UNIVERZA
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Fakulteta za gradbeništvo
in geodezijo

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PARAMETRIC MODELING AND AUTOMATION OF CONSTRUCTION DETAILS IN BIM

PARAMETRIČNO MODELIRANJE IN AVTOMATIZACIJA GRADBENIH DETAJLOV V OKOLJU BIM

BIM A+ European Master in Building Information Modelling

Master thesis No.:

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Ljubljana, 2025

ERRATA

Page	Line	Error	Correction

BIBLIOGRAFSKO – DOKUMENTACIJSKA STRAN IN IZVLEČEK

UDK:	**004.42:624.07(043.2)**
Avtor:	**Marcos Daniel Paz Ballesteros**
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Naslov:	**Parametrično modeliranje in avtomatizacija gradbenih detajlov v okolju BIM**
Tip dokumenta:	**magistrsko delo**
Obseg in oprema:	**66 str., 29 sl., 3 pril.**
Ključne besede:	**Parametrično modeliranje, avtomatizacija, gradbeni detajli, informacijsko modeliranje zgradb (BIM), optimizacija delovnih procesov, IFC.**

Izvleček:

Z uvajanjem informacijskega modeliranja gradenj (BIM) v gradbeništvu se pojavljanje tudi težave z učinkovitostjo dela. Pomemben primer predstavljajo postopki izdelave gradbenih detajlov, ki jih je potrebno v pretežni meri obdelati ročno. S tem se pogosto pojavljajo napake, pri tem pa je delo zelo zamudno, ker se ne izkorišča celoten potencial parametričnega načrtovanja. Ta raziskava obravnava to neskladje z razvojem in validacijo sistematičnega, programsko neodvisnega ogrodja za vključevanje parametrične avtomatizacije v delovne procese izdelave detajlov. V nalogi je uporabljena metodologija študije primera za analizo obstoječega delovnega procesa, pri čemer so bila opredeljena ključna ozka grla pri izdelavi gradbenih detajlov. Na podlagi ugotovitev je bilo razvito štiristopenjsko ogrodje, ki zajema faze razčlenitve in definicije, parametričnega sestavljanja, generiranja elementov BIM z obogatitvijo metapodatkov ter končne dokumentacije. Praktična uporabnost ogrodja je bila potrjena z izvedbo testnega primera, ki je pokazal njegovo učinkovitost v realnem okolju. Rezultati potrjujejo, da ogrodje ne le skrajša čas, ki je potreben za izdelavo detajlov, temveč predvsem izboljša kakovost gradbene dokumentacije. Z vgradnjo pravil načrtovanja v avtomatiziran proces metodologija zagotavlja doslednost, zmanjšuje človeške napake in bogati model s strukturiranimi, interoperabilnimi podatki, skladnimi s standardom IFC. V sklepnem delu naloge predstavimo praktično in prenosljivo metodologije, ki projektantskim podjetjem omogoča premostitev vrzeli med potencialom tehnologije BIM in vsakodnevno prakso izdelave gradbenih detajlov.

BIBLIOGRAPHIC– DOKUMENTALISTIC INFORMATION AND ABSTRACT

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Title: **Parametric Modeling and Automation of Construction Details in BIM**

Document type: **Master Thesis**

Scope and tools: **66 p., 29 fig., 3 ann.**

Keywords: **Parametric Modeling, Automation, Construction Details, Building Information Modeling (BIM), Workflow Optimisation, IFC.**

Abstract:

The construction industry's adoption of Building Information Modeling (BIM) has highlighted a significant inefficiency: construction detailing practices remain largely manual and error-prone, failing to utilise the full potential of parametric design. This research addresses this disconnect by developing and validating a systematic, software-agnostic framework to integrate parametric automation into detailing workflows. The study employs a single-case methodology to analyse an existing industry process, identifying key bottlenecks in the creation of construction details. In response, a four-stage framework was developed, encompassing stages of Deconstruction and Definition, Parametric Assembly, BIM Element Generation with Data Enrichment, and Final Documentation. The framework's practical applicability was validated through the implementation of a proof-of-concept, demonstrating its effectiveness in a real-world scenario. The results confirm that the framework not only reduces the time required for detail creation but, more importantly, enhances the quality of construction documentation. By embedding design rules into an automated process, the methodology ensures consistency, minimises human error, and enriches the model with structured, interoperable data compliant with the IFC standard. The research concludes by presenting a practical and transferable methodology that empowers firms to bridge the gap between the potential of BIM and the daily practice of construction detailing.

ACKNOWLEDGEMENTS

I would like to thank the many people who supported me during my thesis work.

First, I want to thank my supervisor, Tomo Cerovšek. His consistent guidance and constructive feedback were very helpful in shaping this research. I appreciate his support and the space he gave me to develop my work.

My thanks also go to the team at od-do architecture for the opportunity to collaborate. I especially want to thank Aleksi Vičič for his mentorship; his professional perspective and practical advice were a great help throughout the project. I am also very grateful to Nika Razpet for providing the necessary information to gain valuable insight into the company's workflow.

I am also thankful to the staff of the BIM A+ community. I sincerely appreciate being selected as a recipient of the consortium scholarship, which was fundamental to my studies. I am also grateful for the continuous guidance and shared knowledge from all the professors and speakers I had the opportunity to learn from.

Additionally, I am deeply grateful for the friends and colleagues I had the privilege of meeting. Coming from so many different cultural backgrounds, I appreciate the unique opportunity to learn from their perspectives and the supportive environment we built together.

Finally, I want to express my thanks to my family. I am who I am because of them. I have always admired my dad for his personal values and for dedicating his life to his children. I am grateful to my mom, who worked so hard and always cared for us so deeply, ensuring we had what she did not. My siblings have each been a guiding light: Mariel with her infectious optimism, José as a role model I always admired, and Wayra with her profound commitment to serving others. As the youngest, their collective protection and guidance, both spoken and unspoken, have shaped my world.

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1 INTRODUCTION

1.1 Background and Context

Over the past several decades, the construction industry has undergone a significant digital transformation, with Building Information Modeling (BIM) emerging as a fundamental methodology for project design, coordination, and delivery. This evolution translates into a shift from traditional 2D computer aided design (CAD) workflows to comprehensive 3D digital environments that integrate geometric, spatial, and semantic information throughout the project lifecycle [1]. The Evolution of BIM technology can be traced back to the 1970s, when Charles Eastman developed the Building Description system (BDS), which established the foundational concepts of parametric design and integrated databases that characterize modern BIM platforms [2].

Currently, there is an increasing demand for detailed 3D models that extend beyond basic geometric representation to include comprehensive construction detailing. This shift has been accelerated by a growing number of government mandates, though their scopes vary. For instance, the United Kingdom's requirements for Level 2 BIM on centrally procured projects have been influential. Similarly, other nations have introduced targeted mandates; Singapore established a BIM e-submission system for regulatory approval, while South Korea requires BIM on public projects exceeding specific cost thresholds. This trend is also evident in countries such as Germany, Brazil, and across the Nordic countries, where requirements for public and infrastructure projects are increasingly common [3,4]. These requirements pressure design firms to create highly detailed models that clearly depict both interior and exterior building finishes, a process that remains largely manual, tedious, and susceptible to errors. The disconnect between the advanced capabilities of modern BIM platforms and the ongoing dependence on manual detailing highlights a significant inefficiency in current industry practice.

As project complexity continues to grow, the limitations of traditional 2D drawing-based approaches to construction detailing have become increasingly apparent. Two-dimensional drawings inherently lack the comprehensive information-sharing capabilities required for effective multi-disciplinary coordination, leading to misunderstandings, increased project costs, and legal disputes between project participants [5]. The manual calculation of material quantities, spatial relationships, and constructability analysis from 2D representations requires a considerable amount of time and financial resources while remaining susceptible to human error. Furthermore, attempting to coordinate changes across multiple discipline-specific models presents significant challenges, particularly when design modifications must be propagated through various drawing sets and documentation formats [6].

Parametric modeling involves establishing algorithmic relationships between design elements, enabling automatic updates when changes occur. This methodology transforms individual designers into architects of information chains, where relationships between components can be defined to automatically adapt to changing conditions. The application of parametric approaches to construction detailing represents a natural transition of this technology, offering the potential to automate repetitive tasks while maintaining design integrity throughout the project development process [7].

1.2 Problem Statement

While widespread adoption of BIM is becoming a reality, construction detailing practices remain largely dependent on traditional, manual workflows that fail to capitalise on the full potential of modern parametric design environments. The use of outdated practices results in a fundamental disconnect between the advanced capabilities of contemporary BIM platforms and the actual implementation of construction detailing processes, leading to significant inefficiencies that impact project delivery, quality, and resource utilisation across the industry.

Current construction detailing workflows, particularly in residential building projects such as those undertaken by firms like od-do architecture in Slovenia, illustrate the persistence of this industry challenge in practice: professionals continue to invest substantial time and resources in manually creating, modifying, and coordinating construction details throughout multiple project phases. This manual approach results in a cycle of inefficiency where architects and engineers dedicate considerable portions of their time to repetitive, routine tasks that could be significantly streamlined through parametric automation. When design changes occur, these details require manual updates across drawings and documentation sets, resulting in delays and resource allocation issues that extend project timelines and increase costs.

The reliance on traditional 2D drafting conventions for construction detailing introduces quality and consistency challenges that compromise project outcomes. Manual drafting processes are inherently prone to human error, leading to discrepancies between details, inconsistencies in graphic standards, and coordination failures between different building systems and disciplines. These quality issues are amplified in larger projects as the increased number of details significantly raises the complexity of multi-disciplinary coordination and the potential for widespread inconsistencies. Furthermore, ensuring compliance with building codes, industry standards, and company-specific detailing guidelines becomes increasingly difficult when relying on manual verification processes, potentially exposing projects to regulatory compliance risk and construction errors.

Most critically, the construction industry faces a significant technology adoption gap where the parametric capabilities existing in modern BIM platforms remain largely underutilised in construction detailing workflows. While BIM software environments offer advanced parametric modeling tools that enable dynamic, rule-based detail generation and automatic adaptation to design parameters, current industry practices fail to effectively leverage these capabilities. This represents a clear missed opportunity, as parametric approaches could enable construction details to automatically adjust to different building configurations, material specifications, and regulatory requirements, while maintaining consistency and accuracy across entire project documentation sets.

The implications of this problem extend beyond individual project inefficiencies. As construction projects become more complex and delivery times less forgiving, the industry's reliance on manual detailing creates a persistent bottleneck that systematically drains resources. This inefficiency limits opportunities for design iteration and optimisation, prevents the full implementation of BIM benefits, and ultimately constrains the industry's broader competitiveness and capacity to innovate. The challenge is particularly significant for firms operating in diverse markets, where construction details must be adapted to varying regional standards and material availability. In such scenarios, parametric approaches could provide even more tangible advantages.

This research addresses the critical need for a systematic approach to integrating parametric modeling and automation technologies into construction detailing workflows within BIM environments. The fundamental research problem focuses on developing practical and implementable solutions that explore the idea of transforming construction detailing from its current manual state into parametric systems, leveraging the full capabilities of BIM platforms. The urgency of this challenge is highlighted by increasing pressure on construction professionals to deliver higher quality projects more efficiently while maintaining design excellence and regulatory compliance.

1.3 Research Questions and Objectives

The **Primary Research Question** was formulated as follows:

How can parametric modeling and automation technologies be systematically integrated into BIM workflows to improve the efficiency, accuracy, and adaptability of residential construction detailing compared to traditional 2D manual approaches?

The **Secondary Research Questions** were defined to help achieve this goal, and are:

- **Current State Analysis.** What are the specific inefficiencies, time requirements, and error patterns in current manual 2D construction detailing practices within European residential projects, and how do these inefficiencies impact overall project delivery?
- **Framework Development.** What parametric workflow framework and methodological approach can effectively automate the creation and modification of residential construction details while maintaining compliance with European building Standards?

- **Technical Implementation.** How can ArchiCAD, Grasshopper and other technologies be integrated to create responsive parametric construction details that automatically adapt to design changes while preserving geometric accuracy and regulatory compliance?
- **Performance Evaluation.** To what extent does the proposed parametric workflow improve time efficiency, reduce errors, and enhance adaptability compared to traditional manual detailing methods in residential construction projects?
- **Scalability and Transferability.** How can the developed framework be structured to ensure scalability across different detail types and transferability to alternative BIM platforms (Revit + Dynamo, Tekla + Grasshopper) within the context of construction detailing?

Thus, the **Primary Objective** of this research is:

To develop and validate a comprehensive parametric workflow framework that enables efficient automation of residential construction detailing in BIM environments, demonstrating measurable improvements over traditional 2D manual approaches.

Furthermore, the **Specific Objectives** defined to expand the resulting framework are:

- **Analysis and Documentation:** To conduct a systematic analysis of current 2D construction detailing workflows in residential projects, quantify time requirements, resource utilisation, and error frequencies in manual detailing processes, and identify key stakeholder requirements and regulatory constraints within European building standards.
- **Framework Development:** To design a parametric workflow framework that integrates seamlessly with existing BIM processes, establishes parameter definitions, constraints, and rule-based systems for automated detail generations, and develops best practice guidelines for implementing parametric detailing workflows.
- **Technical Implementation:** To create functional parametric construction details using ArchiCAD and its integration with Grasshopper, implement automated adaptation mechanisms that respond to design changes, and ensure compliance with European building standards and IFC export compatibility.
- **Validation and Testing:** To conduct comparative performance analysis between parametric and traditional detailing methods, measure improvements in time efficiency, accuracy, and adaptability to design changes and validate results through a case study implementation and stakeholder feedback.
- **Knowledge Transfer:** To document the methodology for replication across different detail types and BIM platforms, provide implementation recommendations for industry adoption, identify limitations and suggest directions for future development.

1.4 Significance of the Study

This research addresses a critical gap in the construction industry’s transition from traditional 2D detailing practices to automated 3D parametric workflows, contributing to both academic knowledge and practical industry transformation. The study’s significance extends across theoretical understanding, practical implementation, and broader industry evolution.

Academic and Theoretical Contribution. The research contributes to the expanding body of BIM knowledge by systematically exploring the transition from 2D to 3D construction detailing through parametric automation. While existing BIM platforms provide adequate parametric and automation tools, limited attention has been given to developing comprehensive frameworks specifically for residential construction detailing automation. This study fills a methodological gap by providing a structured approach to implementing parametric workflows, moving past theoretical discussion to practical implementation strategies that can serve as a foundation for future research in construction automation and alternative BIM platforms.

Industry Impact and Practical Relevance. The primary practical significance lies in developing a replicable framework that can accelerate the industry's adoption of parametric modeling and automation technologies for creating construction details. This significance is grounded in a direct research partnership with od-do architecture, a collaboration structured to ensure that research outcomes directly address industry needs while advancing academic knowledge. This approach directly supports construction professionals seeking to transition from outdated practices by providing structured pathways for implementation and bridges the critical gap between academic research and actual industry practice. The framework's development addresses the fundamental challenge of making advanced parametric technology accessible to practitioners who may lack specialised technical expertise, thus democratising access to automation benefits across the residential construction sector.

Economic and Efficiency Benefits. The research positions itself to deliver measurable economic benefits through systematic efficiency improvements. By establishing best practices for parametric detailing implementation, the framework can contribute to industry wide productivity gains through reduced time requirements for detail creation and modification, minimised errors and associated rework costs, improved coordination between design changes and documentation, and enhanced accuracy in material specifications and regulatory compliance.

The framework’s focus on residential construction details targets a significant market segment. If adopted, it has the potential to facilitate substantial cost reductions across project delivery cycles by enabling more efficient workflows.

Timing and Strategic Relevance. This research addresses a particularly important period in the construction industry. While companies continue to prefer 2D documentation methods, there is growing recognition that these practices may be insufficient for future competitive demands. The construction industry faces increasing pressure to improve efficiency, making this research strategically positioned for organisations seeking sustainable competitive advantages through technology adoption.

The study's focus on European building standards and regulatory compliance ensures immediate relevance for regional construction markets while providing a model that can be adapted for other regulatory environments.

Scalability and Long-term Impact. The framework's design for transferability across BIM platforms positions it as a foundational methodology that can benefit diverse construction organisations regardless of their current software environments. This scalability enhances the study's long-term significance by ensuring its applicability extends beyond the specific technical implementation demonstrated, establishing a foundation for future automation initiatives in construction detailing and providing a template for effective industry-academic collaboration in technology transfer.

Ultimately, this research contributes to the body of knowledge that supports the broader evolution of construction practice. By providing a systematic methodology for automation, it aims to inform the industry's progression towards more efficient, accurate, and sustainable building processes.

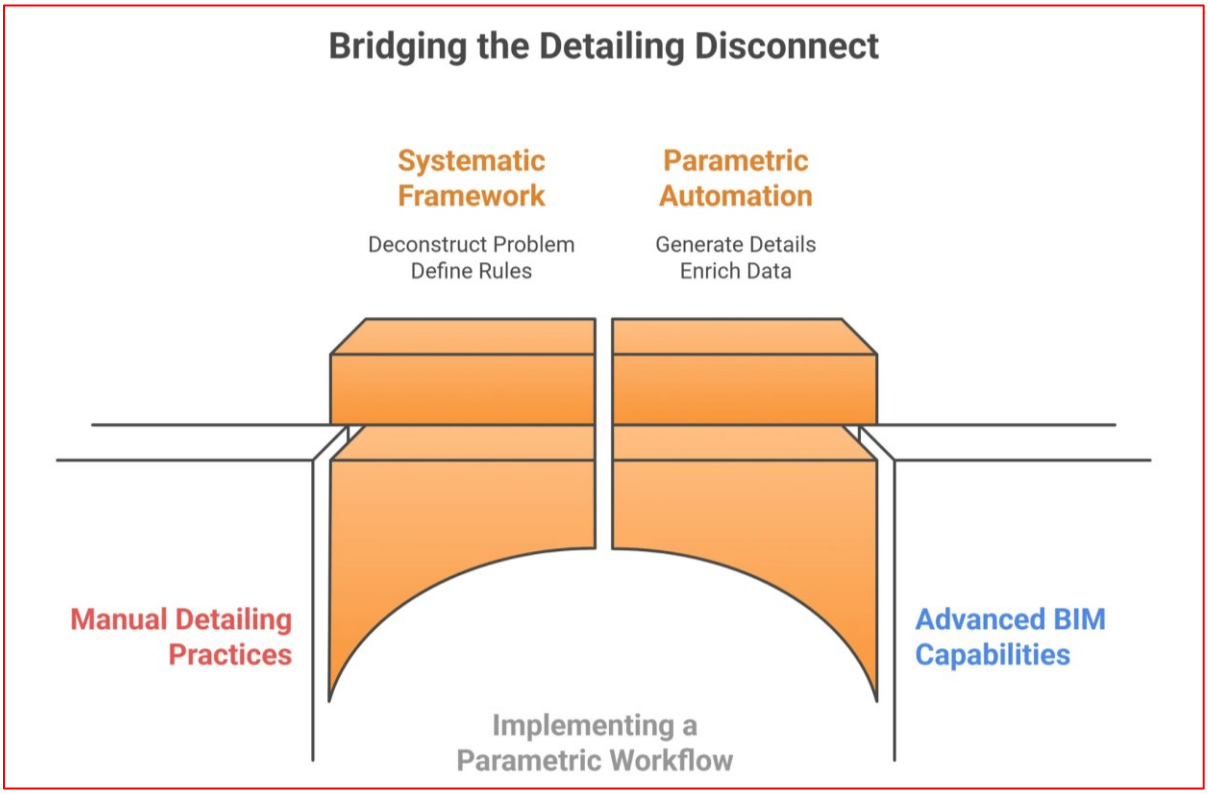


Figure 1.1 Bridging the Detailing Disconnect

1.5 Scope and Limitations

Technical Scope and Platform Focus. The practical implementation is limited to ArchiCAD as the primary BIM platform, with parametric development utilising Grasshopper. The research scope includes a comparative analysis of Autodesk Revit with Dynamo and Tekla Structures with Grasshopper to ensure theoretical framework applicability across industry-standard BIM environments.

The parametric modeling approach includes geometric parameters, material properties, and additional detail specifications as required for comprehensive construction documentation. All developed details must maintain IFC compliance to ensure cross-platform visualisation and data exchange capabilities.

Construction Detail and Building Typology Limitations. This research focuses specifically on residential building construction details, recognising the significance of this building typology while providing manageable complexity for initial framework development. The study acknowledges that while the framework may be applicable to other building types, validation will be conducted exclusively within residential construction contexts.

