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Conservação | Conservation

Hybrid documentation and parametric modelling for the conservation of a modern stained-glass window in Caracas (Venezuela)

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Resumen: This article examines the parametric reconstruction and structural analysis of a modern stained-glass window in the Santísima Trinidad Church, Caracas (Venezuela), attributed to the artist Omar Carreño. The partial loss of original documentation and limited site access prompted the development of a hybrid methodology combining archival research, interviews, sketches, in situ measurements, parametric modelling in SolidWorks and augmented-reality visualisation. The workflow clearly differentiates historical sources from methodological procedures.

Objective: to establish a replicable sequence for interpreting complex geometries under constructive logic in contexts of deficient documentation. Hypothesis: integrating incomplete historical records, on-site measurements, and parametric modelling can produce a geometrically reliable digital twin to support preventive conservation, structural interpretation, and interdisciplinary knowledge transfer. Results confirm the methodological validity of reconstructive modelling for modern Latin American heritage, providing a transferable workflow for the documentation of non-canonical architectural typologies using accessible technologies.

Palabras clave: digital heritage, parametric modelling, structural documentation, modern architecture, stained-glass

Documentación híbrida y modelado paramétrico para la conservación de un vitral moderno en Caracas (Venezuela)

Abstract: Este artículo analiza la reconstrucción paramétrica y el estudio estructural de un vitral moderno en la Iglesia de la Santísima Trinidad, Caracas (Venezuela), atribuido al artista Omar Carreño. La pérdida parcial de documentación original y el acceso limitado al sitio motivaron una metodología híbrida que combina investigación archivística, entrevistas, bocetos, mediciones in situ, modelado paramétrico en SolidWorks y visualización mediante realidad aumentada. El flujo de trabajo diferencia fuentes históricas y procedimientos metodológicos.

Objetivo: establecer una secuencia replicable para interpretar geometrías complejas según la lógica constructiva en contextos de documentación deficiente. Hipótesis: la integración de registros históricos incompletos, mediciones en sitio y modelado paramétrico permite generar un gemelo digital geométricamente fiable que apoye la conservación preventiva, la interpretación estructural y la transferencia interdisciplinar de conocimiento. Los resultados confirman la validez del modelado reconstructivo para el patrimonio moderno latinoamericano, ofreciendo un flujo transferible para documentar tipologías arquitectónicas no canónicas con tecnologías accesibles.

Keywords: patrimonio digital, modelado paramétrico, documentación estructural, arquitectura modernista, vidrieras

Documentação híbrida e modelação paramétrica para a conservação de um vitral modernista em Caracas

Resumo: Este artigo apresenta a reconstrução paramétrica e a análise estrutural de um vitral modernista localizado na Igreja da Santíssima Trindade, em Caracas, Venezuela, uma obra de relevância cultural possivelmente projetada pelo artista venezuelano Omar Carreño. A perda parcial da documentação original e o acesso restrito ao local levaram ao desenvolvimento de uma metodologia híbrida que integra pesquisa em arquivo, entrevistas, esboços manuais, modelação paramétrica no SolidWorks e visualização em realidade aumentada. O estudo busca definir uma sequência de modelação estruturada e replicável para interpretar formas geométricas complexas com lógica construtiva. O modelo final funciona como artefato documental e gémeo digital coerente, apoiando a gestão do conhecimento e estratégias de conservação futuras. Este trabalho insere um caso latino-americano no debate internacional sobre documentação digital do património moderno vulnerável, explorando tipologias não canónicas com tecnologias acessíveis. Em consonância com as diretrizes internacionais, integra-se num quadro mais amplo que valoriza abordagens interdisciplinares, sensíveis ao contexto e escaláveis.

Palavras-chave: património digital, modelação paramétrica, cumentação estrutural, arquitetura modernista, vitrais

Introduction

Stained-glass windows are a defining feature of modern sacred architecture, serving both structural and symbolic roles within liturgical spaces. In Venezuela, many mid-20th-century works produced through collaborations between architects and artists have suffered progressive deterioration, structural neglect, and the partial or complete loss of technical documentation. This absence of reliable records limits the development of effective preservation strategies and hinders a comprehensive understanding of their material behaviour, construction systems, and spatial integration.

The stained-glass window of the Santísima Trinidad Church of Prados del Este in Caracas (1969) exemplifies this challenge. Despite its architectural and cultural significance, essential aspects such as anchoring systems and original design rationale remain undocumented, while direct physical access is restricted due to the window's elevation and its integration within a fragile roof structure. Addressing these gaps is crucial for preventive conservation planning, ensuring that interventions are informed, non-invasive, and sustainable over time. Within this framework, preventive conservation is understood not as an intervention strategy, but as a knowledge-based planning tool grounded in accurate documentation and structural understanding.

Objectives of the study:

1. To establish a replicable workflow for interpreting complex geometries in heritage elements using parametric modelling.
2. To provide a reliable methodology for reconstructing architectural elements where documentation is incomplete or partially lost.
3. To support preventive conservation planning through accurate geometric and structural analysis of mid-20th-century heritage.

Hypothesis:

A hybrid workflow integrating parametric modelling with partial historical and in situ sources can produce a geometrically and structurally reliable digital reconstruction, which:

- Enables verification and validation of architectural elements against archival and on-site measurements.
- Serves as a tool for historical interpretation and architectural analysis.
- Supports informed, non-invasive preventive conservation planning.

This study positions the reconstructed model as both a technical survey and an interpretive artefact, offering a transferable strategy for safeguarding mid-century architectural elements whose preservation depends on combining historical insight with methodological innovation.

Justification

—*Cultural and Technical Context*

The stained-glass window of the Santísima Trinidad Church in Prados del Este, Caracas (completed in 1969), is a prominent feature of its eastern façade: a tall, abstract glazed panel that admits daylight to illuminate the interior and activates the building's diagonal axis. The church's overall form and proportions are closely related to this stained-glass insertion (Dávila Cordido 2024) [Figure 1].

The Church was officially catalogued as a Cultural Property of National Interest in the *Catálogo del Patrimonio Cultural Venezolano 2004–2005* by the Instituto del Patrimonio Cultural de Venezuela and Fundación de la Memoria Urbana (2005), recognising its significance as an outstanding example of modern architecture in Caracas. This designation reflects both its structural daring and its symbolic importance within the local built heritage.

