative case study of the Strutt house, the research underlines the representation disciplines' role in orienting and supporting compatible energy-efficient retrofits on post-war architectures in the global trend of carbon emissions reduction. More specifically, the main outcomes of the current research can be grouped as follows:

On a general level:

- The opportunities of digital representation to interpret and visualize the iconic language, the expressive matrix, and character-defining elements of the architecture of the second half of the 20th century.
- The present study tests an integrated documentation workflow and illustrates the relevance and the replicability of the adopted approach for the interpretation, analysis, and documentation of construction solutions and the architectural lexicon adopted.
- The paper highlights the importance of HBIM to generate coordinated representations of complex geometries and the management of related semantics among different stakeholders. The role of an HBIM approach to orient energy-efficient retrofits on post-war architecture is also illustrated.
- The research proposes an operative strategy to document, interpret and represent post-war architecture to orient the global trend of adapting buildings to comply with governmental emission reduction targets.

On a specific level:

- The research contributes to the knowledge of Canadian architecture of the second half of the 20th century and illustrates the potential of the proposed framework to generate targeted representations to sensitize stakeholders about Strutt's design and its cultural significance.
- The documentation activities and the adopted workflow illustrate the role of integrated survey strategy and 3D modeling in an HBIM environment to visualize the complex architecture of the Strutt house.
- The adopted digital visualization techniques and tools allowed the dissemination of knowledge and the improvement of the understanding of James W. Strutt's architectural lexicon and his built works.
- The relevance of the case study illustrates, with worldwide lenses, the threats of "sustainable" retrofits for the impoverishment of the built heritage of the second half of the 20th century.
- The present study underlines the pivotal role of digital models and 3D representations in orienting the retrofit process's social, cultural, and environmental sustainability.

Further research opportunities include the development of an immersive environment that can be derived from a virtual reality (VR) model-based to communicate and visualize the design, architectural structure, constructive details, and functional and decorative elements. Immersive environments can lay the basis for the multi-level information scenario of the adopted case study to enhance the transmission of information. Some attempts at the VR project have been developed in the software application Twinmotion and Unreal Engine 5, which allows a real-time synchronization of the 3D model exported in McNeel Rhinoceros and then in the VR project.

Additionally, the development of an Augmented Reality (AR) project could be a further research line developing an informative layer overlapped on the existing Strutt house to visualize the meticulousness of the constructive details or to visualize the architect's references and source of inspiration for a full understanding of his architectural language. Moreover, the opportunity of AR is particularly relevant to assess the compatibility of recladding and retrofitting projects to represent multiple scenarios in the outdoor and indoor spaces of the house.

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Author Contributions

Despite this publication being the result of collaborative research, Davide Mezzino wrote: Abstract, Section 1, Section 3, Section 3.1, Section 4.2, Section 5; Pierre Jouan wrote: Section 4, Section 4.1, Section 4.3, Section 4.3.1, Section 4.3.2, Section 4.3.3, Section 4.4.

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