The scope focuses on detail-level automation rather than building-wide parametric systems, ensuring focused development of construction-specific solutions without addressing broader BIM management workflows.

Geographical and Regulatory Context. The research is geographically constrained to Slovenian and broader European construction practices and standards, reflecting the regional focus of industry collaboration and ensuring relevant regulatory compliance frameworks. This limitation acknowledges that construction detailing practices and building codes vary significantly across global markets.

Industry Collaboration and Stakeholder Limitations. The research relies on a partnership with an architectural firm, od-do architecture (Slovenia), which provides industry insight into current practices and validates proposed solutions through professional feedback. While this collaboration ensures practical relevance, it represents a limitation in stakeholder diversity that may not capture the full spectrum of industry perspectives across different firm sizes and specialisations.

These limitations will be addressed through an extensive literature review and secondary research, ensuring that broader industry perspectives are incorporated into the development of the theoretical framework and the comparative analysis phases.

Research Methodology and Validation Constraints. The practical validation phase is limited to initial development and testing of several construction details, with potential expansion depending on time and resource availability. Performance evaluation metrics focus on time efficiency and error reduction, though additional metrics may be incorporated as implementation reveals measurable benefits or challenges.

The research approach includes documentation of the learning curve and adoption challenges from a professional user’s perspective, experienced in parametric modeling with tools like Revit and Dynamo, but new to the ArchiCAD and Grasshopper environment. This perspective provides authentic insight into the practical barriers and learning curve associated with adopting new BIM software within the industry.

Implementation and Automation Considerations. Automation level determination will be conducted during the practical development phase, as the iterative learning process with ArchiCAD and parametric tools will inform a realistic assessment of semi-automated versus fully automated solutions based on practical implementation constraints.

The framework is designed with extensibility principles that support future adaptation to other building typologies and regional requirements, although such extensions fall outside the current research scope.

Distinction from Traditional 2D Detailing. This research explicitly excludes traditional 2D CAD detailing workflows from the practical implementation phase, focusing instead on native 3D BIM detailing approaches. While comparative analysis addresses 2D practices for context and workflow mapping, the developed solutions target 3D parametric environments exclusively, representing a clear departure from conventional detailing methodologies.

1.6 Thesis Structure

This thesis is structured into eight chapters that systematically guide the reader from the foundational research problem to the discussion of its implications.

Chapter 1: Introduction. Establishes the background, articulates the core problem statement, defines the research questions and objectives, and outlines the significance, scope, and limitations of the study.

Chapter 2: Literature Review. Provides a comprehensive review of existing literature on construction detailing, parametric automation, and industry standards, identifying the specific research gaps this thesis aims to address.

Chapter 3: Methodology. Outlines the qualitative, single-case study research design, detailing the data collection methods, analysis approach, and performance evaluation criteria.

Chapter 4: Case Study Context. Provides a detailed analysis of the industry partner, od-do architecture, including their existing "As-Is" workflow and the identified bottlenecks that justify the need for automation.

Chapter 5: Framework Development and Proof-of-Concept. Presents the conceptual architecture of the proposed four-stage parametric framework and documents its technical implementation through a foundation-to-wall detail.

Chapter 6: Results and Validation. Presents the findings from the proof-of-concept, including a functional demonstration, a quantitative and qualitative performance evaluation, and feedback from the industry stakeholders.

Chapter 7: Discussion. Provides a critical interpretation of the results, connecting them to the literature and exploring the practical, theoretical, and future implications of the framework.

Chapter 8: Conclusion and Future Work. Summarises the key findings, presents the final conclusions, and offers recommendations for future research.

2 LITERATURE REVIEW

2.1 Construction Detailing in BIM

Construction details are graphical representations that illustrate the technical characteristics of specific components and assemblies [8]. They serve as drawings that communicate how different building elements connect, interface, and are assembled in practice. These details represent the full-scale representation of different aspects of a project, providing detailed information about specific components that might be described more generally in other drawings [9]. Construction details bridge the gap between conceptual design intent and physical construction reality, ensuring that every element of the construction project is executed according to desired specifications [8].

The construction industry has historically relied on 2D Computer Aided Design (CAD) drawing as the foundation for the communication of design intent and construction specifications. Traditional 2D detailing practices involve creating detailed technical drawings that represent components, connections, and assembly methods using conventional CAD software platforms. These drawings are made up by two-dimensional lines, polylines, and arcs, complemented by text and annotations that provide precise dimensional and material specifications [10].

Current 2D workflows in construction detailing remain predominantly manual and labour-intensive. Industry practitioners commonly develop construction details through iterative processes involving multiple review rounds, manual modifications, and coordination across separate documentation systems [11]. The traditional approach requires skilled drafters to create detailed drawings showing exact specifications for each element, including measurements, materials, and placement details. These drawings serve as the primary communication tool between architects, engineers, contractors, and construction teams, facilitating shared understanding of design intent [12].

Despite technological advances, 2D drafting remains highly relevant in modern construction practice due to its clarity, precision, and cost-effectiveness. The method offers a level of clarity that is challenging to achieve in 3D models, focusing exclusively on critical components and their precise specifications without introducing spatial complexity. Industry professionals continue to rely on 2D detail drawings for regulatory compliance, as building codes and regulations are often written with 2D documentation standards in mind [13].

However, traditional 2D detailing practices face notable limitations in contemporary construction environments. The fragmented nature of 2D workflows often leads to coordination challenges, increased RFIs (Requests for Information), and higher potential for construction errors [11]. Manual processes are time-intensive and prone to human errors, particularly when analysing complex structural details and dimensional relationships. These limitations have prompted industry consideration of enhanced digital approaches that maintain 2D clarity while addressing coordination and accuracy challenges [14].

2.2 Automation and Parametric Approaches

The transition from traditional 2D drawings to fully parametrised 3D detailing represents an important advancement in BIM. In 2D workflows, construction details rely on separate plan, section, and detail sheets, which require manual coordination and are prone to inconsistencies. By contrast, 3D models integrate component geometry, spatial relationships, and metadata in a single environment, enabling real-time updates across all views and reducing errors.

Revit: Parametric Components and Detail Components. Autodesk Revit enables the creation of detailed 3D component families with customisable parameters (materials, layers, joinery). Users extract views (plans, sections, callouts) directly from the 3D model, annotate with detail component families (e.g., insulation, fasteners), and manage detail libraries. Revit's "Detail Level" settings (Coarse, Medium, Fine) allow toggling of construction layers for documentation at various scales, streamlining fabrication output and reducing rework [15].

Tekla Structures: Fabrication-Level Detailing. Tekla Structures excels in structural detailing with part-level accuracy. It automates the creation of welds, connections, and shop drawings from 3D steel models. The system generates CNC-compatible NC files and fabrication drawings directly from the model, supporting standardised detailing workflows and reducing detailing time [16].

ArchiCAD: Integrated 2D/3D Detail Extraction. Graphisoft ArchiCAD provides both 2D drafting and model-based detailing. The Detail Tool places markers on general arrangement views, generating live, cropped detail views that retain linked model data. This hybrid approach enables the inclusion of 2D elements (e.g., membranes, fixings) on layers excluded from the main model, maintaining coordination while enhancing graphical clarity [17].

Emerging Trends (2020-2025):

- AI-Driven Automation: Machine learning is being integrated into BIM platforms for automated clash detection, generative design, and predictive maintenance.
- Cloud Collaboration: Cloud-based collaborative platforms (e.g., BIM 360, Trimble Connect) enable real-time multi-discipline coordination and continuous model updates across sites and offices.
- Prefabrication and 3D Printing: Advances in additive manufacturing are enabling the direct production of model components from BIM data, fostering modular construction and on-site rapid prototyping [18].

The creation of construction details is one of the most critical and challenging aspects of contemporary building design and documentation. Despite advances in digital design tools and methodologies, the construction industry continues to deal with significant obstacles that compromise the quality, completeness, and effectiveness of detailed drawings and specifications.

Information completeness and accuracy. Research indicates that construction professionals waste approximately 35% of their time searching for project information, with more than 14 hours weekly lost to avoidable tasks related to incomplete or inaccurate documentation [19]. Missing dimensions, unclear specifications, and inconsistent scaling across drawings are fundamental issues that affect project execution.

Coordination and communication deficiencies. Multi-disciplinary construction projects require seamless integration between architectural, structural, mechanical, electrical, and plumbing systems, yet coordination failures remain prevalent. The fragmented nature of design teams, often working in isolation, results in conflicting information between drawing sets and specifications [20].

Technical complexity and evolving skills requirements. These are additional obstacles to effective detail creation. The construction industry faces a significant loss of practical field knowledge among design professionals, with many contemporary designers possessing strong software skills but limited construction experience. The disconnect between theoretical design capabilities and practical construction realities results in details that appear technically correct but prove problematic during actual implementation. Furthermore, relying too much on automated design tools, while increasing efficiency, can reduce critical thinking about real world constructability challenges [21].

The development of construction details constitutes a critical phase in the construction documentation process, demanding significant time and resource allocation. The preparation of construction details requires substantial professional expertise, coordination efforts, and technical precision.

Time Requirements for Detail Development. The time required for developing construction details varies considerably based on project complexity and documentation standards. Specifically for residential construction, building regulations drawings typically take 2-4 weeks to produce, with complexity and project scale being the primary factors affecting this timeline [22].

The construction documentation phase, which includes detailed drawings and specifications, typically accounts for the longest duration in the design process, requiring precision and extensive coordination with various consultants [22].

Resource Allocation and Professional Requirements. The development of construction details demands significant human resources and specialised expertise. Professional architectural services for residential projects typically command 5-15% of the construction cost as fees, with construction documentation representing a substantial portion of this allocation [23]. In Europe, where the residential construction market is estimated to be worth €1.40 trillion in 2025, the resource requirements for detailed documentation are considerable [24].

Construction detail development requires coordination between multiple professionals. The process involves extensive collaboration to ensure accuracy and compliance with building regulations, which can extend timelines significantly when coordination issues arise. Industry reports indicate that design professional teams can take up to 28 days on average to respond to construction-related queries, highlighting the resource-intensive nature of the detailed coordination process [25].

Technological and Skill Requirements. The integration of BIM technologies has transformed resource requirements for construction detail development. BIM-skilled professionals must possess proficiency in multiple software platforms, as well as coordination and clash detection capabilities. The European construction sector, which provides around 15 million direct jobs representing 7% of total EU employment, increasingly demands these specialised digital skills [26].

Current industry analysis reveals that there will be nearly 4.2 million vacancies in the construction industry between now and 2035, with significant skill gaps in BIM and digital construction technologies [27]. This shortage directly impacts the time and resources required for construction detail development, as projects compete for qualified professionals capable of producing accurate, coordinated technical documentation.

The economic consequences of construction detailing inefficiencies represent a substantial burden on the European residential construction sector, with direct and indirect cost implications that extend throughout the project lifecycle. Research demonstrates that inefficiencies in the development of construction details contribute significantly to project cost overruns and productivity losses across the European construction industry.

Quantitative Economic Impact. European construction projects experience significant cost implications from detailing inefficiencies. A comprehensive study of construction rework across UK and EU territories found that building errors, many stemming from poor coordination and inadequate detailing, amount to 11% of total project costs [28]. In residential construction specifically, defects discovered during construction are estimated to cost $2.5 billion annually in comparable markets such as New Zealand, with 90% of projects experiencing defects that average 6% of construction costs [29].

European Construction Productivity and Cost Escalation. The European construction sector faces persistent productivity challenges that compound detailing inefficiencies. Between 2005 and 2020, construction prices in the EU almost doubled, while manufacturing prices increased by only 20%. This disparity reflects declining labour productivity, with countries such as France and Austria experiencing productivity declines of more than 15% since 1995, and Spain showing declines exceeding 25% [30]. Between 2015 and 2023, construction costs in Europe rose by 36%, driven partly by inefficiencies in coordination and detailing processes [31].

Rework and Coordination Costs. Residential construction projects consistently experience rework costs. A study in China shows an average of 4.95% of total project costs, with design management accounting for 18.91% of these rework expenses [32]. Swedish construction studies indicate that defects, including those arising from detailing coordination failures, correspond to 4.4% of production costs and require 7% of total working time to correct. The most common defect types include a lack of coordinated design work and mistakes in production planning [33], directly related to inadequate detailing processes.

These quantitative findings demonstrate that construction detailing inefficiencies impose measurable economic burdens on European residential construction, necessitating improved coordination methodologies and technological solutions to enhance project cost performance and industry productivity.

2.3 Interoperability and Standards

Effective construction detailing in a digital environment relies not only on meeting product and performance regulations but also on adhering to standards for data interoperability. These standards ensure that information remains consistent and machine-readable across different software platforms and project phases. Key frameworks governing this data exchange include the Industry Foundation Classes (IFC) for open data models, as well as concepts such as Level of Development (LOD) [34] and Level of Information Need (LOIN) [35], which define the reliability and richness of model data.

European regulatory requirements for residential construction detailing are primarily governed by the Construction Products Regulation (CPR 202/3110), the Energy Performance of Buildings Directive (EPBD 2018/844, revised 2024), and fire safety standards under Eurocodes and the EN 13501 series. Together, these establish harmonised performance criteria for product marketing, thermal insulation, energy efficiency, and fire behaviour, ensuring that detailing in residential buildings meets essential safety, durability, and environmental mandates.

Construction Products Regulation (CPR 2024/3110). Regulation (EU) 2024/3110 [36] replaced CPR No. 305/2011, setting out a performance-based framework for marketing all construction products in the EU single market:

- Requires a Declaration of Performance (DoP) and CE marking aligned with harmonised standards, enabling free movement of products across Member States.
- Defines roles for manufacturers, distributors, importers, notified bodies, and market surveillance authorities.
- Emphasises environmental and circular-economy aspects

Relevance to Detailing: All materials and assemblies specified in detailing (e.g., insulation boards, sealants, joint profiles) must carry a CE marking under the CPR, with declared characteristics (mechanical, thermal, and fire) matching the design requirements.

Energy Performance of Buildings (EU 2024/1275). The EPBD [37] establishes minimum energy-performance requirements for new and existing buildings, aiming for cost-optimal thermal performance and nearly-zero energy buildings (NZEB):

- Member States must adopt national energy-performance frameworks, including thermal transmittance (U values) for walls, roofs and floors, and energy performance certificates (EPCs).
- For residential buildings, typical NZEB thresholds demand wall U values ≤ 0.20-0.30 W/m²K, roof ≤ 0.15 W/m²K, depending on climate zone.
- New 2024 revision mandates a 16% average primary-energy reduction in residential buildings by 2030 and 20-22% by 2035.

Relevance to Detailing: Construction details must integrate continuous insulation layers, thermal-bridge mitigation (e.g., insulated cavity closures and thermally broken connectors), and airtightness detailing to achieve the required U-values and air permeability targets.

Fire-Safety Standards and Eurocodes:

- **Reaction to fire classification (EN 13501-1)**

Products and building elements are classified A1-F for reaction to fire, with A1/A2 being non-combustible and B-F combustible materials. Sub-classes s1-s3 (smoke) and d0-d2 (droplets) further refine performance [38].

> Relevance to Detailing: All façade insulation, cladding, joint sealants, and internal linings must meet minimum reaction-to-fire classes specified by national fire regulations (often ≥ A2-s1, d0 for external walls in residential buildings).

- **Structural Fire Design (EN 1991-1-2 and EN 1992-1-2/EN 1993-1-2 etc.)**

Eurocode 1 Part 1-2 defines thermal actions for standard fire curves (ISO 834) and parametric fire scenarios, with Annex E providing characteristic residential fire-load densities (e.g., 200 MJ/m² for dwellings) [39].

Relevance to Detailing: Construction details at fire compartment boundaries (e.g., separating walls, floor-to-wall junctions, and service penetrations) must be detailed with appropriate fire-stopping materials and junction assemblies to ensure the required REI rating (e.g., caulk-filled controlled joints and intumescent wraps around penetrations).

2.4 Adoption and Industry Barriers

The **technology-industry adoption barrier** represents another critical gap, as evidenced by the persistent disconnect between BIM technological advancement and construction practitioners' knowledge base [40]. This knowledge gap is particularly pronounced in the context of construction details, where traditional detailing methods continue to dominate despite the availability of sophisticated parametric modeling tools. The notable gap in industry knowledge and application of advanced BIM capabilities suggests an urgent need for educational initiatives and practical implementation frameworks.

Industry-academia collaboration initiatives offer significant potential for bridging the technology-practice divide. Research opportunities exist in developing practical implementation strategies that translate advanced parametric modeling capabilities into accessible tools and methodologies for construction practitioners [40]. This includes creating educational frameworks, training programs, and transition strategies that facilitate the adoption of parametric construction detail modeling in traditional construction environments.

2.5 Research Gaps and Opportunities

Despite significant advances in BIM and parametric design technologies, several critical gaps persist in the specific domain of construction details automation and parametric modeling. The literature reveals a fundamental disconnect between technological capabilities and industry implementation, particularly in the detailed construction documentation phase.

One of the most prominent gaps lies in the **limited focus on construction detail-specific applications** within current BIM research. While extensive research exists on broader BIM implementations and general parametric modeling approaches, there is insufficient attention to the spatial scale and technical complexity of construction details. Current research primarily concentrates on large-scale public buildings and macro-level project management, leaving a significant void in understanding how parametric modeling can be effectively applied to the intricate components that form the backbone of construction documentation.

Systematic integration challenges constitute a significant research gap, with current studies lacking comprehensive methodological frameworks for integrating parametric modeling specifically into construction detail development workflows. The absence of systematic integration based on technical research contents has resulted in fragmented approaches that fail to provide cohesive solutions for construction detail automation. This gap is compounded by the limited availability of specific technical application analysis that combines actual design scenarios, resulting in weaker practical guidance for industry practitioners.

The **interoperability and standardisation gap presents ongoing challenges in the construction detail parametrisation**. Current research reveals significant limitations in data exchange protocols and standardisation frameworks specifically designed for parametric construction details [41]. While general BIM interoperability has received considerable attention, the specific requirements for automated construction detail generation and modification remain underexplored, creating barriers to seamless workflow integration across different software platforms and project stakeholders.

The identified gaps present substantial opportunities for advancing the field of parametric construction detail modeling. **Development of detail-specific parametric frameworks** represents a primary research opportunity, focusing on creating systematic methodologies that address the unique requirements of construction detail automation. This includes developing standardised parametric libraries for common construction assemblies and creating adaptive frameworks that can accommodate varying project requirements and regional construction practices.

Artificial intelligence integration presents emerging opportunities for enhancing the automation of parametric construction details. The potential for AI-driven optimisation of construction details, automated error detection, and intelligent adaptation of parametric models based on project-specific constraints represents a frontier research area [42]. This technological convergence could address current limitations in manual parametric model development and create more responsive and intelligent construction detail systems.

Performance-based parametric modeling offers opportunities to integrate construction detail automation with broader building performance objectives. Research opportunities exist in developing parametric frameworks that simultaneously optimise construction details for structural performance, energy efficiency, constructability, and cost-effectiveness [43].

The **standardisation and interoperability** research domain presents opportunities for developing industry-wide protocols specifically tailored to parametric construction details. This includes creating exchange formats, data standards, and collaborative workflows that enable seamless sharing and modification of parametric construction detail libraries across different software platforms and project teams [41].

These research opportunities collectively point toward a transformative potential for parametric modeling in construction detail automation, provided that systematic approaches are developed to address the current technology-industry gap and create practical, implementable solutions for construction practitioners.

3 METHODOLOGY

The research presented in this thesis is structured around a qualitative, single-case study methodology. This approach is specifically designed to conduct an in depth, exploratory analysis of a complex real-world problem within a defined context. The primary objective is to gain a deep understanding of existing workflows, identify specific challenges, and develop a targeted, actionable framework for improvement, rather than producing broad, statistically generalisable findings.

3.1 Research Design

A single case study approach was selected due to the unique opportunity for a close industry-academia collaboration with od-do architecture, an industry partner of the author's master's program. This collaboration provided direct access to an active professional environment and its associated project data, which is essential for understanding the nuances of current construction detailing practices. This methodology allows for a detailed investigation into the "how" and "why" of current processes, providing rich qualitative data that would be difficult to obtain through a large-scale survey or a purely qualitative study. The focus on a single case study allows for a deeper examination of the specific bottlenecks and pain points faced by a real company, making the proposed solution highly relevant and practical for the target audience.