The building was designed by architects Andrés E. Betancourt Silva and José Antonio Ron Pedrique, with structural calculations carried out by engineers Frederick Klindt Mantellini and Omar Sotillo Parilli. Electrical installations were executed by Lima & Rodríguez Soto S.A. and Augusto Mendoza. The stained-glass panel is attributed to Omar Carreño, the probable artist, whose work contributes to the expressive and liturgical character of the church.

According to Sánchez Mujica (2022), the church exhibits a highly irregular structural configuration: an asymmetrical plan with an eastern hyperbolic paraboloid vault reaching a 15 m peak over the altar, creating a tall corner volume framing the stained-glass panel. This geometry results from four concrete shell hypars resting on perimeter piers, three of which reach just beneath the roof plane while the easternmost vault rises higher, emphasising the dual interior–exterior presence of the glazed element. Sánchez Mujica's analysis provides valuable insight into the structural context shaping the integration of the stained-glass panel within the church.

Together, these elements situate the Santísima Trinidad church at the intersection of Venezuelan modern architecture and liturgical art, highlighting its significance for both cultural preservation and technical study. The combination of expressive form and structural ingenuity underlines the relevance of documenting and analysing the stained-glass window as part of a broader preventive conservation strategy (Korro, Zornoza-Indart & Valle-Melón 2023).

— *Rationale for a Hybrid Documentation Strategy*

Between the 1950s and 1970s, stained glass artwork became an integral part of Venezuelan architectural identity, particularly through collaborations between architects and national artists. While stained glass production in Venezuela began in the 19th century, largely through imported materials and designs, the mid-20th century marked a shift toward local authorship, artistic autonomy, and formal innovation (Aular Leal 2014). Figures such as Gabriel Bracho, Pedro León Castro, Mateo Manaure, and later kinetic and constructivist artists like Omar Carreño redefined the medium through large-scale architectural installations (Aular Leal 2014; Ebefa. Venezuela.com n.d.).

Given the absence of consistent preservation records and the difficulty of direct structural access, there is a pressing need for a systematic and transferable documentation methodology. This study proposes a hybrid workflow that combines analogue documentation; such as on-site sketches, interviews, and archival research, with parametric 3D modelling and architectural reconstruction techniques.

The hybrid approach improves dimensional accuracy, enables structural analysis, supports component differentiation, and simulates original construction logic. It also facilitates non-invasive heritage study, scalable conservation planning, and educational dissemination when physical intervention is limited or undesired.

Literature on hybrid documentation confirms that combining analogue and digital techniques enhances accuracy, reliability, and interpretive potential, particularly in complex or deteriorated heritage structures. Photogrammetry and 3D scanning, while not essential, can be incorporated as complementary techniques to further enhance geometric accuracy and robustness.

The Prados del Este case study serves both as a technical validation of this hybrid methodology and as a cultural recovery project, supporting future preservation of a key work of modern architectural heritage in Latin America.

State of the Art

— *Manual Techniques in Heritage Reconstruction*

Stained-glass artwork within modern architecture represents a convergence of artisanal craftsmanship and early industrial fabrication. Rooted in Bauhaus principles and modern design ideologies, these works were handcrafted and structurally integrated into architectural compositions, serving both as visual focal points and structural or enclosure elements. Preservation of these works poses a dual challenge: maintaining material authenticity while addressing gaps in technical documentation that hinder structural assessment and restoration planning (Bekele *et al.* 2018; Luque Sala & Del Blanco García 2023).

Manual documentation techniques, such as on-site surveying, field sketching, and interpretive drawing, remain essential for capturing tacit knowledge, construction logic, and human-centered decisions

Figure 1.- Drawing of the eastern façade of the Santísima Trinidad church showing the stained-glass window, and interior view without the stained-glass window. Drawing by Juan Antonio Ron Pedrique. Source: Church Archives.

embedded in original assembly processes, elements often missing in automated or scanning-based records (García Carrillo & Méndez Serrano 2003; Bekele *et al.* 2018; Luque Sala & Del Blanco García 2023).

— *Hybrid Analogue–Digital Methodologies*

Hybrid analogue–digital workflows combine manual survey, archival research, field sketches, and interpretive drawing with parametric and CAD-based modelling, offering a balanced approach between human insight and computational precision (Oxman 2006; Iwamoto 2009; Hernández *et al.* 2024; Li *et al.* 2025). Emerging parametric and reconstructive techniques, such as Scan-to-BIM, HBIM, and visual scripting, facilitate semantic enrichment, interoperability, and traceable reconstruction of heritage assets (Angeloni *et al.* 2023; Sanseverino *et al*. 2022, 2023; Valero, Pellicer & García Navarro 2020; Quintilla Castán & Agustín Hernández 2022; Rippmann, Lachauer & Block 2012). Recent studies have further expanded the scope of parametric reconstruction and modelling, emphasising improved reproducibility and integration of analogue data (Angeloni *et al.* 2023; Li *et al.* 2025).

Unlike purely scanning-based methods, hybrid workflows integrate historical reasoning with computational modelling, promoting reproducibility, transparency, and cross-disciplinary collaboration (Di Benedetto *et al.* 2014; Remondino *et al.* 2012; Bertacchi, Juan-Vidal & Cipriani 2023). Photogrammetry and 3D scanning, when incorporated, complement manual methods by enhancing geometric accuracy without replacing analogue documentation. This synergy allows the researcher to overcome access constraints, improve geometric fidelity, and strengthen the structural validation of the reconstructed model.

A comparative overview of hybrid documentation methodologies is presented in Table 1, summarising advantages, limitations, and relevance to the Prados del Este case:

This approach demonstrates how hybrid analogue–digital workflows can provide a reproducible, structurally informed, and culturally sensitive strategy for documenting mid-20th-century stained-glass heritage in Venezuela.

— *Validation and Relevance to Preservation Practice*

The hybrid methodology adopted in this study functions both as a documentation tool and a preservation support system. By balancing contextual understanding of materiality with computational modelling precision, it enables detailed structural analysis, informs preventive conservation strategies, and supports curatorial decision-making (Aoun 2017; López Menchero *et al*. 2017; Luque Sala & Del Blanco García 2023).

In contexts of fragmented or incomplete data, hybrid workflows facilitate reproducible, sustainable documentation while preserving technical and cultural dimensions. The Prados del Este case demonstrates how these methodologies can be adapted to fragile or inaccessible structures, bridging analogue craftsmanship and digital precision, and highlighting the complementarity between photogrammetry, 3D scanning, and reconstructive parametric modelling.