3.2 Data Collection Methods

Data for this study was collected through a combination of qualitative and quantitative methods, primarily focused on a deep analysis of od-do architecture's current practices. The following methods were employed:

- **Semi-Structured Interviews and Direct Observation:** Initial data was gathered through semi-structured interviews with key personnel involved in the detailing process. These discussions were supplemented by direct observation of their workflow, allowing for a first-hand understanding of how they translate a 3D BIM model into a final set of construction details.
- **Artifact Analysis:** A complete 1:50 scale BIM model of a residential project, provided by the company, served as a primary artifact for analysis. This model was used to deconstruct their existing detailing workflow and to serve as the basis for developing and testing the proposed parametric framework.

3.3 Data Analysis Approach

It is important to note that due to the single case study methodology and the practical constraints of the project, the sample size for data collection is limited. As a result, the analysis will be descriptive and qualitative in nature, focusing on identifying patterns and inefficiencies rather than generating statistically significant data. The analysis involved mapping the “As-Is” workflow based on observations and artifact review to visually identify patterns of inefficiency and opportunities for automation.

3.4 Performance Evaluation and Success Criteria

Given the qualitative nature of the research, success will be measured through a combination of analytical and observational criteria, rather than through a reliance on extensive statistical data. The primary goal is to provide a comprehensive analysis of the potential for improvement. Key performance indicators will focus on the expected benefits of the parametric framework, including:

- **Efficiency Gains:** An analysis of the time and effort required to produce and modify a specific construction detail using the new parametric framework, in contrast to the time and effort required by the traditional manual process.
- **Error Reduction:** An evaluation of the framework’s capacity to reduce common detailing errors and inconsistencies identified in the initial workflow analysis.
- **Workflow Adaptability:** An assessment of how seamlessly the proposed framework can be integrated into the existing BIM workflow and its ability to adapt to design changes.

The success of this research will be determined by its ability to provide a well-reasoned and documented proof of concept for a parametric workflow, demonstrating a clear and persuasive case for its adoption based on logical analysis and qualitative observation. It will be assessed based on the framework's functionality, the improvements it demonstrates, and its potential for practical implementation. The following criteria will be used to evaluate the outcomes:

1. **Functional Demonstration:** The creation of at least one fully functional parametric construction detail that successfully generates all required elements and accurately responds to changes in the ArchiCAD model.
2. **Comparative Analysis:** A qualitative analysis, supported by observational data, that contrasts the time and effort required to produce a detail using the new parametric framework versus the traditional manual process. This will provide clear proof of concept for the efficiency benefits.
3. **Positive Stakeholder Feedback:** The industry partner (od-do architecture) provides positive feedback on the framework's usability, its ability to address their identified pain points, and its potential for future implementation.
4. **Reproducible Methodology:** The development of a clear and well-documented process that can be replicated and applied to other construction details, demonstrating the framework's scalability beyond the initial proof-of-concept.

3.5 Methodological Limitations

It is essential to acknowledge the methodological limitations inherent in this study's design, which provide context for interpreting its findings.

The primary limitation is the use of a single-case study methodology. While this approach provided deep, qualitative insights into the specific workflow of od-do architecture, the findings are not statistically generalisable to the broader AEC industry. The identified bottlenecks and the effectiveness of the proposed framework are context-specific, and firms with varying sizes, specialisations, or BIM maturity levels may face different challenges.

Furthermore, the data collection relied on qualitative methods, including artifact analysis and semi-structured interviews. This approach yields rich, descriptive data but is also subject to interpretation. The performance evaluation, particularly the time-efficiency comparison, is based on observational data rather than a large-scale, controlled experiment, and therefore reflects a specific instance rather than a universally applicable benchmark.

Finally, the validation of the framework relies on feedback from a limited set of stakeholders within a single architectural firm, which may not capture the full spectrum of industry perspectives across different disciplines. The research also acknowledges the unique perspective of the author, who was new to the ArchiCAD and Grasshopper environment; this provides authentic insight into the learning curve but may differ from the experience of a seasoned expert.

Despite these limitations, the study's primary objective was to develop a deep, contextually relevant proof of concept and a replicable framework rather than to produce broadly generalisable statistics, for which the chosen methodology was well suited.

4 CASE STUDY CONTEXT

This Chapter presents an analysis of the current construction detailing workflow at od-do architecture. This analysis, based on direct observation and project artifact review, serves as the “As-Is” benchmark against which the proposed parametric framework will be developed and evaluated.

4.1 Od-do Architecture: Firm Background

Od-do architecture is an architectural firm based in Ljubljana, Slovenia, with a portfolio of projects ranging from residential buildings to large-scale urban developments. The firm places a strong emphasis on sustainable design, technological innovation, and a collaborative approach. This commitment to detail, combined with their active use of modern BIM workflows, makes them an ideal partner for this research, as they represent a forward-thinking firm that still encounters challenges with manual detailing.

4.2 Existing BIM Workflow (As-Is)

The current workflow at od-do architecture for generating construction details is a hybrid, model-centric process that utilises ArchiCAD’s native capabilities. This approach is already more advanced than traditional 2D CAD workflows, as it leverages a central 3D model as the single source of truth. The process can be broken down into the following key steps:

1. **Initial Model Creation:** The design team creates a comprehensive 3D BIM model of the entire building in ArchiCAD at a scale of 1:50. This model is primarily developed for documentation purposes and aligns with a Level of Development (LOD) 300 standard. While newer standards, such as Level of Information Need (LOIN), are becoming more prevalent in BIM, the LOD framework remains a widely understood and practical metric for describing the visual and geometric content of a model at various stages. The use of LOD 300 indicates that the model contains specific information about the elements, allowing for accurate quantity take-offs and coordination [34].
2. **Detail Enhancement:** After the core model is complete, the team manually adds specific elements that are required for detailed construction drawings but are not typically included in the general 1:50 model. These elements include specialised layers and components, such as waterproofing membranes, insulation layers, flashing, and specific fasteners.
3. **2D Detail Generation:** Using ArchiCAD’s native detailing tools, the team creates 2D sections and callouts from the enhanced 3D model. These live views are then further annotated with 2D linework, fills, and text to create the final construction details

This process, while model-centric, still contains a significant manual step. The workflow will be visually represented as an As-Is diagram (Figure 4.1).

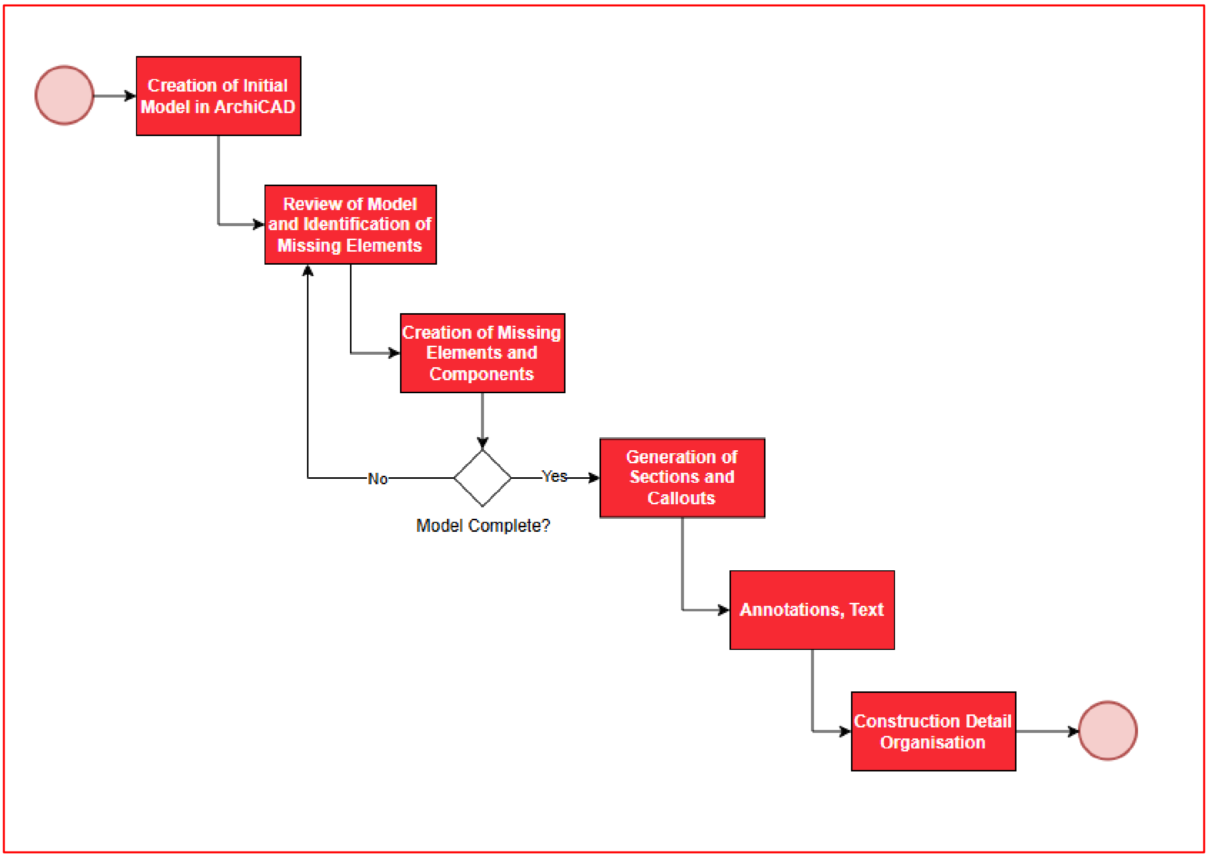


Figure 4.1 As-Is Diagram of the current process

4.3 Identified Bottlenecks and Automation Opportunities

Based on the analysis, the most significant bottleneck in the current workflow is the time-consuming manual process of Step 2: Manually Add Specialised Detail Elements. Although ArchiCAD's layering system makes core elements, such as floors and walls, straightforward to model, the specific components required for accurate construction details must be created and placed manually. This task is repetitive and prone to error, as it requires meticulous attention to material dimensions and compliance with specifications.

This manual process creates a direct and compelling opportunity for automation. A parametric framework could address this inefficiency by:

- **Automating Detail Generation:** Instead of manually creating each element, a parametric component could generate the full detail automatically based on high-level parameters (e.g., wall type, floor thickness, roof pitch).

- **Ensuring Consistency and Accuracy:** The framework could embed rule-based logic to ensure that all generated elements comply with predefined standards, reducing the risk of human error and inconsistencies.
- **Improving Adaptability:** When a change occurs in the main building model, a parametric detail would automatically update, eliminating the need for a manual review and rework of every related detail.

The development of this research will be guided by these identified bottlenecks, with the goal of creating a "To-Be" workflow that significantly streamlines the detailing process and improves overall project efficiency. The success of the project will be determined by the framework's ability to address these specific challenges effectively.

Figure 4.2 Od-do's architecture model for documentation

5 FRAMEWORK DEVELOPMENT AND PROOF OF CONCEPT

This chapter presents the core practical contribution of this research: the development of a parametric framework designed to automate the creation of construction details in a BIM environment. The preceding chapters established the theoretical foundation and the industry context, culminating in a detailed analysis of the current "As-Is" workflow at od-do architecture (Figure 4.1). That analysis identified a critical bottleneck: the time-consuming and error-prone manual process of modeling specialised components required for construction detailing, even within a sophisticated model-centric workflow.

The framework detailed here directly addresses this inefficiency. It represents the practical application of the proposed "To-Be" workflow (Figure 5.1), moving beyond traditional, static detailing methods towards a dynamic, rule-based approach. By leveraging the interoperability between **ArchiCAD**, as the primary BIM authoring tool, and the visual scripting capabilities of **Rhino/Grasshopper**, this research demonstrates a replicable method for transforming construction detailing from a manual task into an automated system. The goal is not only to improve efficiency but also to enhance accuracy, consistency, and adaptability to design changes.

This chapter is structured to guide the reader from the high-level conceptual design of the framework to its specific technical implementation, using a proof-of-concept detail, the foundation slab and external wall connection, to demonstrate the framework’s practical application.

5.1 Development Strategy and Toolchain

The framework development strategy is a direct response to the workflow analysis presented in the previous chapter. This strategy is designed to create a practical, integrated solution that addresses the specific bottlenecks identified in od-do architecture's current detailing process. The goal is to develop a parametric framework that replaces the manual effort of modeling detail-specific elements with an automated, rule-based system, thereby improving efficiency and consistency.

The technical foundation of this research will be built upon a specific and interoperable software stack that aligns with the industry partner's existing environment. The framework will be developed using ArchiCAD 28 as the primary BIM authoring tool. For the parametric modeling and automation logic, Rhino 8 and its visual scripting plugin Grasshopper will be used. This combination is ideal as Grasshopper provides a powerful, graphical environment for defining complex geometric and data relationships, which can then be directly integrated with the ArchiCAD model. This toolchain was selected to ensure the framework is fully compatible with the company's current software and can be implemented without a complete overhaul of their existing processes.

The integration of the parametric framework is designed to be a direct replacement for the most time-consuming part of the current workflow: the manual modeling of specialised detail elements. Instead of manually enhancing the base 1:50 model, the detailer will use the new parametric tool to automatically generate and place these components. This approach significantly streamlines the process and embeds a higher level of accuracy and consistency from the start.

The new "To-Be" workflow can be visualised as a logical evolution of the current process:

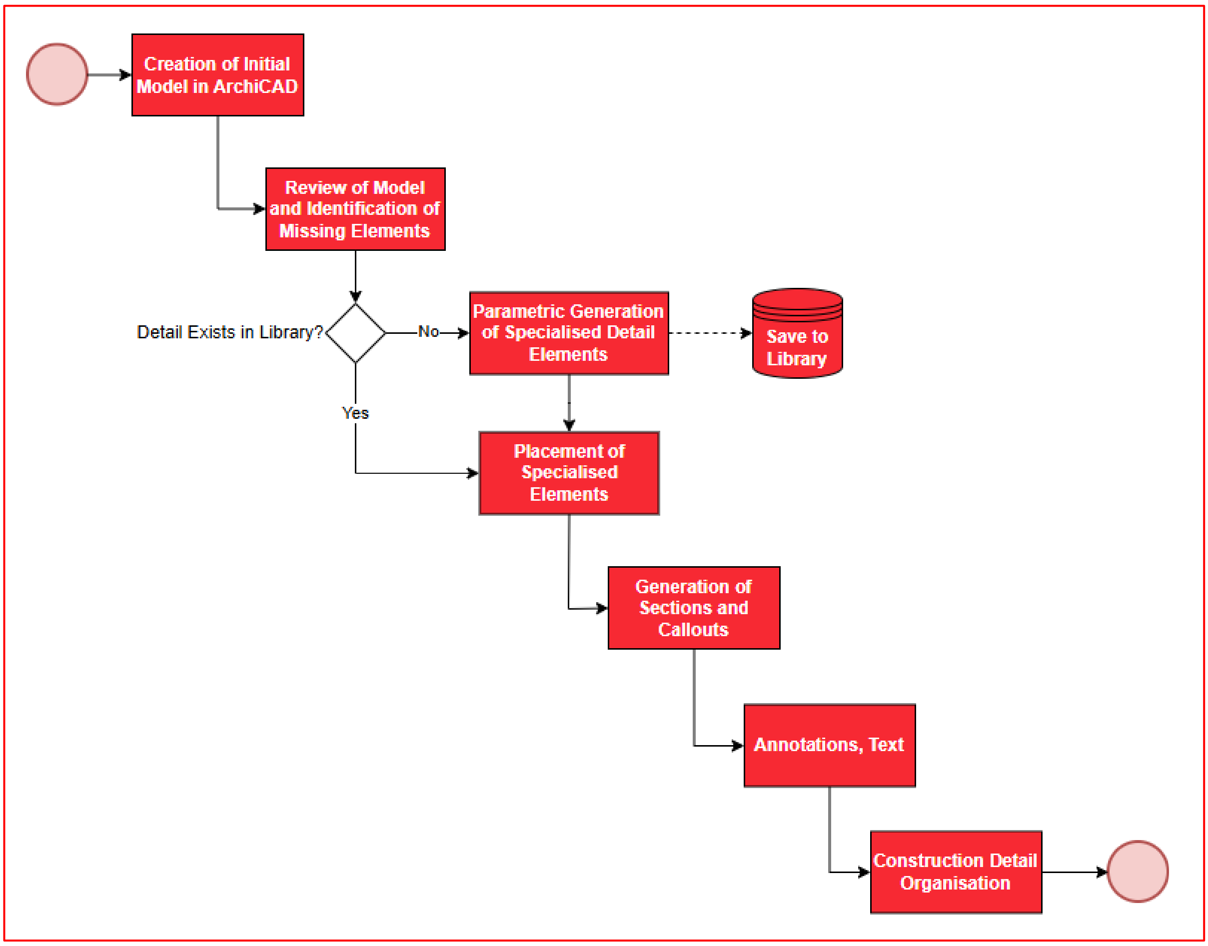


Figure 5.1 To-Be diagram of the proposed workflow

This methodology enhances the existing workflow by automating the most laborious step. It allows the detailer to focus on the higher-level design decisions and final annotation, while the framework handles the repetitive and rule-based generation of components. This approach minimises disruption while maximising the potential for efficiency gains.

5.2 Conceptual Framework Architecture

The development of the parametric framework is guided by a clear conceptual architecture designed to ensure its effectiveness, usability, and relevance to industry practice. This architecture is not merely a technical solution but a strategic approach to systematising the creation of construction details. It is founded on a set of guiding principles and a logical, repeatable workflow that defines how users interact with the system to produce accurate and consistent results.

Guiding Principles. To ensure the framework is robust and practical, its design is based on four fundamental principles:

- **Modularity:** Each parametric detail is designed as a self-contained, independent block. This means that a foundation detail, for example, contains all the logic, parameters, and geometry needed for its own generation without relying on other detail components. This modularity prevents the development of overly complex, interdependent systems and allows details to be developed, tested, and updated individually.
- **Reusability:** The underlying logic developed for one detail is structured to be adaptable for others. By establishing a consistent methodology for defining parameters and geometric relationships, the core scripting techniques can be reused to create new details more quickly. This principle ensures that the initial effort of creating the framework yields compounding benefits over time.
- **Compliance:** The framework is designed to embed regulatory requirements and best practices directly into the parametric logic. By referencing manufacturer's technical drawings, which are developed to meet legal standards, the geometric constraints and material properties are pre-set to ensure compliance. This shifts quality control from a final review step to an integral part of the generation process, reducing the risk of non-compliant design.
- **Replicability:** A primary goal of this research is to demonstrate that parametric automation can be accessible and straightforward to implement. Therefore, the framework is intentionally designed for simplicity and ease of replication. The processes are clearly defined, and the Grasshopper scripts are organised logically, allowing another designer with a basic understanding of the tools to replicate or adapt the framework for their own specific project needs.

5.3 The Four-Stage Framework

From the designer's perspective, the framework operates on a four-stage model that defines the user’s progress from initial data analysis to the final, documented construction detail. This workflow is designed to be intuitive and to integrate smoothly into the existing design process.

- **Stage 1: Deconstruction and Parametric Definition:** The **Setup**; the process begins with the designer deconstructing the required information from both manufacturer specifications and the existing BIM model. The geometric rules are identified, the BIM context is established with host elements, and the key dimensional variables are defined as parametric controls.

- **Stage 2: Parametric Assembly**: The **Process** itself, the script executes the core logic and takes the dimensional parameters, applying a series of pre-defined geometric constraints to generate the complete assembly of the construction detail as raw 3D geometry.
- **Stage 3: BIM Element Generation**: In this stage, the 3D geometry is translated into an **Intelligent Object**. It is necessary to ensure that essential data, such as building materials, is present to ensure interoperability capabilities and IFC compliance.
- **Stage 4: Documentation and Validation**: The **Final Deliverable**. It is important to ensure that the 2D drawing of the construction detail is correctly developed. For this, it may be needed to make graphical refinements to address software-specific display behaviour. Ultimately, a final, validated deliverable is obtained.

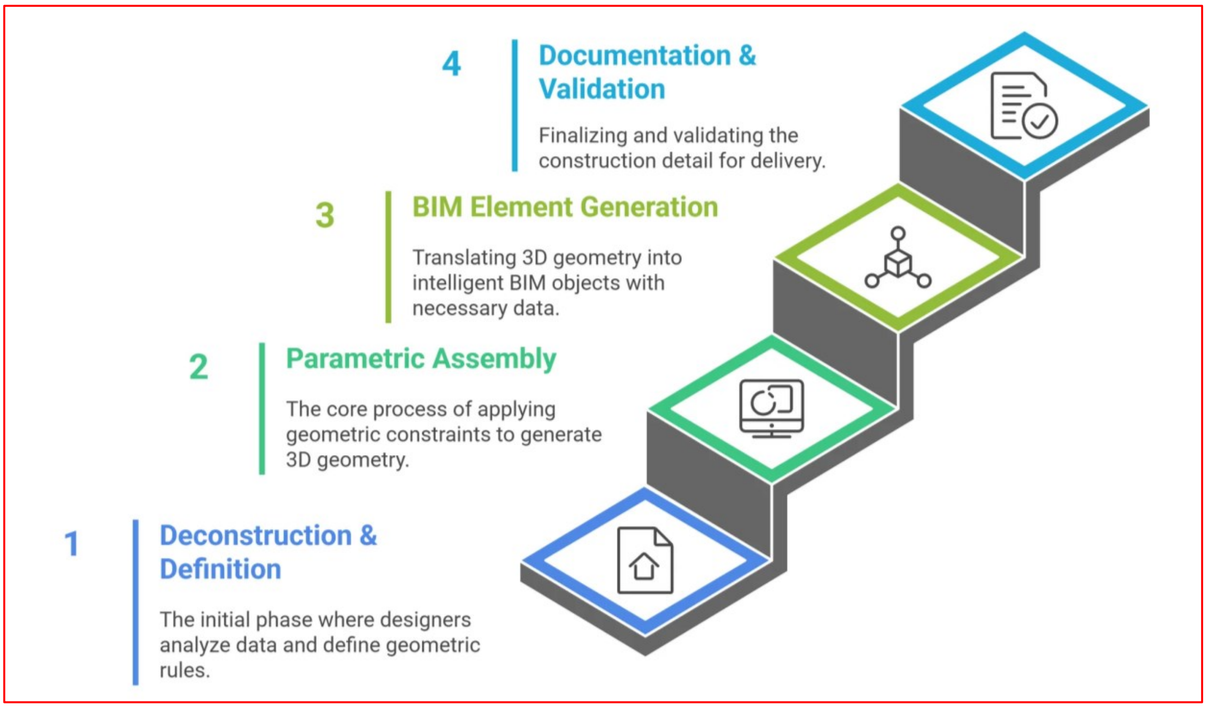


Figure 5.2 Proposed Framework

5.4 Proof of Concept: Foundation-to-Wall Detail

This section details the practical development of the parametric framework, documenting the process from initial analysis to the creation of a functional script. It follows the development workflow, the methodology used by the researcher to translate a standard industry drawing into a dynamic, automated tool.

For the proof-of-concept, the **foundation slab-to-external wall connection** was selected. This choice was made for several strategic reasons. First, foundation walls and slabs are fundamental elements that are modeled in virtually every residential project. Architectural firms, including the industry partner od-do architecture, typically have standardised composite wall and slab assemblies that are used consistently across projects. While modeling these main elements is a straightforward task in ArchiCAD, the specific junction between them requires the manual addition of several specialised components to be construction-ready.

Second, this detail represents a perfect balance of **practicality and relevance**. It is one of the most common details in residential construction, and the process of creating it, while not overly complex, is repetitive and time-consuming. This makes it an ideal candidate to demonstrate the efficiency gains of automation without introducing unnecessary complexity that deviates from the research's core goal: to showcase a simple and replicable framework.

Finally, the correct execution of this detail is critical to building performance. Errors in the placement of insulation or waterproofing can lead to significant long-term issues such as thermal bridging, which compromises energy efficiency, and water ingress, which can cause structural damage. Automating its creation can therefore directly contribute to higher quality and more reliable building envelopes.

5.4.1 Stage 1: Deconstruction and Definition

The development of the parametric script began with an analysis of an industry-standard technical drawing provided by the manufacturer FRAGMAT. The selected drawing in Figure 5.3 [44] details the assembly for the Hidroproof MT system, which provides a compliant solution for waterproofing and insulating a foundation.

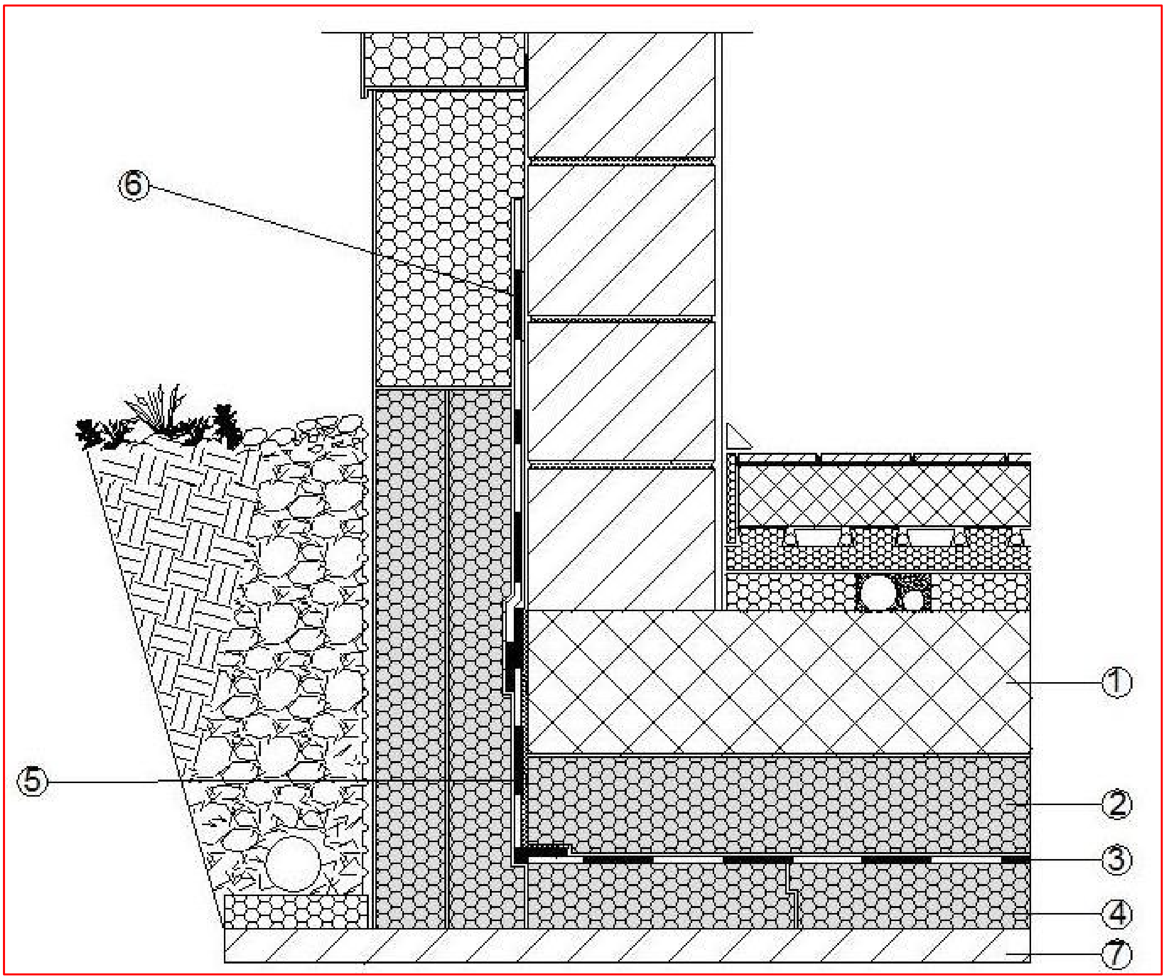


Figure 5.3 Fragmat Hydroproof MT manufacturer drawing

Composition of the detail:

1. Reinforced Concrete.
2. Horizontal Thermal Insulation (Top).
3. Horizontal Waterproofing Membrane.
4. Horizontal Thermal Insulation (Bottom).
5. Vertical Waterproofing Connection Membrane.
6. Vertical Waterproofing Membrane.
7. Blinding Concrete.

The primary goal of the framework is not to remodel the main elements (the wall and slab), as these are assumed to exist in the architect’s base model. Instead, the framework focuses on automating the addition of the specialised components required to complete the detail.

In Figure 5.4, the connection between the composite slab and wall, as it originally appears in ArchiCAD, is shown. It can be seen that the insulation that sits on top of the reinforced concrete and the backfill that goes below the blinding concrete are part of the composite. These layers should also be considered when developing the script.

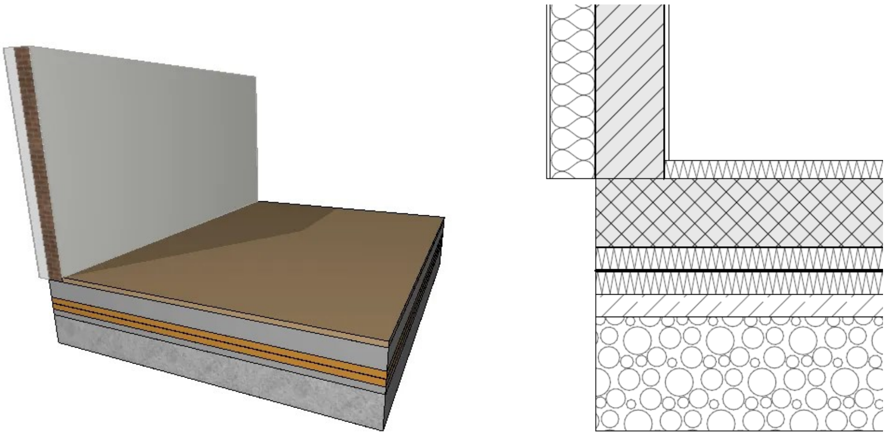


Figure 5.4 Original connection

Based on an analysis of the drawing and the original model, the following key components were identified for parametric generation:

- **Vertical Waterproofing Membrane**: Number 6 on Figure 5.3, it has a vertical disposition and an overlap with the waterproofing connection that should be modeled.
- **Vertical Waterproofing Connection Membrane**: Number 5 on Figure 5.3, it has an “L” shape and overlaps with both the horizontal and vertical waterproofing membranes.
- **Horizontal Waterproofing**: Number 3 on Figure 5.3, although it is already present as part of the composite slab’s structure, a length of this element was considered to ensure proper positioning.
- **Vertical Thermal Insulation**: Unnumbered in the reference figure, it starts above the blinding concrete and meets with the thermal insulation of the wall.
- **Blinding Concrete Extension**: Also unnumbered, it is the part where the blinding concrete extends past the slab.
- **Backfill Extension**: Similar to the previous element, it is the extension corresponding to the backfill.
- **Drainage Pipe**: Sitting on top of the blinding concrete extension.

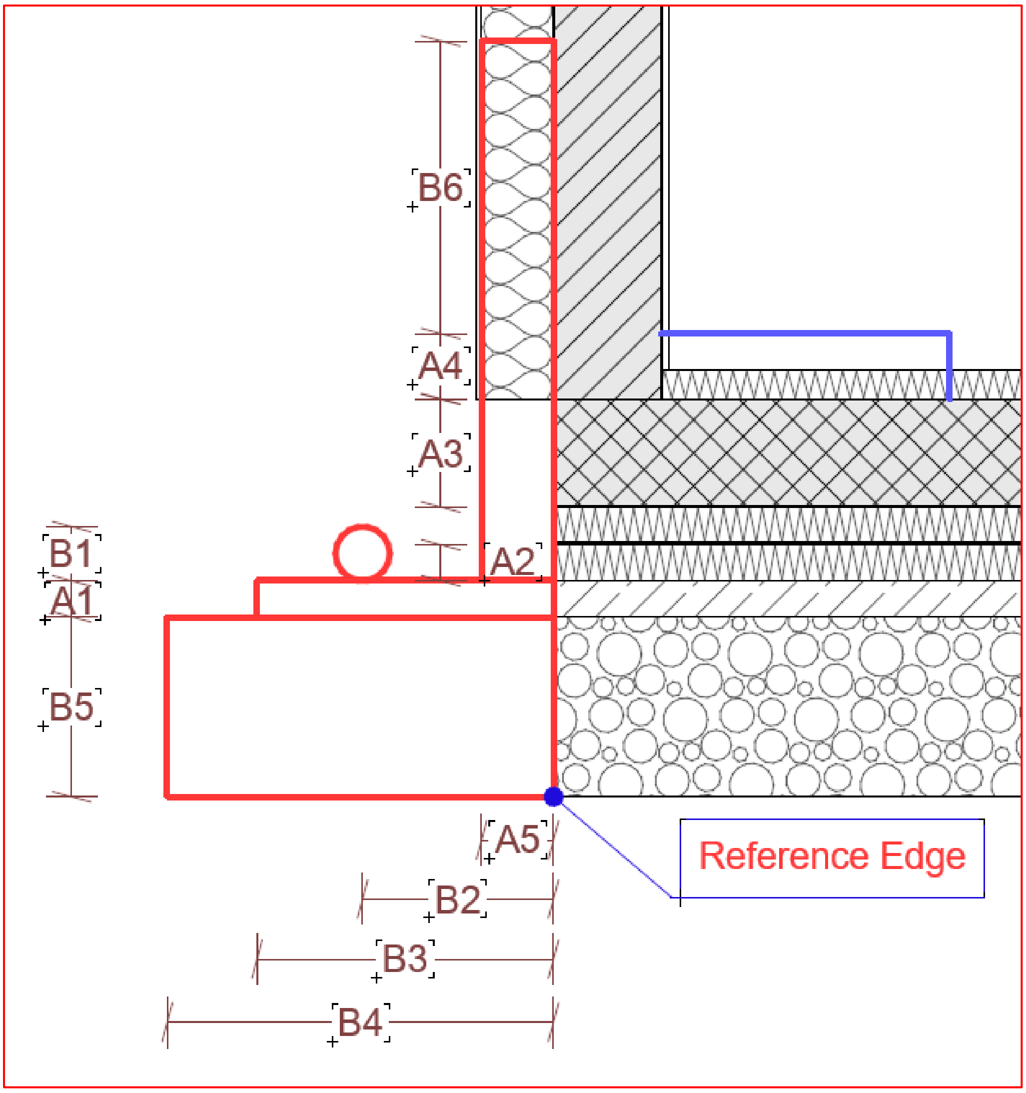


Figure 5.5 Identification of variables

Defined Inputs (Figure 5.5):

- A1: Thickness of the blinding concrete.
- A2: Thickness of one layer of the horizontal thermal insulation.
- A3: Thickness of the reinforced concrete.
- A4: Finished floor build-up.
- A5: Vertical thermal insulation thickness.
- B1: Drainage pipe diameter.
- B2: Drainage pipe extension.
- B3: Blinding concrete extension.
- B4: Backfill extension.
- B5: Backfill thickness.
- B6: Vertical thermal insulation overlaps.

After identifying the missing elements, it was important to determine the variable dimensions that control the geometry of such elements. The variables A1-A5 were defined as the primary inputs (dimensions that are commonly changed), and the variables B1-B6 were defined as the secondary inputs (dimensions that do not normally change, but are still important to define the geometry).

An important variable that is not explicitly defined is the **finished floor build-up** (A4). This thickness corresponds to the build-up that exists on top of the reinforced concrete, and it is important to determine the ground level. Having this input allows us to correctly draw the vertical waterproofing membrane, which should end at least 30 cm above this elevation.

5.4.2 Stage 2: Parametric Assembly

With the BIM context and parameters established, the core logic of the Grasshopper script generates the 3D geometry. The primary geometric strategy employed was to create a 2D cross-section of each element, position it correctly in 3D space, and extrude it along the reference to create a final 3D solid.

To achieve this, it is important to find an appropriate reference. In this case, we can obtain the edges of the slab by deconstructing the geometry in Grasshopper. From a section perspective (Figure 5.5), the bottom left corner of the slab was selected as the primary reference, and all the elements were made by applying geometric relationships to this point/line.

Since the information obtained from the slab already provides a horizontal and vertical reference that permits the creation of all the necessary elements, referencing the wall becomes unnecessary. This means that the script works for any connection slab-wall as long as the slab has the same order of layers, making it applicable to a large number of combinations.

It is important to use the most appropriate Grasshopper components to create the elements in ArchiCAD. In the case of the most complex geometries, the elements were created as morphs. The rectangular and circular elements, on the other hand, were created with the “beam” component.

The reference edge mentioned before was therefore moved as needed to create references specific to each element. For the morphs, a polyline was drawn with all the corners of the element, then it was extruded and finally converted to a morph. For the beams, the centre of the rectangle was found, and the parameters of thickness and width were adjusted. In both cases, the location of the references and dimensions were dependent on the variables set as inputs or on the previously created elements, meaning that the elements correctly adjust to the different geometric conditions defined by all the variables.

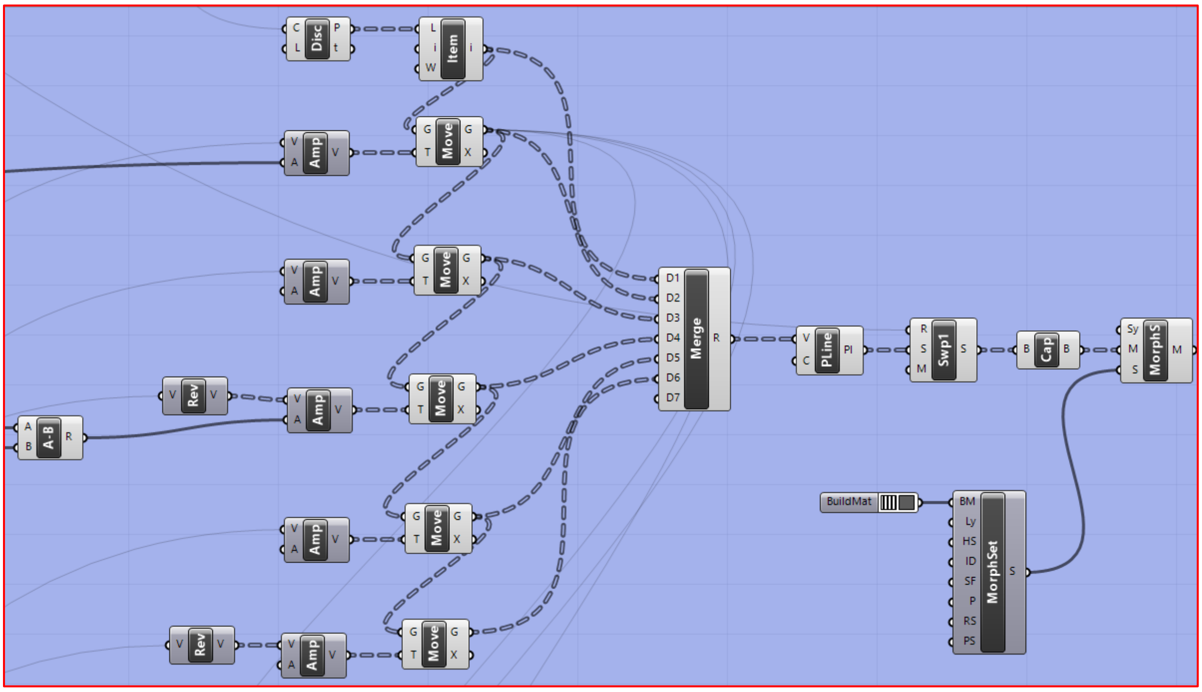


Figure 5.6 Grasshopper creation of the waterproof connection

For instance, in Figure 5.6, the generation of the waterproof connection membrane (number 5 in Figure 5.3) is displayed. Looking at the manufacturer's drawing, it can be seen that the membrane has an “L” shaped section. To create a profile, six points are required. The first point depends on the location of the horizontal waterproof membrane, which was created beforehand, and the other five points depend on the first point. Where necessary, information from the variables is included to ensure the parametric behaviour. In Figure 5.7, we can see the disposition of this element and the elements with which it interacts.