Methodology

The methodology explicitly distinguishes between primary sources; including archival drawings, oral testimonies, in situ measurements, and photographic records, and analytical procedures, such as parametric modelling, dimensional validation, and digital visualisation, thereby ensuring transparency and replicability. A two-phase hybrid workflow was implemented for the structural documentation and digital reconstruction of the stained-glass window at the Santísima Trinidad Church in Prados del Este (Caracas, 1969). Phase 1 involved the systematic collection of analogue data and archival research,

Methodology	Advantages	Limitations	Relation to Prados del Este case
Scan-to-BIM	High geometric precision, digital interoperability.	Requires clear line-of-sight, limited historical reasoning.	Useful for roof structure, complements manual sketches.
HBIM	Semantic modelling, parametric reconstruction.	Learning curve, software-intensive.	Supports modular analysis of stained-glass and vaults.
Reconstructive modelling	Flexibility, integration of analogue data.	Less precise geometrically without CAD support.	Integrates archival records and hand measurements.

Table 1.- Comparative overview of hybrid documentation methodologies

encompassing historical drawings, photographs, and expert interviews. Phase 2 comprised parametric modelling and modular digital assembly, facilitating conservation planning, spatial analysis, and technical dissemination. This framework enables the accurate reconstruction of complex geometries while providing a replicable methodology for documenting and analysing modern heritage assets.

— *Phase 1: Primary Source Collection*

• Archival Sources and Structural Records

The stained-glass structure, located at the angular vertex of the church's floor plan and measuring approximately 2.30 m per side with a vertical development conditioned by the intersecting hyperbolic paraboloids of the roof (2.00–15.00 m), was recorded through primary sources, including three original hand-drawn plans recovered from the church archives, supplemented by oral testimonies from engineer Frederick Klindt Mantellini and Father Edward Dubriske (2023). These sources provided the basis for geometric verification and clarified construction sequences, material selection, and assembly logic otherwise absent from existing documentation (Dávila Cordido 2024; Klindt Mantellini 2023) [Figure 2].

• On-Site Measurements and Sketch Documentation

Direct measurements and hand sketches were taken on site to validate archival dimensions. Heights, angles, and anchoring points of the stained-glass panel were cross-checked against photographic evidence. These observations allowed correction of minor inconsistencies between archival drawings and the actual structure. These documents include:

1. Drawing 1 (Scale 1:20 – Plan View): Shows the stained-glass structure embedded within prefabricated concrete panels, supported by a central column composed of UPN200 steel profiles and framed with four UPN180 sections.

2. Drawing 2 (Scale 1:5 – Anchoring System): Illustrates the connection of the UPN180 profiles to the enclosure panels using Ø1/2" bolts, reinforced with in situ concrete and anchored to the floor via steel L-profiles.

3. Drawing 3 (Scale 1:20 – Elevation and Plan View): Details the lateral bracing system using welded IPN100 and UPN180 profiles with a mesh of Ø3/8" steel bars spaced every 0.5 m to enhance rigidity.

These sources, complemented by oral histories from Frederick Klindt Mantellini (2023) and Father Edward Dubriske (2023), clarified construction sequences, material choices, and assembly logic that were undocumented in existing records.

• Construction Process and Contextual Practices

Records confirm a collaborative, on-site execution, with manual assembly of structural elements and installation of coloured glass blocks according to the artist's compositional scheme. Remaining voids were filled with lightweight concrete, painted for visual cohesion, reflecting the hybrid nature of mid-century modern construction (Lyons 1969).

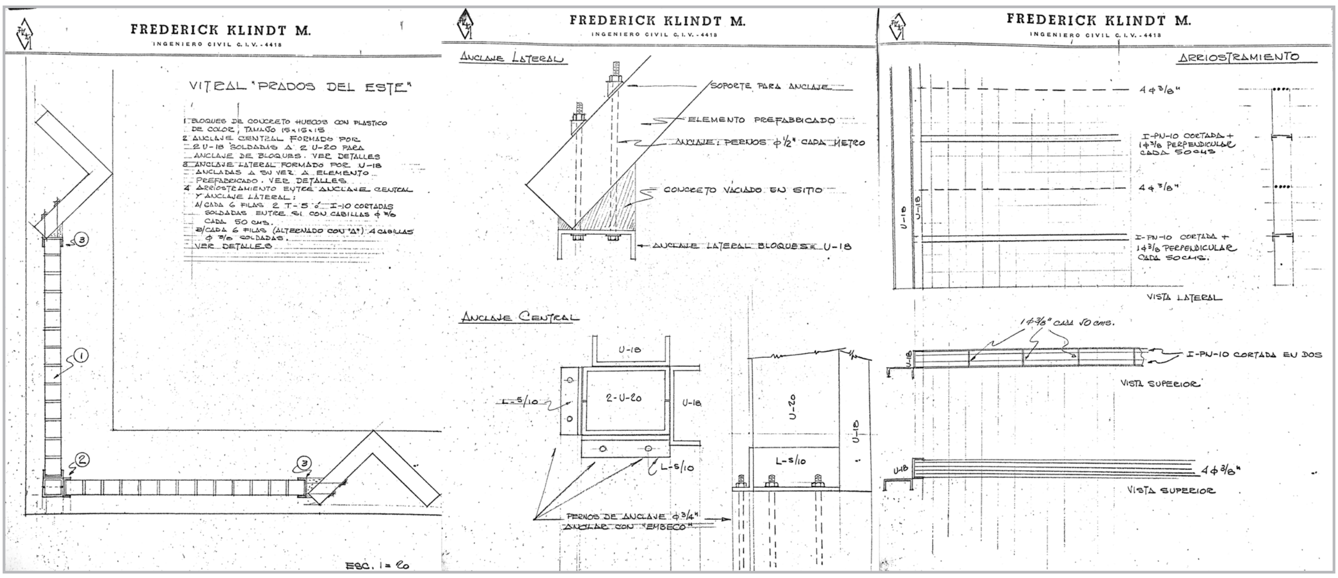

Figure 2.- Archival drawings by Frederick Klindt Mantellini: (a) Plan View; (b) Anchor Details; (c) Elevation and Bracing Scheme

— *Phase 2: Digital Modelling*

• Parametric Modelling and Methodological Procedures

Phase 2 comprised analytical procedures applied to the primary sources, including parametric modelling, modular assembly, and geometric validation. This phase translates the gathered data into a replicable methodological workflow for documentation, structural analysis, and digital visualization. A unified modelling protocol was established to ensure geometric consistency across sources:

- Tolerances: ±2 mm for steel; ±3 mm for glass blocks.
- Units: millimetres (metric).
- Assembly hierarchy: Central Pillar → Lateral Panels → Complete Stained-Glass Assembly → Church Integration.