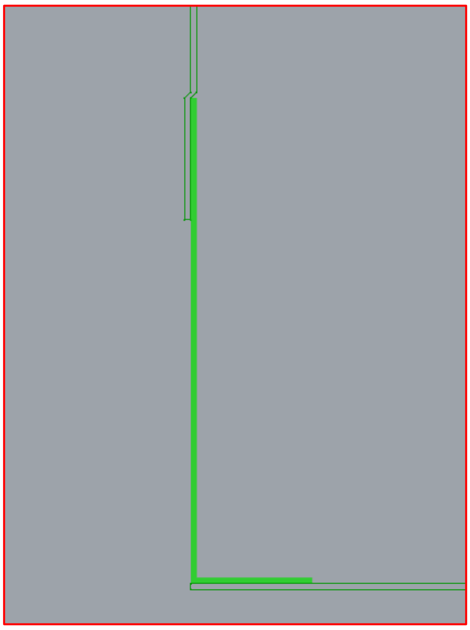


Figure 5.7 Preview of the waterproof connection in Rhino

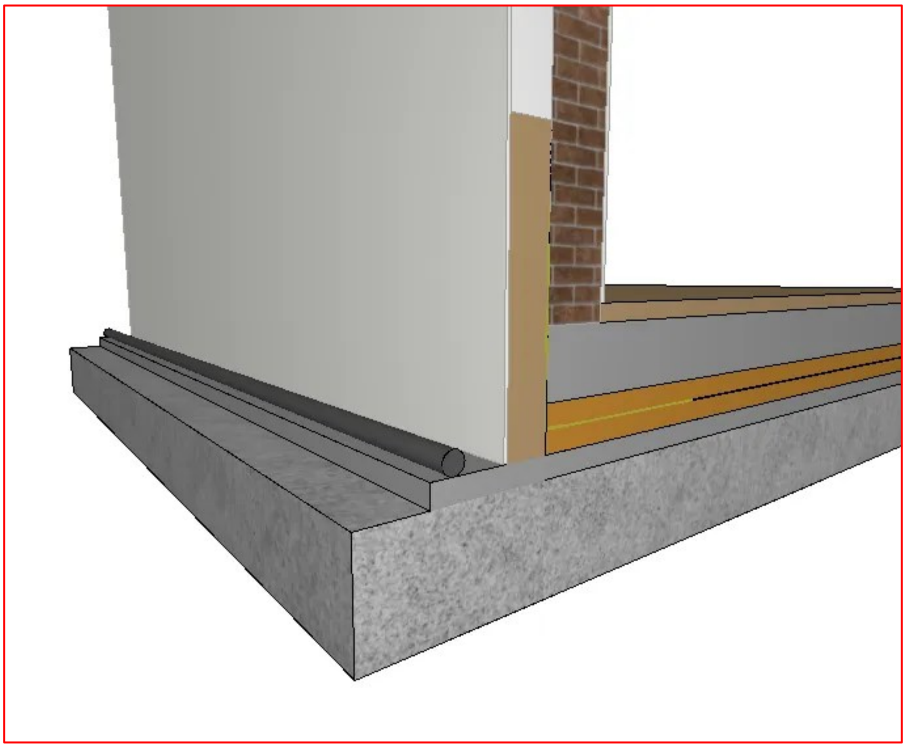


Figure 5.8 3D view after creating the elements

Figure 5.8 shows the final 3D shape of the connection after the elements are created with the script, it can be seen that all the elements have the correct geometry and are properly placed.

5.4.3 Stage 3: BIM Element Generation and Data Enrichment

Following the geometric assembly of the detail in Stage 2, the third stage of the framework focuses on the critical process of transforming the raw, algorithmically generated geometry into semantically rich and interoperable BIM components. This phase is fundamental to ensuring the output is not just a 3D model but a collection of intelligent elements compliant with the IFC standard. The methodology was executed through three phases, designed to establish a data schema, configure export protocols, and parametrically populate the model with specific information.

It is important to mention that this procedure is adapted to ArchiCAD; the same guiding principles can be used in software like Revit, but the technical implementation differs, and this should be considered when ensuring IFC compliance.

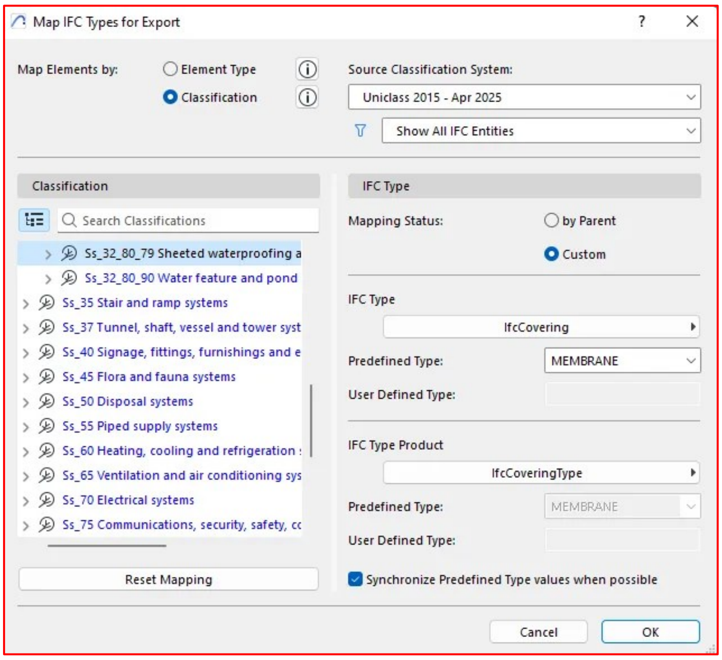
Phase 1: Establishing the Data Schema in ArchiCAD

The foundation for data integrity was established within the ArchiCAD authoring environment prior to any geometric generation. This involved two key steps:

- **Implementation of a Standard Classification System**: To ensure a consistent and industry-recognised taxonomic structure, the **Uniclass 2015** classification system was imported into the project file. It was selected for its comprehensive coverage of building systems and products, providing a precise classification for each component of the foundation detail.
- **Definition of Custom Properties**: Using ArchiCAD's Property Manager, a set of custom properties was defined to hold essential non-geometric information. These properties included performance specifications, manufacturing data, and physical attributes. It was then important to link the availability of each property to specific classifications. This ensures data relevance and prevents the assignment of inappropriate parameters to elements.

Phase 2: Configuration of the IFC Export Protocol

To ensure that the data would be correctly translated upon export, the IFC translator was configured before the data assignment in Grasshopper. This approach ensures that the rules for data exchange are established as part of the core framework. A translator was created with a specific focus on **Type Mapping by Classification.** This setting establishes a direct link between the project's Uniclass codes and their corresponding IFC entities. For instance, the waterproofing membrane (exemplified in Figure 5.9), classified as Ss_32_80_79 Sheeted waterproofing and tanking systems, was explicitly mapped to export as an IfcCovering with a MEMBRANE PredefinedType. This ensures that the element's semantic identity is correctly preserved in the IFC file, regardless of the native ArchiCAD tool (such as Morph or Beam) used for its geometric generation.



Map IFC Types for Export

Map Elements by: ○ Element Type ● Classification

Source Classification System: Uniclass 2015 - Apr 2025

Show All IFC Entities

Classification

Search Classifications

Ss_32_80_79 Sheeted waterproofing a
Ss_32_80_90 Water feature and pond
Ss_35 Stair and ramp systems
Ss_37 Tunnel, shaft, vessel and tower syst
Ss_40 Signage, fittings, furnishings and e
Ss_45 Flora and fauna systems
Ss_50 Disposal systems
Ss_55 Piped supply systems
Ss_60 Heating, cooling and refrigeration :
Ss_65 Ventilation and air conditioning sys
Ss_70 Electrical systems
Ss_75 Communications, security, safety, cc

IFC Type

Mapping Status: ○ by Parent ● Custom

IFC Type: IfcCovering
Predefined Type: MEMBRANE
User Defined Type:

IFC Type Product: IfcCoveringType
Predefined Type: MEMBRANE
User Defined Type:

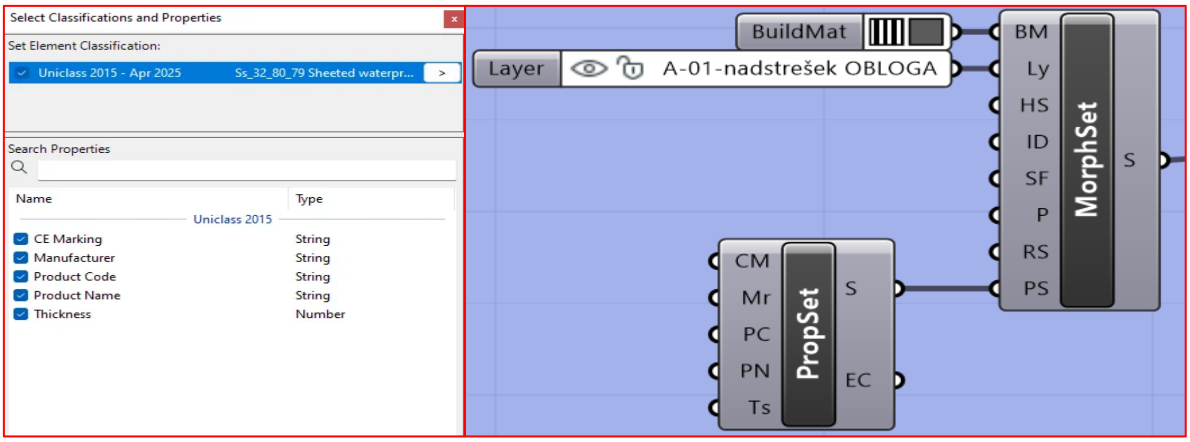
☑ Synchronize Predefined Type values when possible

Figure 5.9 Assignment of IFC types based on the Classification

Phase 3: Parametric Data Assignment in Grasshopper

With the data schema and export rules defined, the final step was to populate this framework using the Grasshopper script. For each component generated, an ArchiCAD Property Settings component was used. The workflow involved first assigning the correct Uniclass classification to the element. This action exposed the specific set of custom properties that were made available for that classification in the property manager. The properties can then be populated with text panels or number sliders.

Figure 5.10 displays the classification and property assignment to an element in Grasshopper. It's also important to define the layer for visualisation, and the building material to match the model's materials.



Select Classifications and Properties

Set Element Classification:

☑ Uniclass 2015 - Apr 2025 Ss_32_80_79 Sheeted waterpr... >

Search Properties

Name	Type
Uniclass 2015	
☑ CE Marking	String
☑ Manufacturer	String
☑ Product Code	String
☑ Product Name	String
☑ Thickness	Number

Layer: A-01-nadstrešek OBLOGA

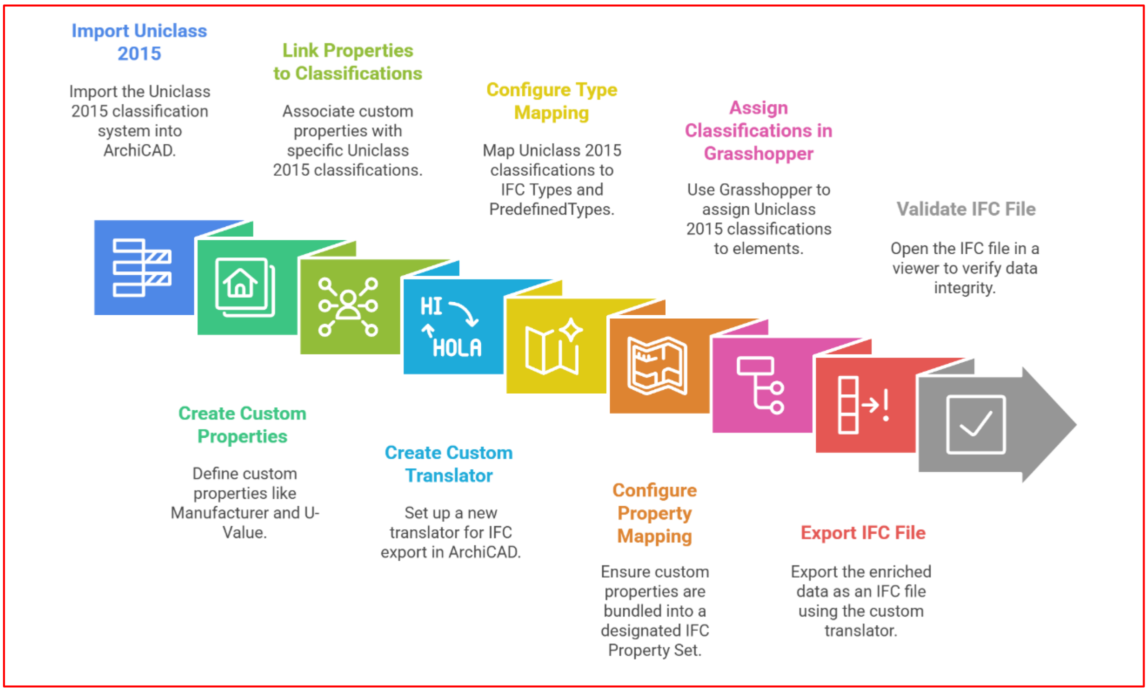
Figure 5.10 Property assignment in Grasshopper

By executing this structured process, the framework successfully enriches the parametrically generated geometry, transforming it into a collection of fully classified BIM components. Each element now carries not only its geometric definition but also a structured, interoperable data payload, fulfilling the core objective of Stage 3 and preparing the detail for the final documentation and validation phase.

The classifications used were the following:

- **Waterproofing Membranes:** Sheeted waterproofing and tanking system **Ss_32_80_79**
- **Thermal Insulation:** Rigid insulation boards and panels **Pr_25_71_70**
- **Blinding Concrete Extension:** Unreinforced concrete pad and strip foundation systems **Ss_20_05_15_91**
- **Backfill Extension:** Backfill systems **Ss_15_10_30_05**
- **Drainage Pipe:** Unplasticized polyvinyl chloride (PVC-U) solid wall below-ground drainage pipes and fittings **Pr_65_52_07_88**

For each classification, it was ensured that proper IFC types were mapped in the translator and relevant properties were created and successfully assigned within Grasshopper.



Import Uniclass 2015
Import the Uniclass 2015 classification system into ArchiCAD.

Create Custom Properties
Define custom properties like Manufacturer and U-Value.

Link Properties to Classifications
Associate custom properties with specific Uniclass 2015 classifications.

Create Custom Translator
Set up a new translator for IFC export in ArchiCAD.

Configure Type Mapping
Map Uniclass 2015 classifications to IFC Types and PredefinedTypes.

Configure Property Mapping
Ensure custom properties are bundled into a designated IFC Property Set.

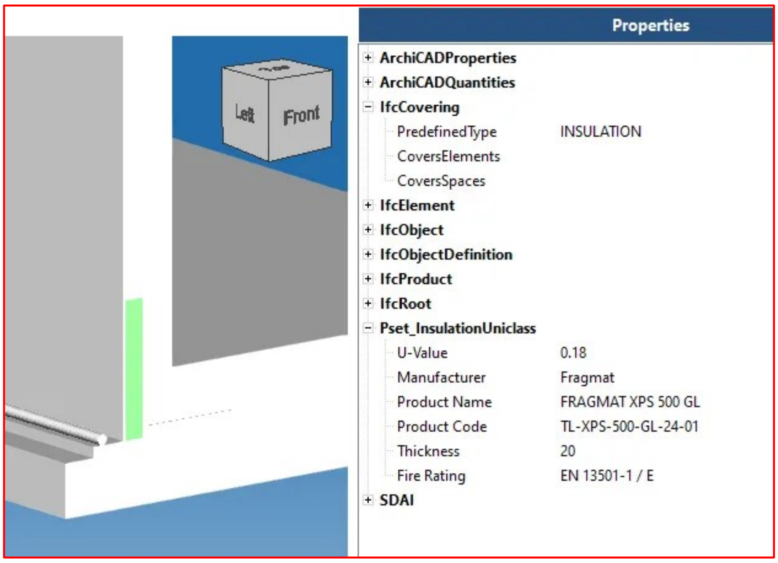
Assign Classifications in Grasshopper
Use Grasshopper to assign Uniclass 2015 classifications to elements.

Export IFC File
Export the enriched data as an IFC file using the custom translator.

Validate IFC File
Open the IFC file in a viewer to verify data integrity.

Figure 5.11 IFC Data Enrichment Process

To validate the results, the file was exported to IFC and opened in various IFC viewers, ensuring that the IFC type, predefined type, and desired properties were correctly implemented. For instance, the vertical insulation should be IfcCovering and have properties such as the fire rating and the U-value (Figure 5.12). All these properties can be parametrically set using Grasshopper, provided that the steps outlined in Figure 5.11 are followed.



Properties

```
+ ArchiCADProperties
+ ArchiCADQuantities
− IfcCovering
    PredefinedType      INSULATION
    CoversElements
    CoversSpaces
+ IfcElement
+ IfcObject
+ IfcObjectDefinition
+ IfcProduct
+ IfcRoot
− Pset_InsulationUniclass
    U-Value             0.18
    Manufacturer        Fragmat
    Product Name        FRAGMAT XPS 500 GL
    Product Code        TL-XPS-500-GL-24-01
    Thickness           20
    Fire Rating         EN 13501-1 / E
+ SDAI
```

Figure 5.12 Validation of the IFC file

5.4.4 Stage 4: Documentation and Validation

The ultimate goal of the framework is to facilitate the creation of accurate construction details. After the 3D elements are generated in ArchiCAD, a standard section view is created. A key finding of this research is that a fully automated workflow has practical limitations due to software-specific display behaviours. To produce a final, professional-quality drawing, a manual graphical refinement is necessary.

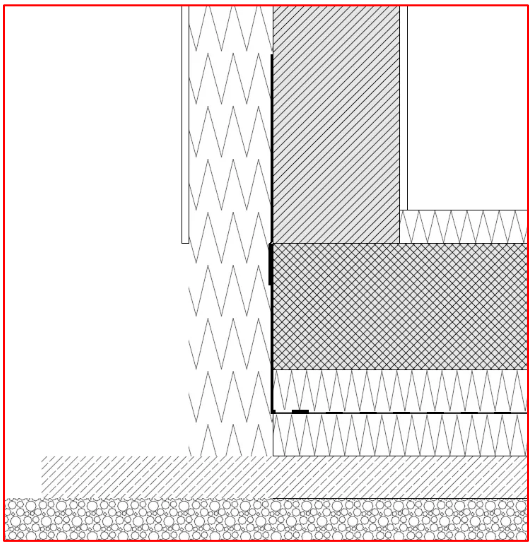


Figure 5.13 Initial section view after creating the elements

Figure 5.13 displays the initial section view after the script application; It can be seen that the elements do not have an outline line and the fills are sometimes incorrect. For instance, since ArchiCAD internally thinks the vertical insulation is a beam, the fill is generated horizontally. The waterproofing membranes have the incorrect direction in the vertical spans as well. These lines and fills can be corrected in a matter of minutes and do not represent a significant setback.

It is acknowledged that the parametric script is a powerful tool for generating the core geometry and data, but the final step of documentation requires direct user intervention to achieve the desired graphical output. This step, however, is being performed in the current company workflow, as it is recognised to be a necessary manual intervention to achieve a high-quality drawing.

Therefore, a comparison was made between the final section view and the current company's section view generated for a similar construction detail. Ensuring that the result has the same level of detail and properly showcases the disposition of the elements in the construction detail.

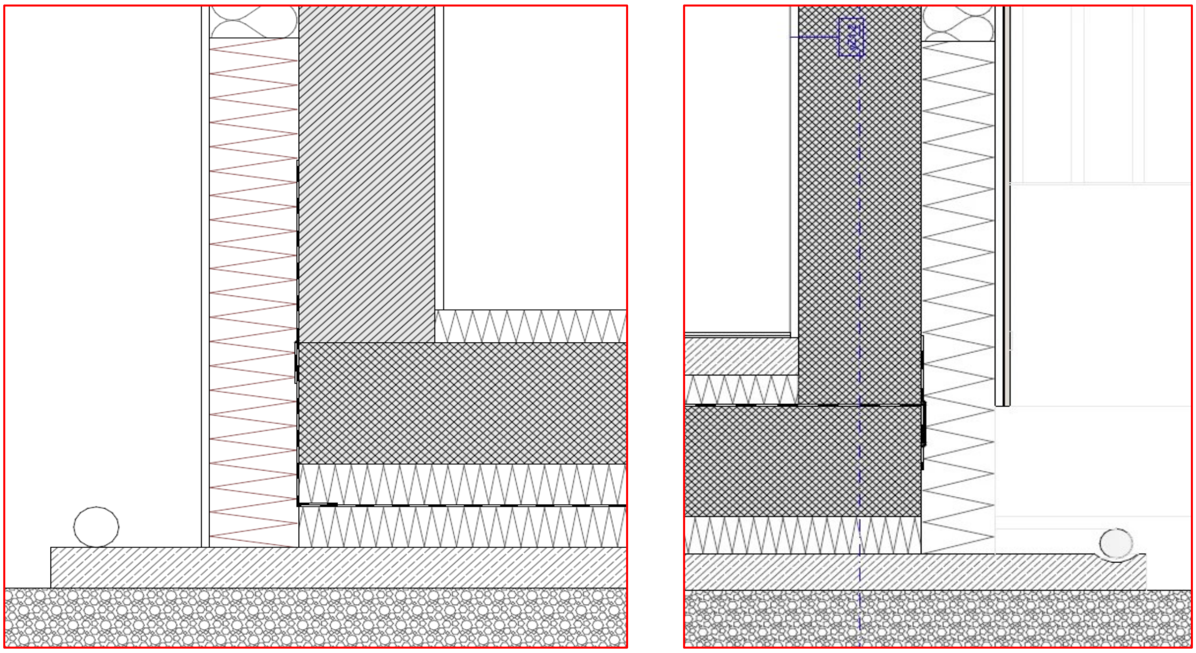


Figure 5.14 Comparison between the proposed framework and the current workflow

As shown in Figure 5.14, the final result between the view generated after the framework (left) and the current complex profile based workflow of the company (right) for a different solution of the same manufacturer, Fragmat Hidroproof AB [45], the necessary level of detail and geometric disposition of elements has been successfully achieved.

The most delicate part of this specific detail was ensuring that the transition between the different waterproofing membranes was correctly showcased in the same way as the original manufacturer's drawing (Figure 5.15).

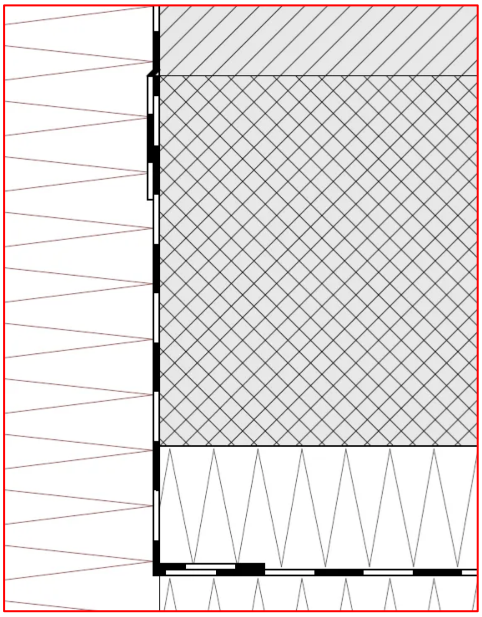


Figure 5.15 Disposition of the waterproofing membranes

Having achieved the desired result, it must be mentioned that there is a more automated way of approaching this problem; Creating the elements as GDL objects disposes of the need of the manual adjustment of fills and lines for the drawings, as GDL scripting is designed natively within the ArchiCAD environment and has 2D scripting capabilities Grasshopper does not. However, this approach was discarded as it focuses on a specific environment and cannot be reliably generalised into broader concepts, which endangers the replicability of the framework.

5.5 Quality Assurance

The framework inherently improves quality assurance by embedding geometric rules and constraints directly into the script, which significantly reduces the potential for human error and ensures consistency across all generated details. The final validation protocol is a straightforward comparison. The generated and refined 2D section view is visually compared against the original manufacturer's technical drawing to ensure all components are present, correctly dimensioned, and accurately positioned, thus validating the output for use in official construction documentation.

6 RESULTS AND VALIDATION

6.1 Functional Demonstration of the Parametric Detail

The primary validation of the framework involved a functional demonstration of the proof-of-concept script. The test aimed to confirm that the generated construction detail behaved as a true parametric system, automatically adapting its geometry in response to changes in user-defined inputs.

The script was executed multiple times, with systematic adjustments made to both the primary (A1-A5) and secondary (B1-B6) input parameters, as defined in Figure 5.5.

In all test cases, the script performed successfully. The geometric components generated by the Grasshopper script updated instantly and accurately within the ArchiCAD environment, maintaining all predefined geometric relationships and overlaps. For instance, modifying the slab thickness resulted in the correct repositioning of all associated waterproofing membranes and insulation layers without requiring any manual intervention. This dynamic behaviour confirms that the core logic of the parametric assembly is robust and functions as intended. The successful and immediate regeneration of the detail across various configurations serves as a definitive validation of the script's core functionality.

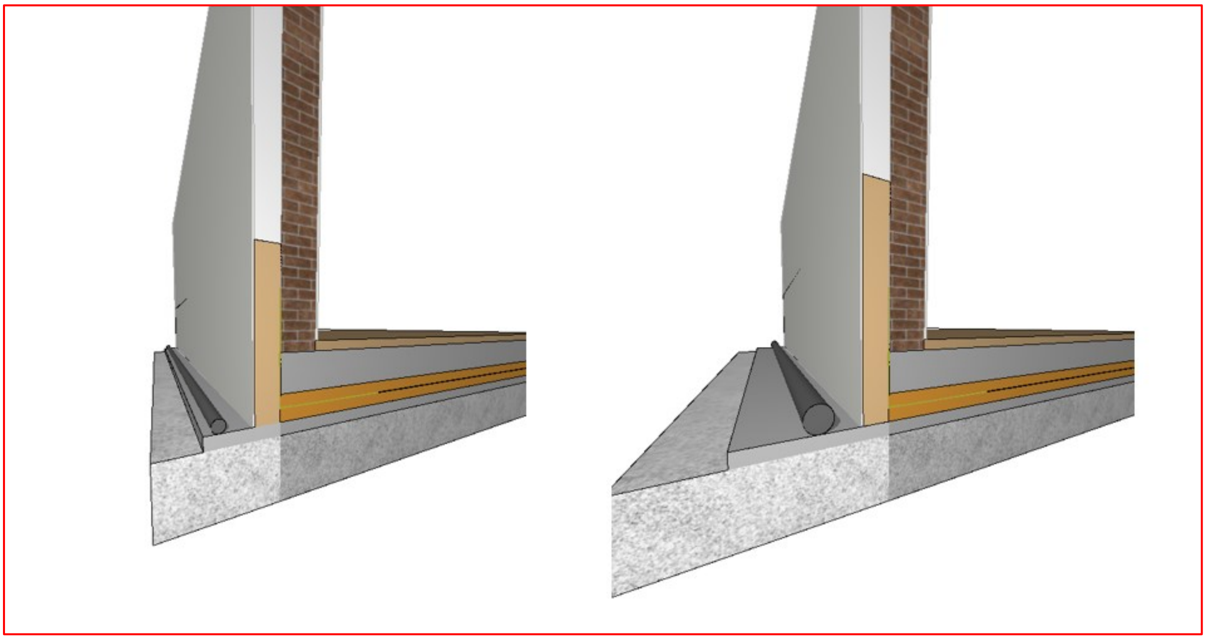


Figure 6.1 Elements created with different variable values

6.2 Quantitative and Qualitative Performance Evaluation

A comprehensive performance evaluation was conducted to measure the effectiveness of the proposed parametric framework against the traditional "As-Is" workflow. The assessment focused on both measurable efficiency gains (quantitative) and improvements in process quality and data integrity (qualitative).

Quantitative Evaluation: Time Efficiency

The primary bottleneck identified in the "As-Is" workflow was the manual, time-consuming process of modeling specialised detail components. The quantitative evaluation directly compares the time required for this task in both workflows.

It is important to acknowledge the initial time investment required for the development of the parametric script itself. This development phase involves a learning curve and a one-time effort to deconstruct the details, define parameters, and author the Grasshopper logic. However, once a script is created and added to a firm's library, the efficiency gains become significant and scalable.

The comparison is as follows:

- **Traditional Manual Workflow**: As mentioned before, a complex profile is created once the solution is selected. Just like the script, this is a one-time effort. Then, the complex profile can be saved and used for future details. However, it is a static solution, which means that after using it in different conditions, every single parameter must be adjusted to correspond to the new conditions. The time required varies depending on the assembly; the more elements that need to be created, the more manual adjustments are necessary. A detail like the one used as a proof of concept can take approximately 2 minutes to create.
- **Proposed Parametric Workflow**: This workflow is completed in two distinct phases:
    1. **Parametric Generation (30 seconds)**: The user selects the host element in ArchiCAD, inputs the required parameters in Grasshopper, and runs the script to automatically generate all geometric components.
    2. **Initial Graphical Refinement (1 minute)**: The user performs minor manual adjustments to correct software-specific display issues (e.g., fill orientation, line weights) to bring the drawing to the same level of completion as the manual method.

    These phases do not depend on the number of elements or variable dimensions, which means that the time saved is more noticeable the more complex the detail is.

For the specific case of the slab-wall connection selected as a proof of concept, to achieve the same result, the framework is 30 seconds faster. As mentioned, this gap increases according to the complexity of the detail. While it may seem that saved time is not particularly considerable, it is important to recognise that a project has a significant number of construction details. If the framework is applied to every detail across all future projects, the time saved becomes very significant in the long run.

It is important to note that the current company's workflow is already BIM-oriented and more efficient than a traditional, fully 2D oriented method, such as using AutoCAD to individually draw each detail. This demonstrates the importance the company already gives to effectiveness and the application of good practices in documentation.

Qualitative Evaluation: Process Quality and Data Integrity

Beyond speed, the framework introduces critical qualitative improvements:

- **Consistency and Error Reduction**: The manual creation of details is inherently prone to human error, such as forgetting a component, using incorrect dimensions, or creating inconsistencies between similar details. The parametric framework eliminates these risks. By embedding the geometric rules and manufacturer specifications directly into the script's logic, it ensures that every detail generated is consistent, complete, and accurate, thereby enhancing the overall quality and reliability of the construction documentation.
- **Data Integrity and IFC Compliance**: The "As-Is" workflow often results in geometrically correct but data-poor elements. In contrast, Stage 3 of the proposed framework is dedicated to data enrichment. As planned, the final output will be validated by exporting the generated detail to IFC and examining it in an independent IFC viewer. This step will confirm that each component is correctly classified (e.g., IfcCovering for membranes), carries the appropriate predefined type, and contains all assigned custom properties. This ensures the detail is not merely a drawing but a set of intelligent, interoperable BIM elements that support downstream processes, fulfilling a core promise of BIM that is often unmet in traditional detailing workflows.

6.3 Stakeholder Feedback

To validate the industry relevance and practical applicability of the framework, the proof-of-concept and its results were presented to the industry partner, od-do architecture. As the firm's "As-Is" workflow provided the foundational context for this research, their professional assessment was critical in evaluating the success of the proposed "To-Be" solution.

The feedback from the firm was positive, with the stakeholders validating that the research accurately identified a genuine bottleneck in their detailing process. Key points of positive feedback included:

- **Practical Problem-Solving**: The firm appreciated that the framework provides a targeted solution to the time-consuming and repetitive task of modeling specialised components, a challenge they face in daily practice.

- **Efficiency Gains**: The reduction in modeling time demonstrated in the quantitative evaluation was viewed as a compelling benefit, with clear potential to improve project productivity and allow designers to focus on more critical tasks.
- **Improved Quality and Consistency**: The stakeholders recognised the value of embedding design rules into a script to reduce human error and ensure a higher level of consistency across all construction details, which is a key aspect of quality assurance.

In addition to validating the benefits, constructive feedback was also provided, focusing on the practicalities of firm-wide adoption. The firm raised concerns regarding the initial investment required to train staff in Grasshopper and to develop a robust library of parametric details. Furthermore, the successful proof of concept led to discussions about its scalability and applicability to other, more complex construction details, such as window-to-wall or roof-to-wall junctions.

Overall, the feedback from Od-do Architecture served as crucial validation, confirming that the developed framework is not only a successful academic exercise but also a relevant and valuable solution with tangible potential for implementation in a professional architectural practice.

6.4 Reproducibility and Applicability of Methodology

A key objective of this research was to develop a framework that is not only effective for a single use case but is also reproducible and broadly applicable. The validation of the methodology, therefore, extends beyond the functional performance of the proof-of-concept to an assessment of its potential for future use and adaptation.

Reproducibility. The reproducibility of the research is grounded in the structured, four-stage conceptual framework presented in section 5.3. This framework provides a clear and repeatable workflow, from deconstruction and definition to final documentation, that can be followed to create other parametric details. The detailed documentation of the proof-of-concept in this thesis serves as a practical guide, demonstrating how the principles of each stage are put into practice. The guiding principles of **Modularity** and **Replicability** ensure that the process is straightforward to understand and implement for a designer with foundational knowledge of the software tools.

Applicability and Scalability. The developed methodology is inherently scalable and applicable to a wide range of other construction details. The process of analysing a manufacturer's drawing, identifying host elements, defining variables, and scripting geometric relationships is a universal approach to parametric modeling. This same methodology could be applied to automate other rule-based and repetitive details, such as roof-to-wall junctions, façade-panel connections, or window sill and jamb details.

While the specific geometric logic would change for each new detail, the overarching four-stage workflow for developing the parametric tool would remain identical, demonstrating the framework's versatility.

Transferability to alternative BIM Platforms. A critical aspect of the framework's applicability is its conceptual independence from a specific software toolchain. While this research used ArchiCAD and Grasshopper, the core methodology is transferable to other industry-standard BIM environments.

For instance, the framework could be implemented using Autodesk Revit and Dynamo:

- **Stage 1 (Deconstruction & Definition)**: This conceptual phase remains unchanged.
- **Stage 2 (Parametric Assembly)**: Dynamo would be used instead of Grasshopper. Although the specific nodes and syntax differ, the visual scripting logic of defining relationships between parameters and geometry is conceptually the same.
- **Stage 3 (BIM Element Generation)**: The Dynamo script would generate native Revit Families (e.g., Generic Models) instead of ArchiCAD elements. Parameters, materials, and classification data would be assigned using Revit's corresponding systems.
- **Stage 4 (Documentation & Validation)**: The process of creating and refining section views is a standard function within Revit.

This transferability confirms that the primary contribution of this research is a **systematic methodology** for automating parametric detail, which can be adapted by different firms regardless of their preferred BIM platform.

7 DISCUSSION

7.1 Interpretation of Results vs Literature

The findings presented in this thesis directly address the research questions and objectives established in Chapter 1. The research successfully addressed the guiding questions by systematically fulfilling the specific objectives outlined in the research design. The developed four-stage framework serves as the core outcome, providing a comprehensive methodology for integrating parametric modeling and automation into construction detailing workflows.

The primary objective was to **develop and validate a comprehensive parametric workflow framework that enables efficient automation of residential construction detailing.** This objective was fully achieved through the design, implementation, and testing of the framework documented in Chapter 5.

The successful fulfilment of this objective provides a direct answer to the primary research question: **How can parametric modeling and automation technologies be systematically integrated into BIM workflows to improve the efficiency, accuracy, and adaptability of residential construction detailing?** The research demonstrates that this systematic integration is achieved by following the proposed framework, which addresses the core goals as follows:

- **Efficiency** is achieved in Stage 2 (Parametric Assembly), replacing time-consuming manual modeling with rapid, automated generation.
- **Accuracy** is embedded by codifying geometric rules and manufacturer specifications in Stage 1 and assigning precise, IFC-compliant data in Stage 3, minimising human error.
- **Adaptability** is proven by the parametric logic, allowing the detail to instantly regenerate in response to parameter changes, a dynamic capability that manual methods lack.

The secondary questions were answered through the targeted completion of each specific objective:

- **Analysis and Documentation** were fulfilled through the "As-Is" workflow analysis of the od-do architecture in Chapter 4. This achievement directly answered the secondary question concerning the **current state of inefficiencies**, providing a foundational benchmark and justification for the research.
- **Framework Development** was met by designing the conceptual four-stage parametric workflow framework presented in Chapter 5. This provided a direct answer to the question of **what methodological approach** can effectively automate residential construction details while maintaining compliance with industry standards.

- **Technical Implementation** was achieved by creating a functional proof-of-concept detail using ArchiCAD and Grasshopper. This successfully answered the question of **how these technologies can be integrated**, with the fact that it was accomplished in a software environment new to the researcher underscoring the framework's practical simplicity.
- **Validation and Testing** were completed through the quantitative and qualitative performance evaluation in Chapter 6. This process answered the question regarding the **extent to which the proposed workflow improves performance**, confirming measurable gains in time efficiency and significant enhancements in accuracy, error reduction, and data integrity.
- **Knowledge Transfer** was fulfilled by designing the framework with modularity and replicability as guiding principles and documenting the methodology. This addresses the question of how the framework can be structured for scalability and transferability, ensuring its broad applicability beyond the initial proof of concept.

7.2 Academic and Theoretical Contributions

From an academic perspective, this thesis contributes a practical and accessible methodology that helps bridge the persistent gap between theoretical research and industry application. While much of the literature focuses on the high-level potential of parametric design, this research provides a clear, replicable, and software-agnostic workflow for a specific, often-overlooked application: construction detailing. The framework's value lies in its simplicity. It is not an abstract theory but a straightforward process grounded in universal best practices of parametric modeling that can be implemented using a firm's existing toolset. In doing so, it fills a methodological gap by providing a tangible "how-to" guide that translates theoretical automation concepts into an achievable reality for practitioners.

7.3 Practical and Industry Implications

The most significant practical implication of this research is that it demystifies the adoption of parametric automation for architectural firms. Rather than proposing a disruptive, all-encompassing overhaul of existing workflows, the framework advocates for a targeted intervention strategy. By identifying and automating a single, repetitive bottleneck like the manual modeling of specialised components, firms can achieve significant gains in consistency and error reduction without committing to a radical transformation. This approach lowers the barrier to entry, making technological adoption a manageable, incremental process rather than a daunting, high-risk investment. It demonstrates that meaningful automation is not an "all or nothing" endeavour, providing a practical pathway for firms like od-do architecture to enhance their existing BIM processes.

7.4 Scalability and Industry Trends

The conceptual nature of the framework ensures its high degree of scalability and transferability. Because the methodology is based on a universal process (Deconstruct, Assemble, Enrich, Document) it is not limited to the foundation detail developed in the proof-of-concept. The same logical steps can be applied to automate a wide range of other rule-based details, such as window-to-wall junctions or roof assemblies. Furthermore, the framework is conceptually independent of any specific software. The principles and workflow can be directly transferred to other industry-standard BIM environments, such as Autodesk Revit with its visual scripting tool Dynamo, confirming that the core contribution is a versatile methodology, not a single, platform-specific solution.

The framework is strategically significant as it prepares detailing workflows for two critical future shifts in the AEC industry: the transition to fully 3D, model-centric processes and the integration of Artificial Intelligence.

Readiness for Fully 3D Workflows. As BIM maturity increases across Europe, the industry is gradually moving away from a reliance on traditional 2D drawings. The framework supports this transition by focusing on the creation of high-fidelity, data-rich 3D components with IFC-compliant data (Stage 3). This defines detailing not as a means to produce 2D documentation faster, but as a process of creating intelligent, machine-readable assets essential for future model-based coordination and fabrication. The shift is not merely theoretical; pioneering infrastructure projects, such as the Randselva Bridge in Norway [46], have already demonstrated the feasibility of a fully model-based construction process, validating the strategic importance of developing workflows that produce intelligent 3D components rather than static drawings. This trend is further accelerated by the rise of on-site mobile technologies, which allow workers to access and query the live BIM model from tablets, extracting the specific information they need in real-time [47]. The ultimate pace of this industry-wide adoption, however, will depend on the dynamics of cultural factors, governmental mandates for digital permits, and a sociological move away from physical deliverables.

Foundation for AI Integration. From MCP servers to help communicate LLMs with specific software APIs, to using object detection models to generate BIM elements from images of old plans, AI implementation is experiencing a great number of approaches being driven by different start-ups and industry stakeholders. While currently it seems that AI in the context of BIM is best suited to reading information and interpreting it, it’s just a matter of time until AI is fully implemented as a normal automating mechanism capable of improving most, if not all of our current industry workflows.

AI and machine learning algorithms thrive on structured, logical data, not on static 2D lines or unclassified geometry. The parametric approach transforms a construction detail from a simple drawing into a system of rules, parameters, and relationships. This structured data is precisely what AI needs to perform advanced tasks such as generative design optimisation, automated code compliance analysis, or constructability reviews. The framework thereby makes detailing "AI-ready," serving as a foundational step toward a more intelligent and automated future.