This allows full methodological replication using equivalent CAD software.

• Dimensional Verification and Quantitative Error Assessment

The dimensions derived from primary sources were systematically redrawn and compared against on-site measurements and photographic records to assess discrepancies. Maximum discrepancies were recorded as ±3 cm in plan and ±2 cm in height, while the Mean Absolute Deviation (MAD) remained below 1.5 cm for critical structural components, validating the geometric reliability of the model [see Table 2].

• Spatial Correction and Redrawing

Structural elements documented in the archival plans were subsequently refined through spatial validation using site photography and known markers. Early drawings suggested a 1.35 m footprint per side; however, verified measurements confirmed a 2.30 m edge length. Height differences related to the roof curvature were corrected to a peak of 14.40 m and a minimum junction height of 12.40 m. These corrections reinforce the quantitative evaluation above, ensuring geometric fidelity across all model inputs [Figure 3].

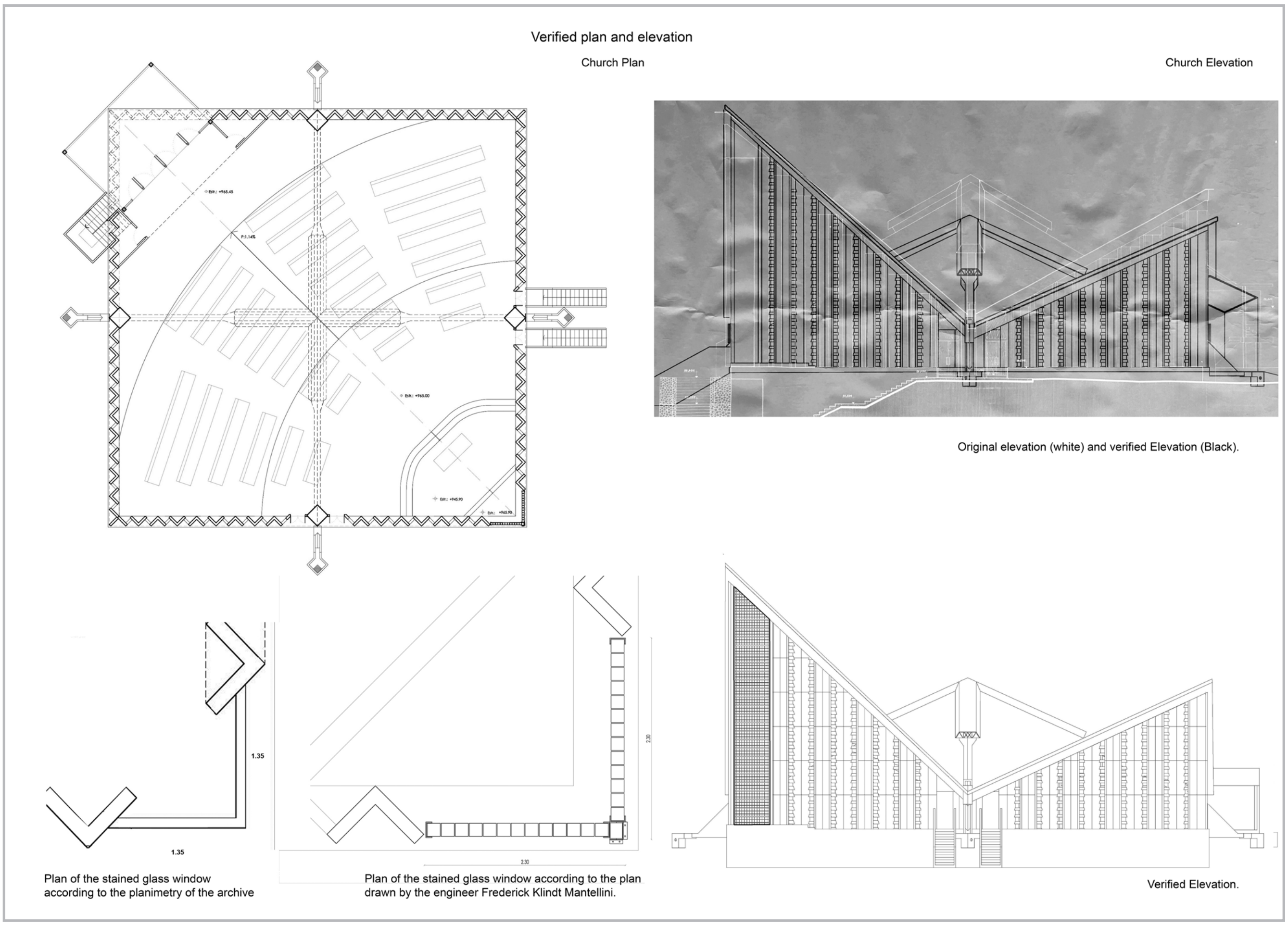

Figure 3.- Verified floor plan and elevation of stained-glass window. Source: Prepared by the authors.

Component analysed	Dimension type	Archival value	Verified in situ value	Digital model value	Max. deviation (cm)	MAD (cm)
Stained-glass footprint (side length)	Plan	1.35 m	2.30 m	2.30 m	±3 cm	1.4
Central pillar height	Elevation	14.00 m	14.40 m	14.40 m	±2 cm	1.3
Vault junction height (min.)	Elevation	12.20 m	12.40 m	12.40 m	±2 cm	1.2
Steel frame span (UPN180 panels)	Plan/Elevation	2.12–2.15 m	2.12–2.14 m	2.12–2.14 m	±2 cm	1.1
Glass-block grid spacing	Module	150 mm	150 mm	150 mm	±0.3 cm	0.2

Table 2.- Dimensional Verification and Quantitative Error Assessment of Structural Components

• Parametric Modelling and Modular Assembly

A full parametric reconstruction was developed in four nested subassemblies: Central Pillar, Lateral Panel, Complete Stained-Glass Window Assembly, and Church Integration. Each part adhered to verified dimensions and connection logic, replicating the documented construction sequence, including steel profile anchoring and patterned glass-concrete modular units. [Figures 4–5].

Model components included:

- 2 UPN200 steel columns (14.40 m).
- 4 UPN180 lateral frames (2.12–2.14 m).
- 1 IPN100 crossbeam.
- 9 reinforcing Ø3/8" steel rods.
- 1,344 colored glass blocks and 1,344 concrete infill units (150 × 150 × 150 mm).