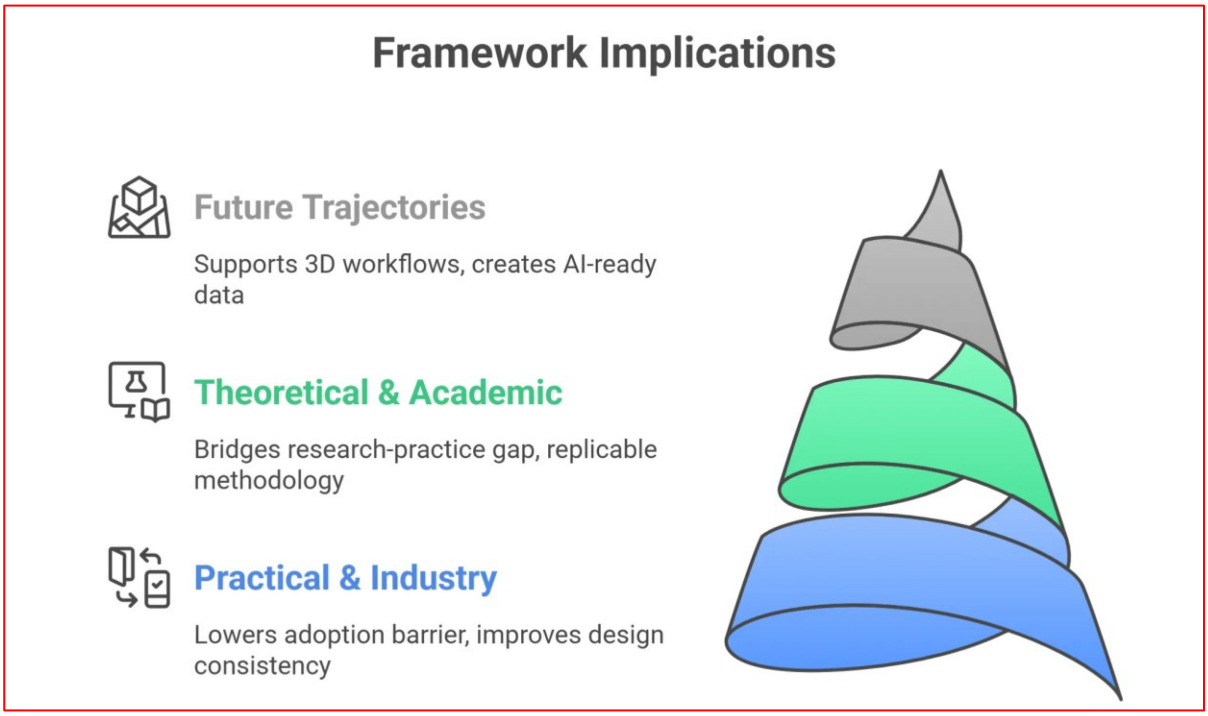


Figure 7.1 Framework Implications

The development and validation of the four-stage parametric framework carry significant implications that extend beyond the immediate findings of the proof-of-concept. The true value of this research lies in its strategic relevance to industry practice, its contribution to academic knowledge, and its alignment with the future trajectory of the AEC industry.

7.5 Study Limitations

It is important to acknowledge the limitations of this research, which define the boundaries of its findings and provide context for future work. These limitations stem from deliberate choices in the research design aimed at achieving depth and practical relevance within a specific context.

First, the single-case study methodology, while providing rich qualitative insights into the workflow of od-do architecture, means the findings are not statistically generalisable to the broader AEC industry. The primary goal was to develop a deep, contextually relevant solution rather than to achieve broad, quantitative validation.

Second, the scope of the proof-of-concept was intentionally focused on a single, common foundation detail. While the conceptual framework is designed for scalability, its practical validation has been confined to this specific assembly. A more comprehensive validation would require applying the framework to a wider range of detail types with varying levels of complexity.

Third, the technical implementation is specific to the ArchiCAD and Grasshopper toolchain. Although the framework's four-stage logic is conceptually transferable to other platforms, such as Revit and Dynamo, the developed script itself is not directly interoperable.

Finally, while the research suggests the learning curve for applying the framework is manageable, any adoption of new tools and workflows presents a practical implementation barrier for firms. The proof-of-concept demonstrated that a basic application of visual scripting is sufficient to achieve significant results, and deeper software expertise would yield even more sophisticated outcomes. This limitation, however, is likely to diminish over time. With the increasing integration of scripting languages like Python in both Grasshopper and Dynamo, and the rapid advancement of AI in code generation, the technical barrier to entry is continually being lowered. A designer who can clearly articulate the logic required in Stage 1 of the framework may soon be able to leverage AI assistants to generate the necessary scripts, further democratising the adoption of parametric automation.

8 CONCLUSION AND FUTURE WORK

8.1 Summary of Key Findings

The primary findings of this research are grounded in the practical validation of the proof-of-concept detailed in Chapter 5. The results confirm that the proposed parametric framework delivers measurable improvements in efficiency, quality, and data integrity.

First, the framework demonstrably **reduces repetitive manual labour**. By automating the generation of specialised detail components, the time required to produce the complete assembly was reduced compared to the established manual workflow, confirming the potential for significant productivity gains.

Second, the methodology **enhances design consistency and quality**. By embedding geometric rules and specifications directly into the script, the framework minimises the risk of human error and ensures that all generated details adhere to a consistent, pre-defined standard.

Finally, the research validates that the automated process successfully **enriches the model with structured, IFC-compliant data**. The validation confirmed that each parametrically generated component was correctly classified and populated with the necessary data, producing intelligent BIM elements rather than simple, unclassified geometry.

8.2 Conclusion

The AEC industry's adoption of BIM has outpaced its detailing practices, creating a persistent gap where manual workflows undermine the potential of digital environments. This thesis addressed this inefficiency by developing and validating a systematic framework for parametric automation. The results from the proof-of-concept lead to several evidence-based conclusions.

The research demonstrated that the framework can **improve efficiency by automating repetitive modeling tasks**, reducing the number of manual steps required to produce a complete detail. It also concluded that embedding design rules into a script enhances consistency, suggesting a tangible improvement in the quality and reliability of construction documentation. Finally, the framework successfully produced **data-rich, intelligent 3D components that align with IFC standards**, a critical step away from static geometry and towards more advanced, model-based workflows.

While these findings are based on a single-case study and require broader validation, the principal contribution of this study is a practical and transferable methodology. It provides an accessible pathway for firms to transition from static detailing conventions to the creation of dynamic, data-rich, and intelligent 3D components, establishing a foundational step toward a more efficient and data-driven future.

8.3 Recommendations for Future Research

Building upon the findings of this thesis, the following recommendations are proposed to validate and expand the potential of parametric automation in construction detailing. They are organised by urgency and feasibility.

The most urgent and feasible future work involves broader validation of the framework. First, a **quantitative validation study** should be conducted across multiple residential projects to rigorously measure long-term benefits such as productivity gains and error reduction rates. Second, the framework should be applied to develop an **expanded library of parametric details**, tackling more complex and common assemblies such as roof-to-wall junctions and window sill details. This would further test the methodology's scalability and increase its practical value.

Looking further ahead, several strategic research avenues could be explored. One ambitious goal is the development of a **"master script"**, a single tool that could apply a library of parametric details holistically to an entire building model. A parallel path could investigate platform-native solutions, such as GDL objects in ArchiCAD or adaptive components in Revit, which offer deeper integration at the cost of a steeper learning curve.

Finally, a crucial area for future inquiry is the **integration of AI-assisted scripting.** As generative AI becomes more capable, studies could test the ability of AI assistants to author the necessary scripts based on logical requirements, potentially lowering the technical barrier to adoption and further democratising parametric automation.

This is not a distant prospect; current Large Language Models (LLMs) already function as powerful assistants. The potential of this approach became evident during the development of this thesis, where an LLM significantly accelerated the learning curve for Grasshopper by providing contextual component suggestions and debugging assistance. Furthermore, their ability to synthesise information from community forums and technical documentation can rapidly solve complex tasks, such as configuring IFC data schemas. A critical avenue for future research, therefore, is to move beyond external tools and investigate the impact of **natively integrated AI** within BIM platforms. Such studies could explore how these tools might offer real-time, context-aware guidance on best practices and interoperability, further democratising the adoption of parametric workflows.

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APPENDICES

A. Full Grasshopper Script

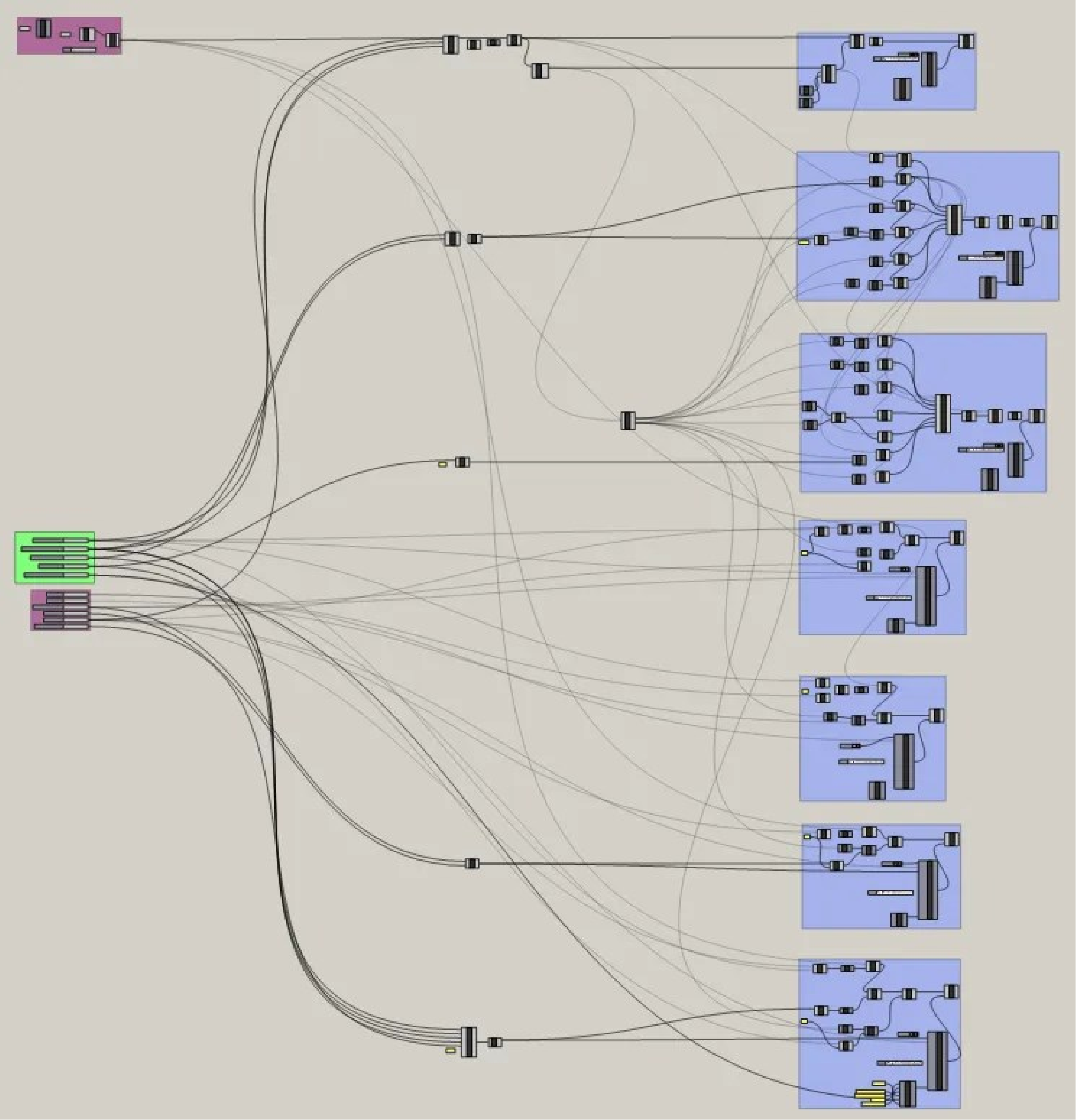
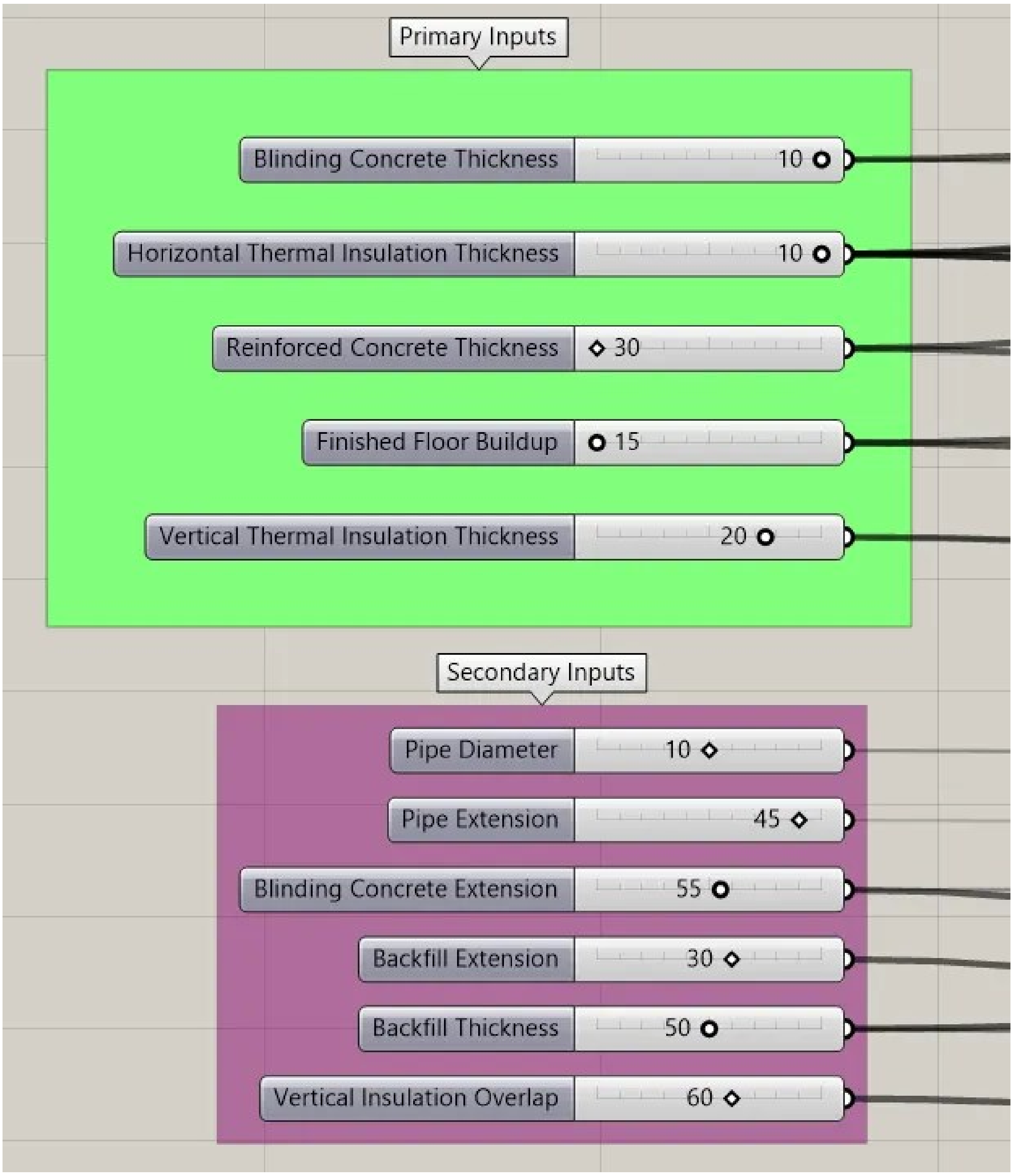


Figure A.1 Full Grasshopper Graph

The image provides a complete overview of the Grasshopper definition. The components on the far left manage the inputs, which include the host slab geometry referenced from ArchiCAD and the user-defined parameters identified in Stage 1 of the framework. The script processes this information through a series of geometric operations, with each of the distinct component groups on the right responsible for generating and enriching the data for a specific element of the foundation detail.

B. Variables Utilised



Primary Inputs

Blinding Concrete Thickness	10
Horizontal Thermal Insulation Thickness	10
Reinforced Concrete Thickness	30
Finished Floor Buildup	15
Vertical Thermal Insulation Thickness	20

Secondary Inputs

Pipe Diameter	10
Pipe Extension	45
Blinding Concrete Extension	55
Backfill Extension	30
Backfill Thickness	50
Vertical Insulation Overlap	60

Figure B.1 Variables Used

This image displays the user-configurable inputs for the script, which correspond directly to the dimensional variables identified during the analysis in Stage 1. The variables are organised into two distinct groups based on their expected frequency of change, as defined in the thesis.

C. Detail Components

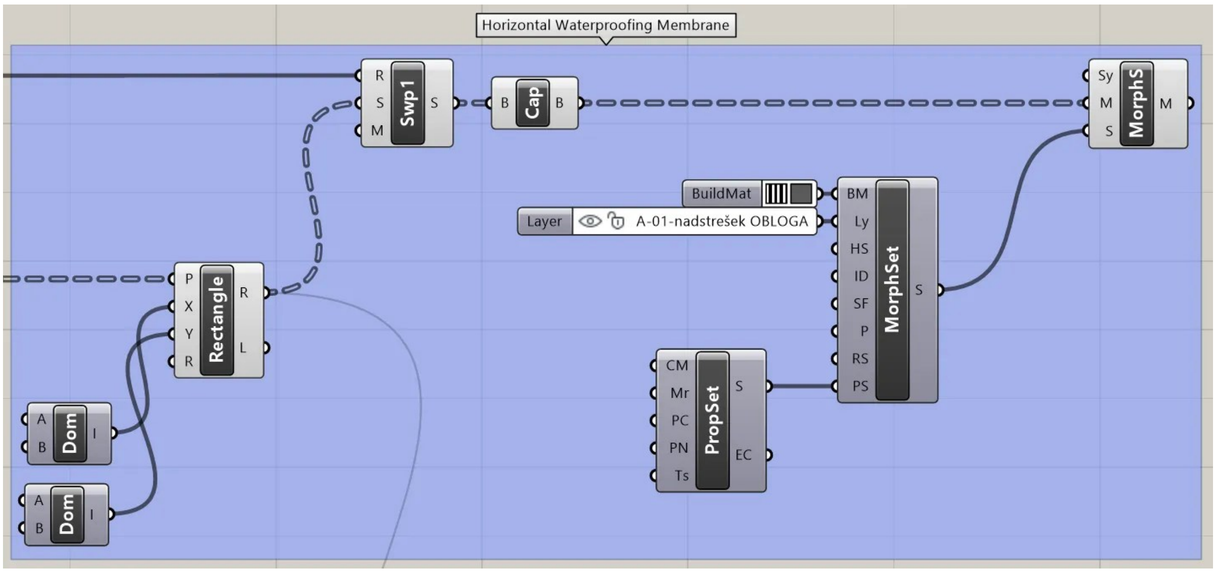


Figure C.1 Horizontal Waterproofing Membrane

This section of the script details the generation of the Horizontal Waterproofing Membrane. The logic follows the primary geometric strategy of the framework: a 2D cross-section. In this case, a rectangle defined by parametric inputs is created. This profile is then extruded along a reference curve derived from the slab's edge to form a 3D solid. The native ArchiCAD Morph created contains all the necessary IFC classifications and data properties before the element is generated.

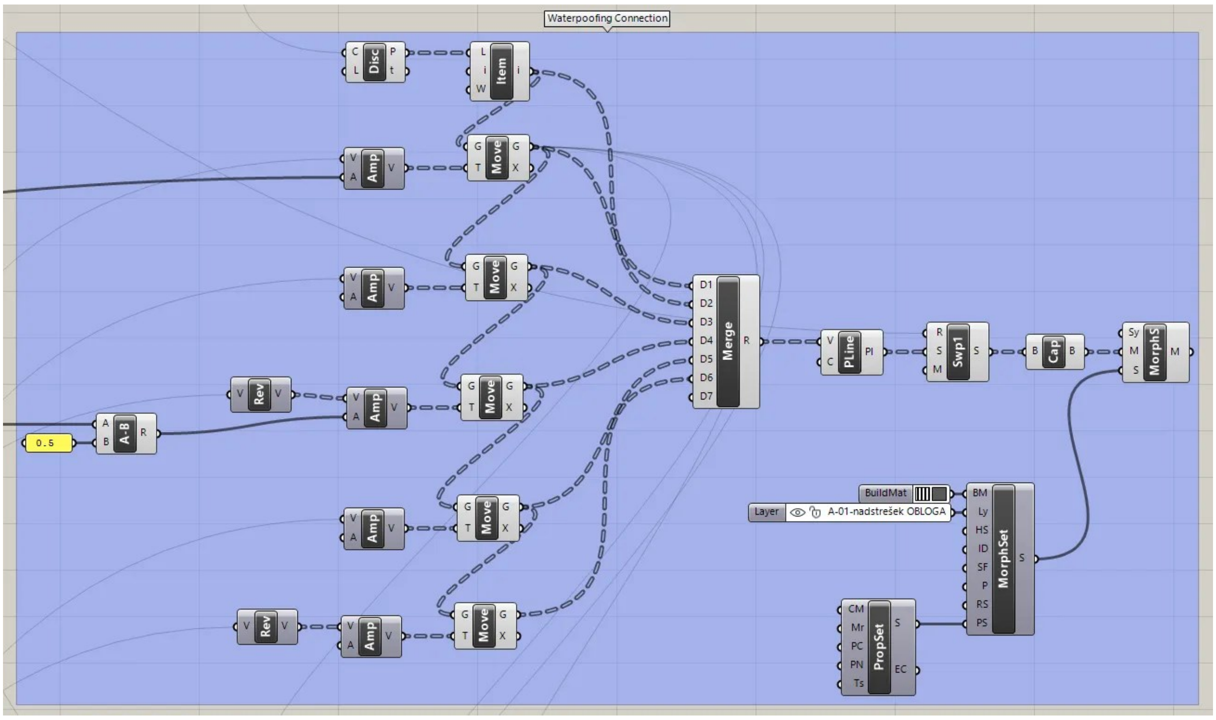


Figure C.2 Waterproofing Connection Membrane

Next, the image shows the logic for the Vertical Waterproofing Connection Membrane; As described in the thesis, this element has an "L" shape and ensures a proper overlap with the other layers.