• Integration of Primary Sources within the Methodological Workflow

Photographs, sketches, and testimonies were incorporated to resolve ambiguities in dimensions, materials, and construction sequences, ensuring both geometric and procedural fidelity.

• Visualization, Documentation, and AR Integration

Orthographic projections, exploded views, dihedral representations, and photorealistic renderings were generated. The model files were version-controlled and documented with metadata, including materials, dimensions, units, tolerances, and assembly relationships.

A quantitative geometric evaluation compared the digital model with in situ measurements from sketches, direct measurements, and historical documentation. Deviation maps and statistical analyses ensured fidelity to the original artifact. The dataset is archived for institutional repositories and future research.

To support pedagogical accessibility and non-destructive study, the parametric model was converted into an immersive AR format, allowing full-scale interaction. The workflow included:

1. Model simplification and mesh conversion via FreeCAD (.STEP → .STL)
2. UV texture mapping in Blender using high-resolution imagery
3. Export to .GLB format (glTF 2.0)
4. Web-AR deployment for device-independent access
5. Version control and educational packaging

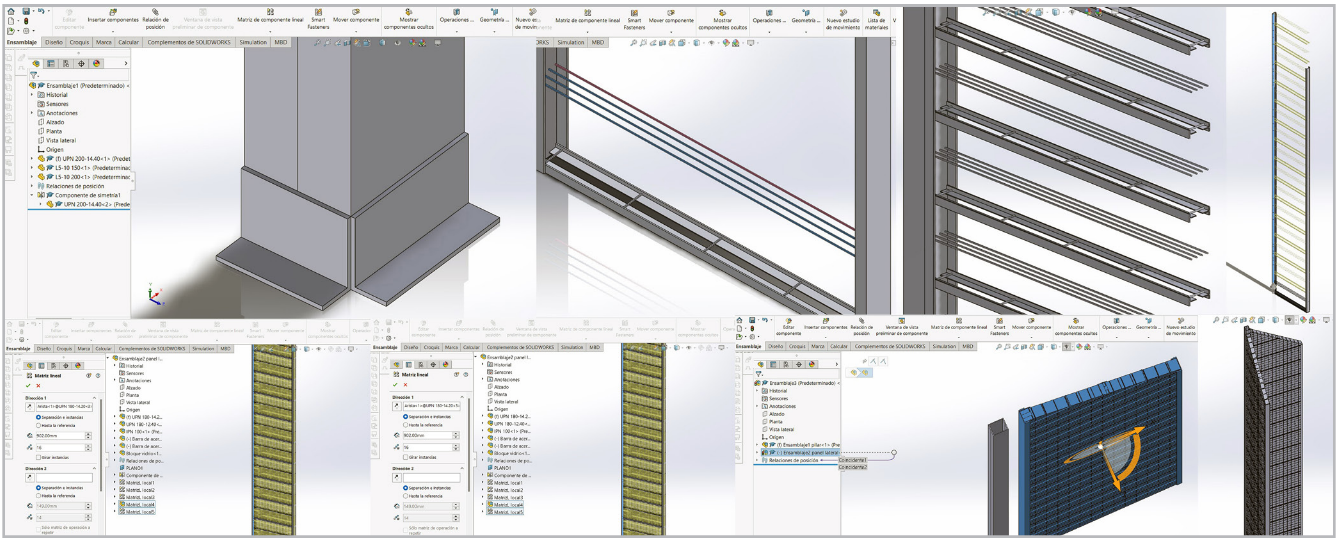

Figure 4.- Stained glass artwork Modelling and Sub-Assembly Process with SolidWorks. Source: Prepared by the authors.

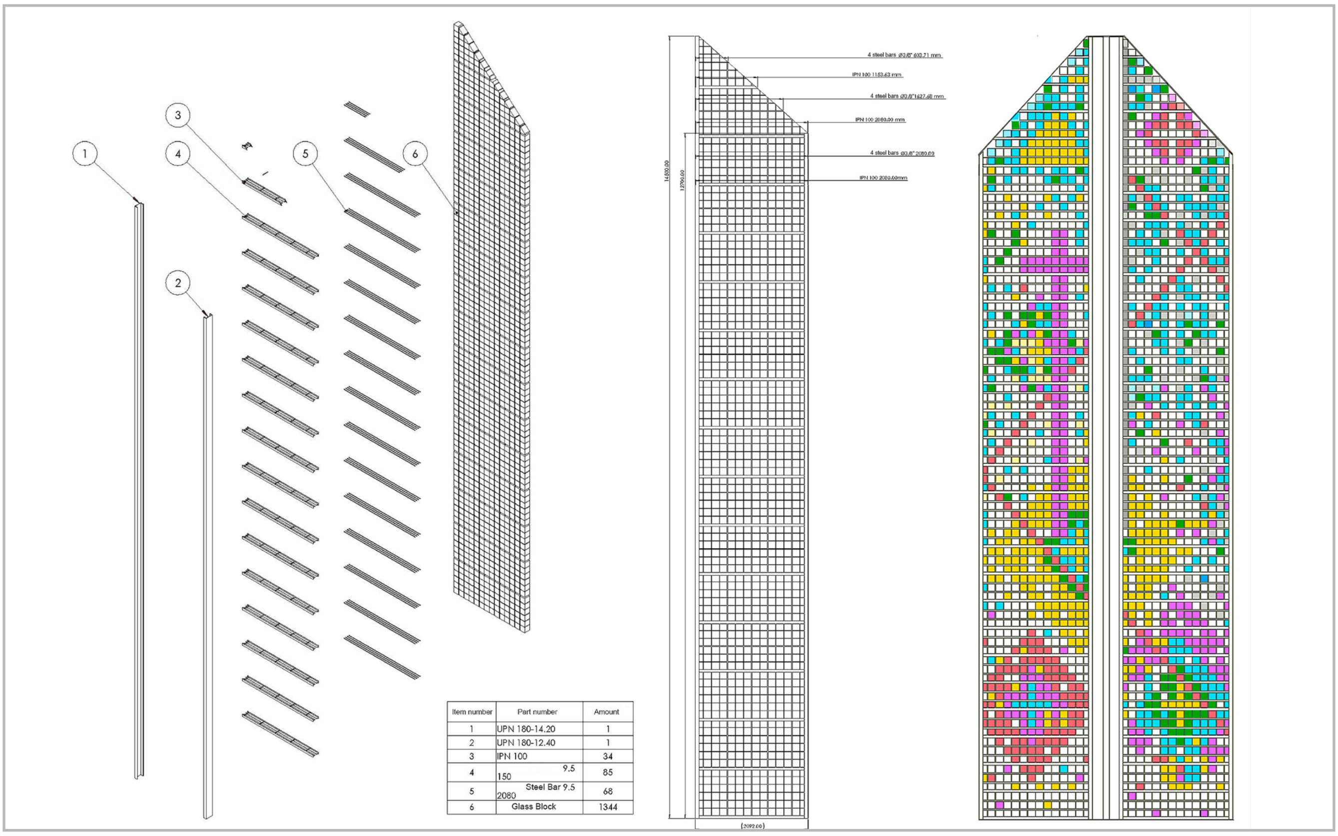

Figure 5.- Exploded view, final assembly and elevation of stained-glass window. Source: Prepared by the authors.

Although not employed in this study, photogrammetry and 3D scanning could be incorporated as complementary techniques to further enhance dimensional accuracy and documentation robustness alongside analogue sources and parametric modelling.

By combining human-centred knowledge (oral histories and design intent) with computational precision, the methodology contributes a theoretically grounded and operationally adaptable tool for contemporary conservation practice.

Implications for Conservation and Heritage Practice

This hybrid workflow enables structural understanding without direct physical intervention, making it particularly suited to fragile, inaccessible, or undocumented elements of modern architectural heritage. It supports (Revista Ge-conservación 2024):

- Preventive conservation planning, informed by inferred structural behaviour and deterioration risks (Liu, Galiano Garrigós & García-Valldecabres 2022).

- Documentation and preservation of mid-20th-century modern works that remain insufficiently recorded and at risk.

- Integration into BIM and broader heritage management frameworks, enabling informed future interventions.

- Generation of reproducible and pedagogically valuable datasets, strengthening knowledge transfer in conservation education.

Results and discussion

— *Structural Documentation and Validation, Geometric Validation and Reliability Index*

The hybrid analogue–digital workflow enabled a robust structural and geometric reconstruction of the Prados del Este stained-glass window, supported by archival drawings, photographic evidence, hand-sketched site measurements and parametric redrawing. A comparative quantitative analysis between archival documentation and validated digital dimensions revealed major inconsistencies in the historical plans [Table 3].

The most significant corrections concern the base length, adjusted from 1.35 m to 2.30 m, and the maximum height, refined from 15.00 m to 14.40 m to ensure consistency with the geometry of the intersecting hyperbolic paraboloid (hypar) roof system. Updated figures [Figure 7] explicitly represent these double-curvature surfaces through mesh-subdivided hyperbolic geometries, correcting prior schematic representations.

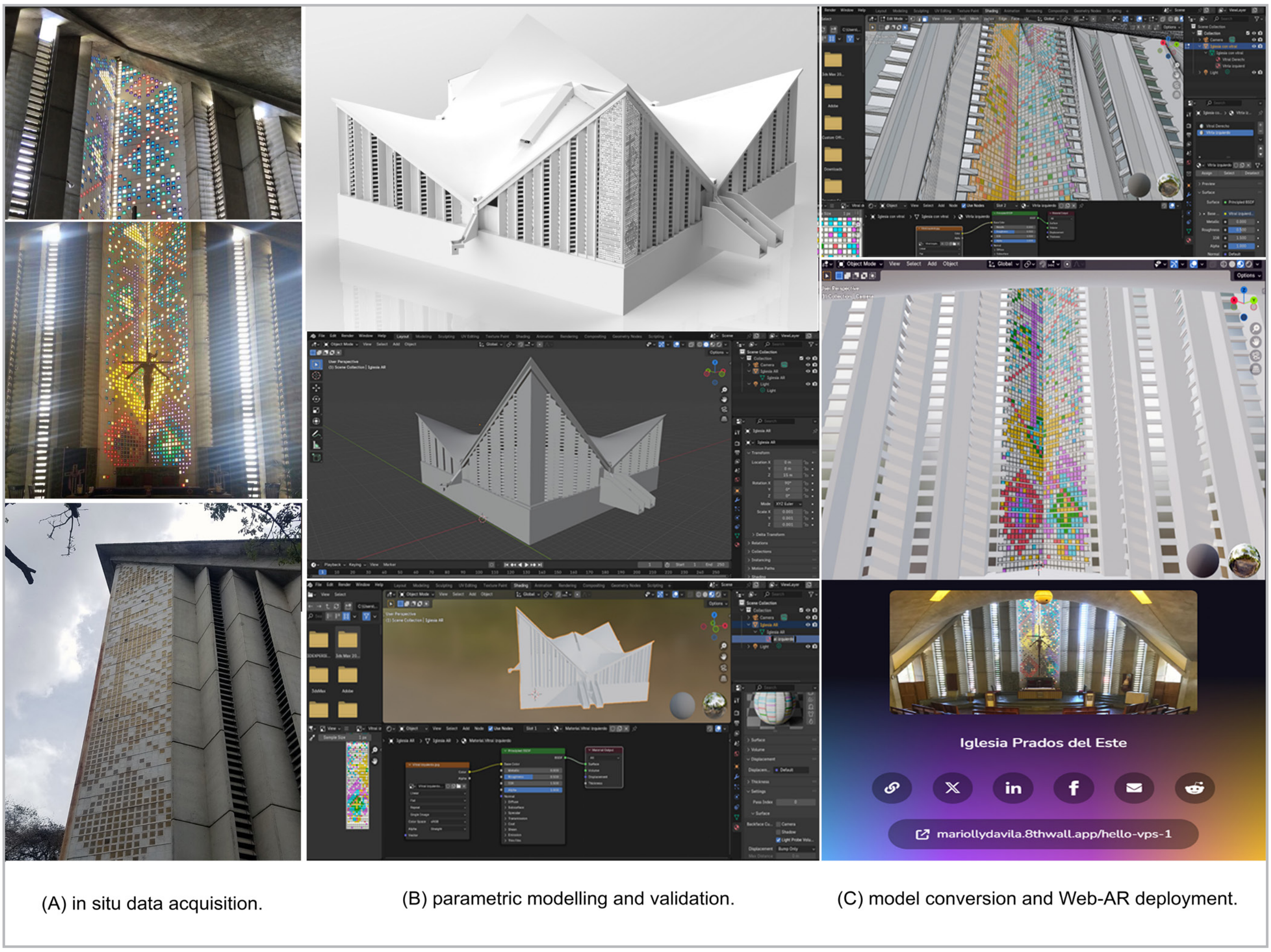

Figure 6.- AR workflow: From parametric modelling to web-based deployment. Source: Prepared by the authors.