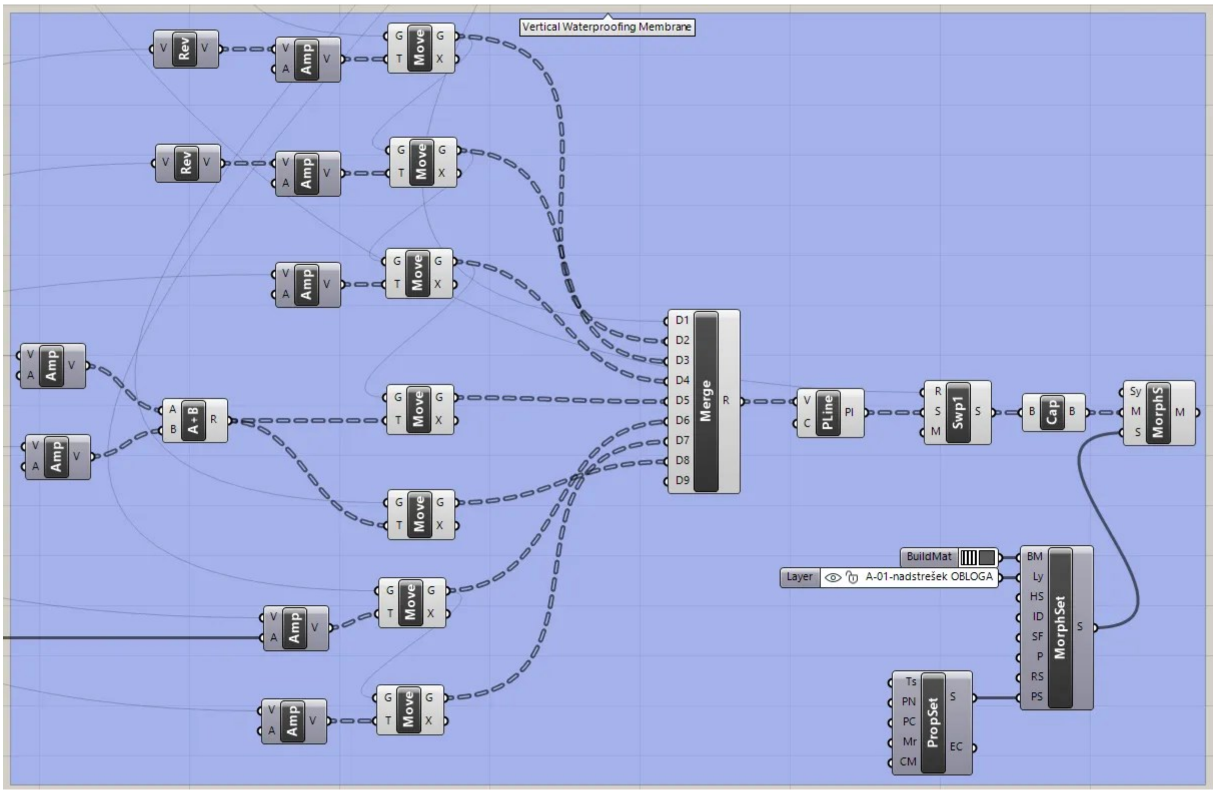


Figure C.3 Vertical Waterproofing Membrane

This section of the script generates the Vertical Membrane, the most geometrically complex component in the detail. Its complexity arises from the need to accurately model the overlap with the "L" shaped membrane, a requirement identified during the deconstruction stage. To achieve this profile, the script parametrically defined eight points in space. The position of the initial point is dependent on the geometry of the previously created element to ensure a seamless interface. The subsequent points are then positioned relative to it using the input variables. Finally, these points are connected to form a polyline cross-section, which is swept and converted into an ArchiCAD Morph.

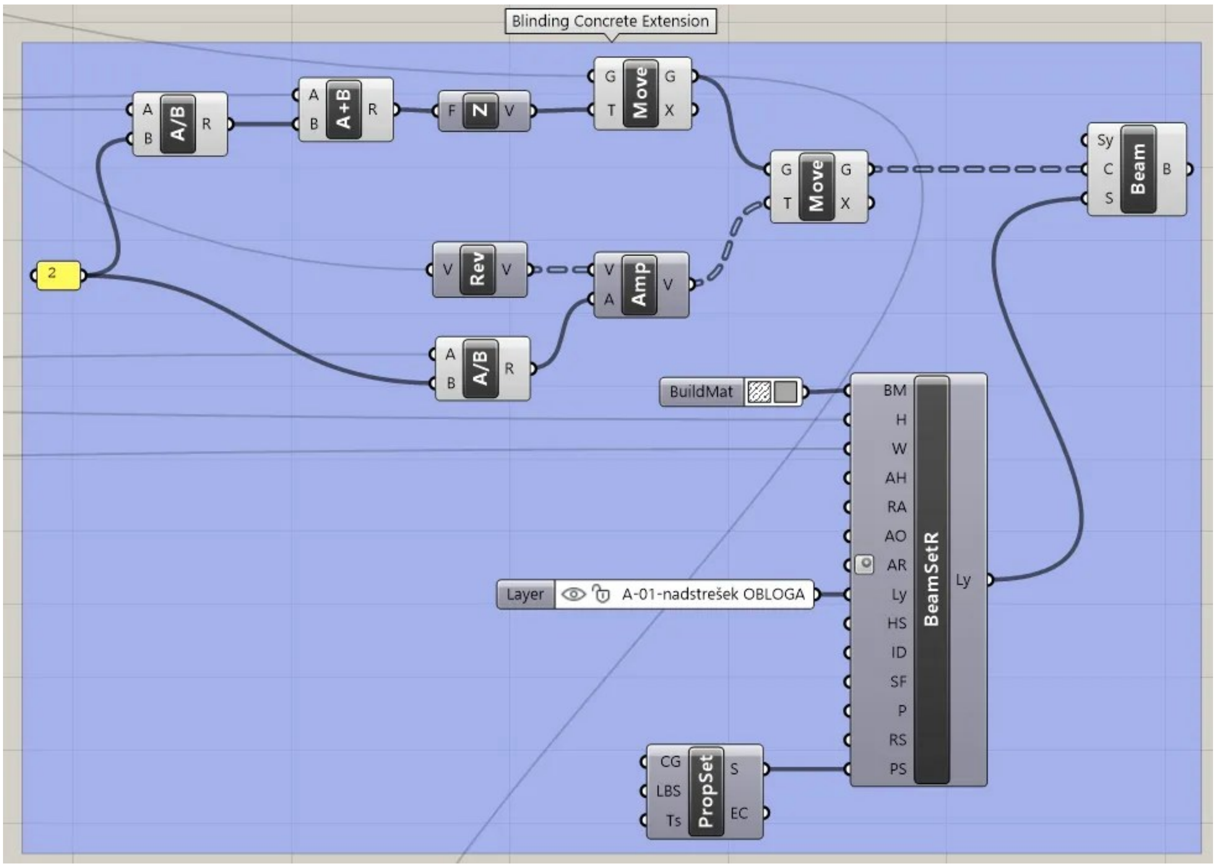


Figure C.4 Blinding Concrete Extension

As described in the thesis, a different and more direct method was used for components with simple rectangular sections. Instead of creating a polyline, this part of the script uses vector operations to parametrically calculate the centre point, width, and height of the extension. This information is then fed directly into an ArchiCAD Beam component, which creates the geometry as a native Beam element. The classification mentioned for the IFC data becomes important in these elements because ArchiCAD still natively treats the elements as beams, while the IFC export will assign the correct entity according to its classification.

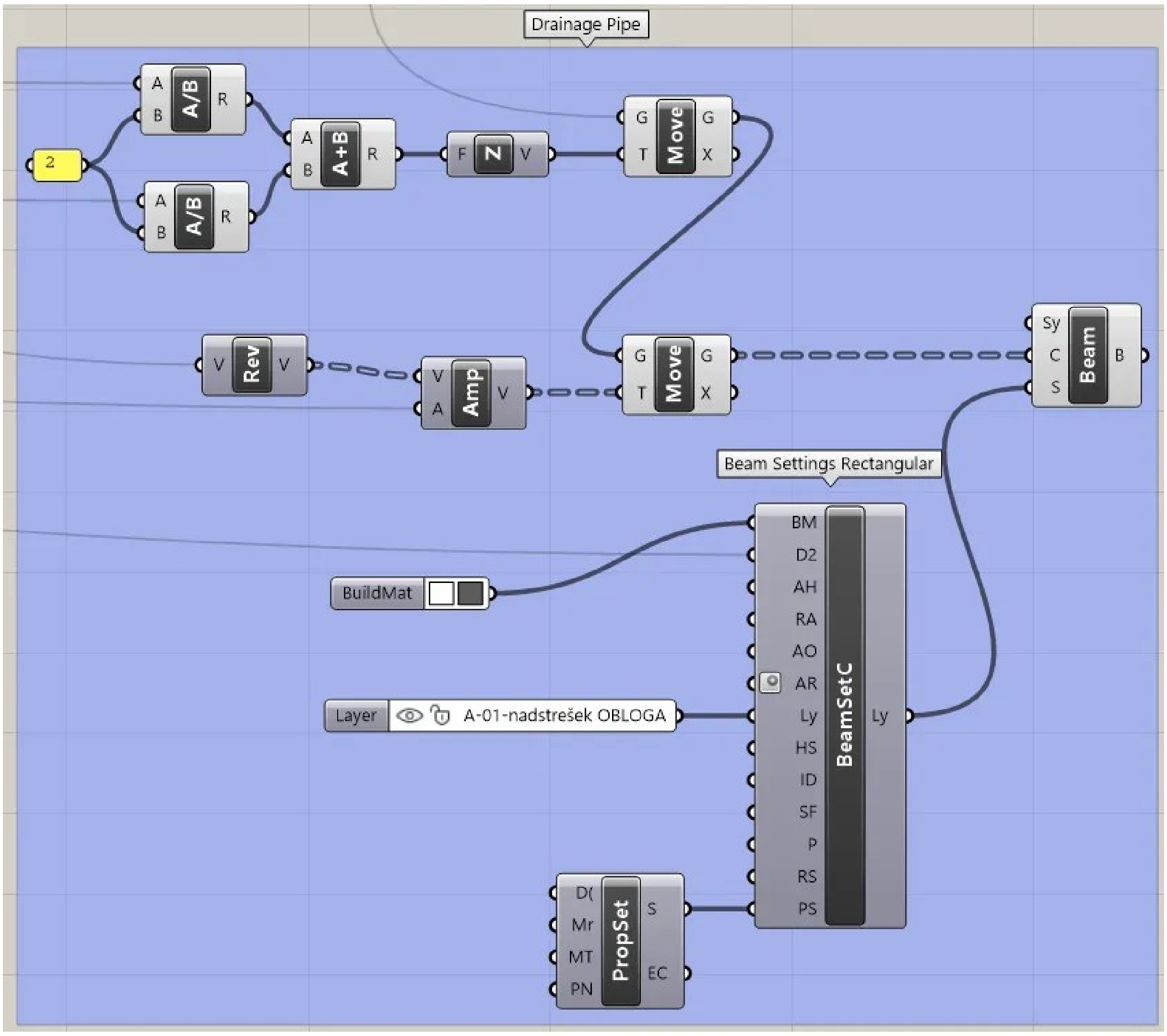


Figure C.5 Drainage Pipe

In line with the methodology previously explained, this circular element is created using ArchiCAD’s native Beam tool. The script first calculates the correct centre line, ensuring it is positioned on top of the previously generated blinding concrete extension. Then the defined diameter is applied and the circular beam is created.

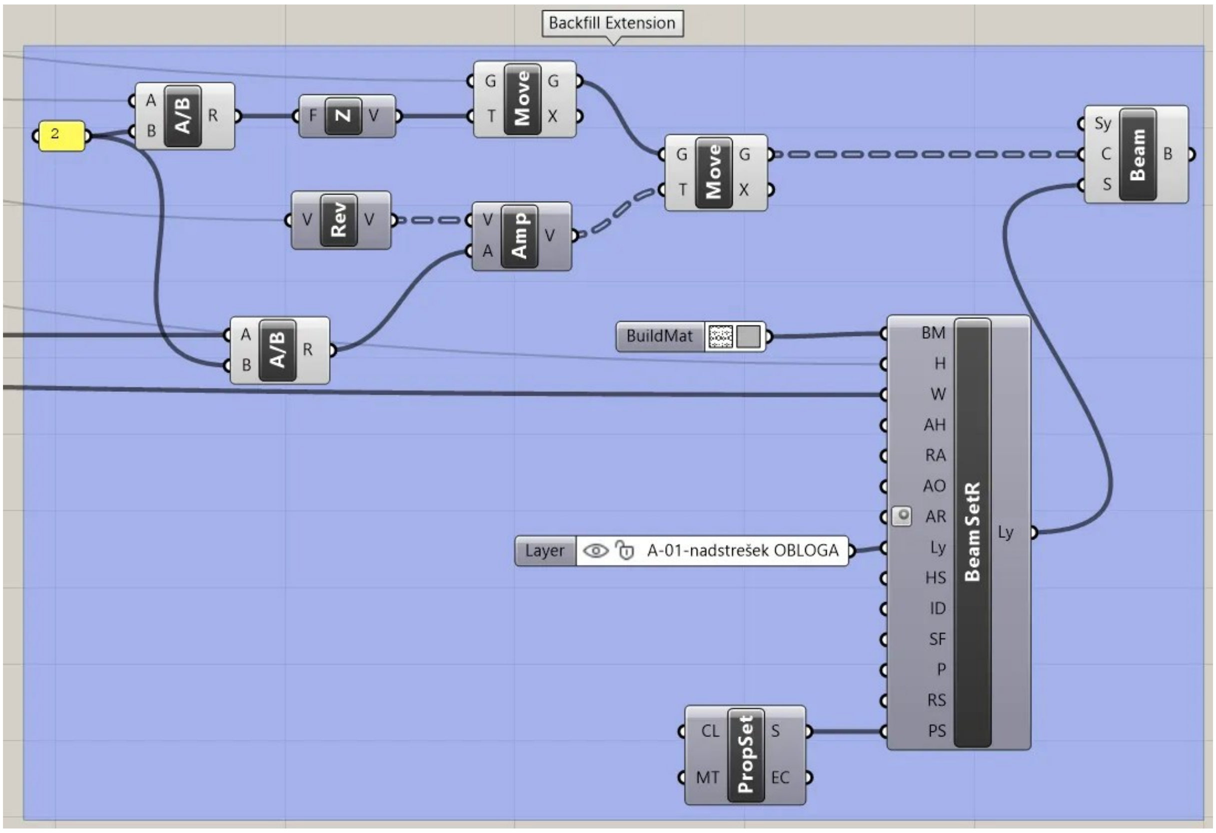


Figure C.6 Backfill Extension

The image illustrates the generation of the Backfill Extension. Following the same procedure as the blinding concrete extension, the script uses vector operations to calculate the centre point and dimensions of the backfill. This data is then used by the Beam component to create the geometry and the needed data is assigned with the Property Set component.

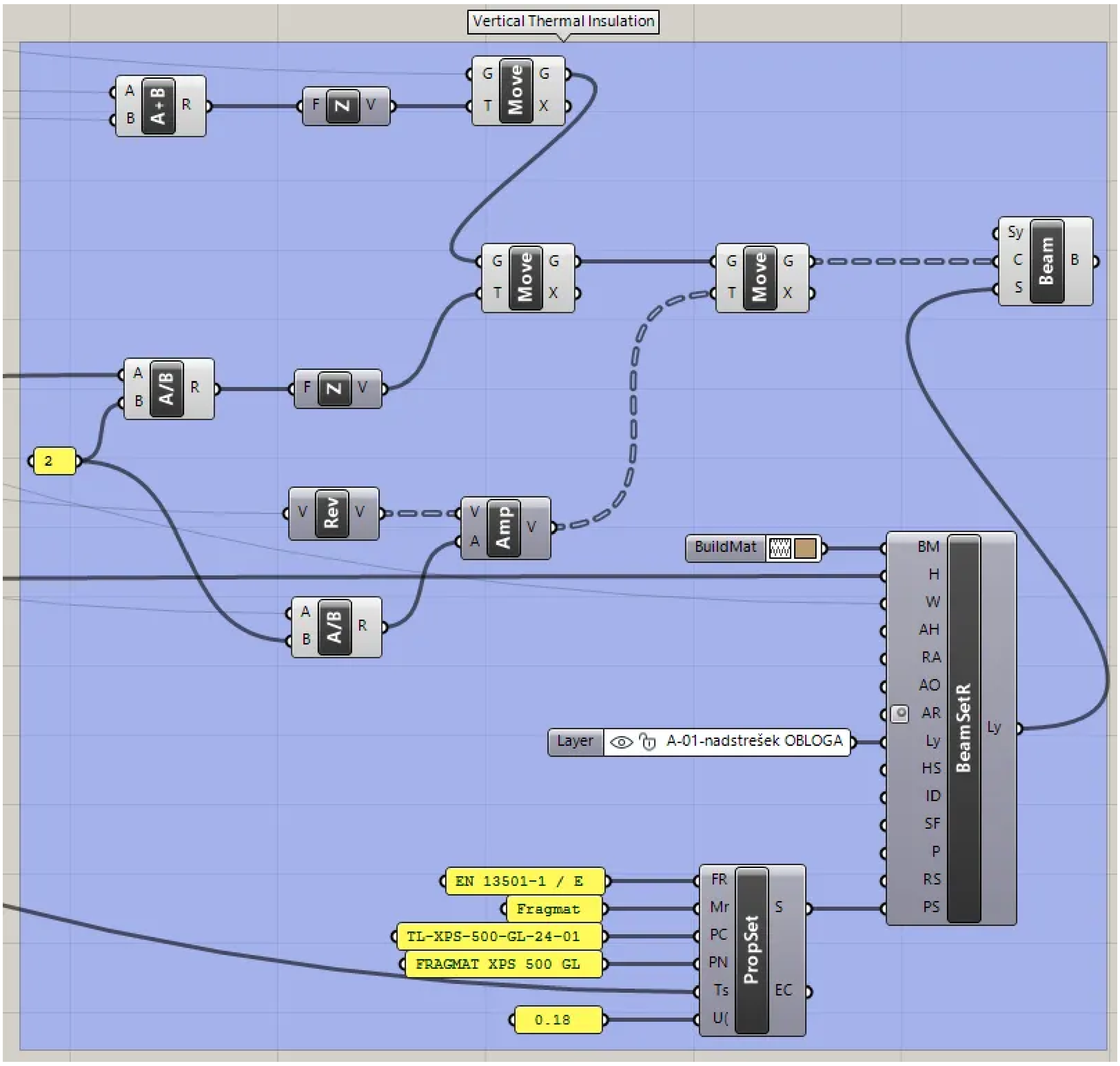


Figure C.7 Vertical Thermal Insulation

This final section of the script handles the creation of the Vertical Thermal Insulation. It follows the established methodology for rectangular components. The image clearly demonstrates Stage 3 of the framework in practice; the PropSet component is used to assign a rich set of specific, performance-related data to the element, including its manufacturer, product code, fire rating and u-value. This parametrically embedded information was later validated in an IFC viewer, as detailed in Figure 5.12 of the thesis, confirming the framework's ability to create intelligent, data-rich BIM components.