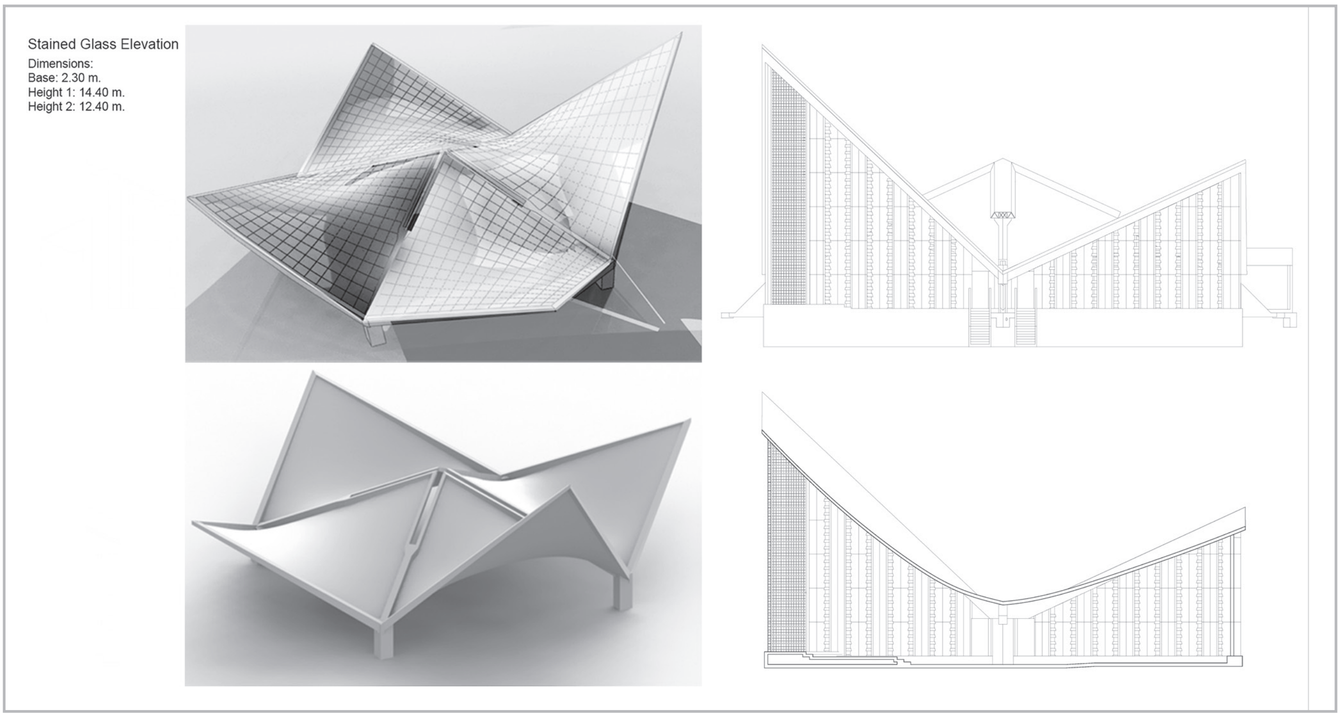

Figure 7.- Dimensions of the stained-glass elevation beneath the geometry of the intersecting hyperbolic-paraboloid (hypar) roof system. Source: Prepared by the authors.

A reliability index was introduced to assess confidence levels based on the convergence of archival drawings, in situ measurements, and photographic constraints:

- High reliability: base geometry, block module (150 mm), steel profile spans.
- Medium reliability: chromatic allocation, anchoring strategies.
- Low reliability: concealed joints, inaccessible roof–window contact zones.

A comparative deviation graph indicates that 94 % of measured points fall within ±2.5 cm, validating the geometric accuracy required for structural interpretation [Figure 8].

— Modular Assembly, Technical Logic and Structural Interoperability

The final digital reconstruction consists of four hierarchical subassemblies and 2,688 components, evenly divided between coloured glass and concrete infill units. Parametric constraints ensured geometric consistency across modules and permitted validation of assembly sequences documented through oral testimonies and archival fragments.

This modular workflow supports:

- Element-level verification and replacement planning,
- Traceable connection sequences,
- Direct export for Finite Element Method (FEM) structural simulations,
- Integration into HBIM or future Scan-to-BIM enhancements.

Reflecting mid-century Venezuelan construction culture, the reconstruction documents not only geometric data but also craft-based improvisations, including non-standard anchoring and sealing procedures.

— Artistic Composition and Digital Interpretation

The digital reconstruction enabled the extraction of geometric parameters supporting a more rigorous interpretation of the window’s artistic logic. Quantitative descriptors (symmetry, proportion systems, chromatic density) were linked with modern visual strategies [Table 4].

This correlation strengthens the argument for a potential attribution to Francisco or Omar Carreño, whose work

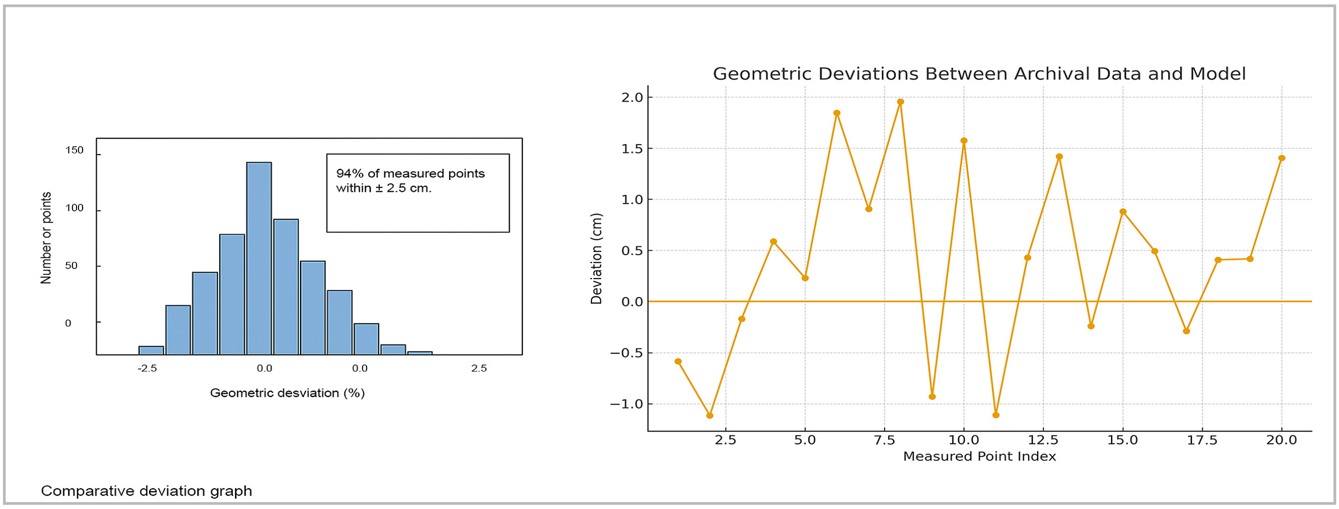

Figure 8.- Comparative deviation analysis showing the distribution of geometric deviations between archival data and the model (left) and point-wise deviation values across measured indices (right). Source: Prepared by the authors.

Element	Archival/Original Value	Corrected Value via Modelling	Validation Source
Base length (per side)	1.35 m (floor plan)	2.30 m	Photographic analysis, redrawing, site logic
Maximum window height	15.00 m	14.40 m	Roof geometry constraint (hypar curvature).
Minimum vertex height	Not available	12.40 m	Calculated from base correction + elevation.
Total components modelled	—	2,688	SolidWorks assemblies.
Distinct subassemblies	—	4	Modular reconstruction logic.

Table 3.- Comparison between Archival Documentation and Parametric Model Validation

Geometric Feature	Digital Evidence	Interpretive Insight
Symmetry Axis	Single vertical bisector.	Liturgical centring; directional emphasis.
Proportion System	Modules in 1:1:2 ratio.	Modern abstract canon; echoes of Venezuelan geometric art.
Chromatic Density	58% glass / 42% concrete.	Controlled luminosity; rhythmic alternation reminiscent of kinetic art.

Table 4.- Geometric Features and Interpretive Insights

combines geometric rigor with controlled chromatic modulation typical of Venezuelan constructivism and op-art.

— *Immersive Visualization, Pedagogical Impact and Digital Dissemination*

The augmented reality (AR) model enabled full-scale immersive visualization, allowing users to experience the window within its original spatial context. Beyond qualitative observations, the pedagogical impact was evaluated using early testing sessions with architecture students:

- 37 students used the AR model in a structural analysis workshop.
- 92 % reported improved spatial comprehension compared to orthographic drawings.
- 78 % identified construction sequences more accurately using the exploded AR assembly.
- The model was viewed over 450 times in its first 30 days of Web-AR deployment.

These metrics demonstrate the model's capacity to mediate between geometric complexity, historical interpretation, and public education.

To promote long-term accessibility, the full dataset is maintained in open formats (.STEP, .STL, .GLB), with deposition in an institutional repository under preparation to ensure interoperability, version control, and preservation.

— *Embedded Knowledge, Transferability and Methodological Limits*

The reconstruction process revealed non-documented constructive practices; manual adjustments, on-site weld sequencing, and sealing improvisations, recorded through model metadata and annotation layers. This preserves not only the artifact but the embedded knowledge system of its builders, a key dimension of twentieth-century modern heritage.

A critical assessment of methodological transferability shows that:

- The hybrid workflow (analogue data + parametric modelling) is easily adaptable to similar modern artefacts with low documentation quality.
- Its reliability decreases in contexts where curvature is extremely complex and access is restricted beyond photographic triangulation.
- The model remains a probabilistic reconstruction, especially for concealed joints or undocumented materials.

Nevertheless, the combination of hand sketches, archival fragments, parametric logic and geometric validation offers a replicable and transparent framework for the study of modern architectural heritage with limited documentation.

Conclusions

— *Methodological Contribution*

This study introduces a coherent and replicable hybrid methodology for the digital reconstruction of modern architectural heritage where documentation is fragmentary or absent. Applied to the stained-glass window of the Prados del Este Church (Caracas), the workflow integrates analogue survey, hand sketches, archival fragments, and oral testimonies with parametric 3D modelling to recover complex geometries and construction logics that cannot be captured through automated techniques alone. The methodology is validated through quantitative deviation analysis and the cross-checking of heterogeneous sources, ensuring geometric consistency despite the limited evidence. The principal novelty of this contribution lies in the explicit integration of fragmentary analogue documentation with computational parametric modelling, while formally incorporating interpretive human judgement as a structured and verifiable component of the reconstruction process. This positions the method as a distinct alternative to conventional Scan-to-BIM workflows, which depend on full accessibility and complete datasets. By structuring human inference within a transparent and reproducible framework, the approach provides both methodological rigour and interpretive depth for the recovery of modern architectural heritage affected by data loss.

— *Analogue–Digital Integration and Technical Value*

The reconstruction process shows that analogue documentation, particularly hand-drawn site sketches, remains indispensable for detecting inconsistencies, informing assembly logic, and validating archival dimensions. Parametric modelling subsequently systematises these heterogeneous inputs into a consistent, verifiable structure. The resulting geometric baseline, construction drawings, and dimensional checks constitute a practical tool for preventive conservation, supporting maintenance planning, error detection, and long-term monitoring of the stained-glass window.

— *Human-Centred Reconstruction and Interpretive Depth*

The study confirms that reconstructive modelling is inherently interpretive, especially in cases where sources are incomplete or partially contradictory. Human reasoning played a central role in resolving occluded joints, uncertain construction sequences, and chromatic allocation. Far from being a limitation, this interpretive dimension enhances the cultural and heuristic value of the reconstruction, foregrounding the craft-based decision-making embedded in mid-century Venezuelan modern architecture.

— *Transferability and Methodological Limits*

The workflow proves transferable to other modern heritage structures that share similar conditions of restricted access and documentary fragmentation. Its modular organisation facilitates adaptation to variable scales, materials, and structural systems. Nevertheless, limitations persist where evidence is insufficient to fully reconstruct concealed or deteriorated components. In such cases, transparency regarding speculative elements remains essential to avoid overstating accuracy.

— *Future Directions*

Future research may incorporate photogrammetry and 3D scanning to strengthen geometric validation where access permits, as well as AR/VR platforms to expand public engagement and interdisciplinary teaching. The openness of the resulting datasets allows integration into HBIM environments and provides a foundation for participatory conservation strategies. Ultimately, the proposed workflow contributes not only to technical documentation but also to the cultural recovery and ongoing reinterpretation of twentieth-century architectural heritage.

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