REINCARNATE

D3.3 – Parametric design tool for reused building parts and recycled materials

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Reviewer(s)	Timo Hartmann (TUB), Sabine Kruschwitz (BAM), Samaneh Rezvani (DMO), Eren Cavusoglu (DMO).

Abstract

This report summarizes the results of Task 3.3, a parametric design tool for reused building parts and recycled materials. The type of deliverable 3.3 is "other"; nevertheless, the partners contributing to this task decided to present a concise report to shed some light on different aspects of the deliverable. It is important to note that this report is only a supporting document to facilitate using the REINCARNATE Parametric Design Tool (PDT) for reused building parts and recycled materials, which is the final deliverable of Task 3.3. This report aims to introduce the Reincarnate parametric design tool and its features. This supporting tool for the stakeholders is available for download by external users on the GitHub repository1. In the context of the Reincarnate project, the PDT generates secondary marketplace database to facilitate the reuse of building parts from buildings that are about to be demolished or have already been demolished buildings (referred to as donor buildings). It also enables architects and engineers to matchmake within second-hand marketplace as a part of construction products and components selection process for new designs or renovation projects.

Deliverable of the task T3.3

The type of this deliverable is "**Other**": a website (source code) and an additional report (not part of the deliverable).

[1] https://github.com/JorgTheunissen/Automated-Reclaimed-Window-Integration-Tool-for-Revit

Keywords

Circular Economy, Reuse, Building Information Modelling (BIM), Parametric Design

Revisions

Version	Submission date	Comments	Author
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v0.6	25.03.2025	Final Draft was modified based on reviewers	Begum Aktas (TUB)

Disclaimer

Acronyms and definitions

Acronym	Meaning
BIM	Building Information Modelling
CDW	Construction and Demolition Waste
CE	Circular Economy
CP-IM	Circular Potential Information Management
IFC	Industry Foundation Classes
TRL	Technology Readiness Level
UML	Unified Modelling Language
VPL	Visual Programming Language

Reincarnate project

The average lifespan of a building is 39 years — in Europe, it is only 25-30 years — and the main reason for demolition is obsolescence. This is why there is a large amount of construction and demolition waste (CDW) — representing approximately 25-30% of all waste in Europe —, in addition to that generated in current construction works.

The recycling rate for CDW is relatively high (above 75%). This activity generated $126.89 billion in 2019 — Europe contributed the largest share, almost two-fifths of the total global market — and is projected to reach $149.19 billion by 2027. Unfortunately, many of the most valuable materials in CDW cannot be meaningfully separated and end up in landfills.

This helps to get an idea of the efficiency potential for climate neutrality that exists in construction.

Reincarnate aims at advancing circular economy practices within the European construction industry and enabling to significantly maximise the life cycle of buildings, construction products and materials, reduce CDW by 80%, increase the reusability of buildings, construction products and materials and, as a result, lower the sector's emissions by 70%.

As a result of these actions, Reincarnate will significantly advance circular economy practices within the European construction industry.

First, it will create a Circular Potential Information Management (CP-IM) platform and a set of innovations to use it. These solutions will draw upon emerging digital technologies, such as digital twin representation, artificial intelligence, and robotic automation.

Three empirically proven social science insights will allow fostering widespread adoption of reused high-quality construction products and materials, and business eco-system development frameworks to combine actors within sustainable value chains. All innovations will be demonstrated on eleven selected real-world projects and value chains. Furthermore, business process guidelines and an e-learning platform will be developed to drive the dissemination and exploitation of the Reincarnate results.

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1. Introduction

This report is only a supporting document outlining the outcomes of Deliverable 3.3, 'Parametric design tool for reused building parts and recycled materials,' (PDT) as part of Work Package (WP) 3, Task 3.2, 'Component and Product Reuse.' The type of deliverable 3.3 is "other." This report documents the technical development of the tool as a component of WP3-T3.2, carried out in close collaboration with PlanB. This partnership was crucial to developing a practical and efficient parametric tool through UML diagrams that meet the needs of two primary user groups: architects and property owners. The tool, designed with practicality and efficiency in mind, aims to achieve a Technology Readiness Level (TRL) of 4-6, aligning with the objectives of Task 3.2 in the Reincarnate project. The structure of this report is designed to explain the purpose of the tool's development, focusing on the reuse of building components, its implementation in a case study involving windows, and demonstrating it through the window use case. The report also details the integration of the CP-IM platform, highlighting how the tool supports the circular economy by facilitating component and material reuse.

This accompanying report aims to explain deliverable 3.3: the method and BIM-based parametric design tool for reused building parts and recycled materials tool into Building Information Modelling (BIM) models within the Revit environment. The main aim of this report is to guide project stakeholders in implementing BIM-based tools for both renovation and new building projects. The tool enables the stakeholders to facilitate the reuse of building products by identifying and matching them with available items in a second-hand marketplace. The parametric design tool is developed to extract building products from demolished or soon-to-be-demolished buildings to create a secondary marketplace, a hypothetical market within the scope of this report, an inventory based on key dimensions such as 'width' and 'height.' To validate its functionality, the PDT was initially tested using small-scale Tiny House project, where windows served as the primary reusable product. Further testing in the Kathreiner Haus ensured its robustness across different contexts.

A core function of the tool is its automatic matching feature, which streamlines the design process while reinforcing Circular Economy (CE) principles. The feature of PDT automatically pairs available building components in the Revit environment with those listed in the hypothetical market, accounting for user-defined tolerances during the building product selection process for new building design or renovation project. The PDT's tolerance feature of the tool allows users to adjust the range between 0 and 100 for increasing flexibility in comparisons and improving the likelihood of successful matchmaking within the listed products in the hypothetical market. This ensures that components or products in the Revit model, such as windows, are accurately paired with those in the marketplace, factoring in user-defined tolerances. Once matched, the BIM model updates to reflect the newly integrated components, enhancing both design accuracy and environmental efficiency. As a Dynamo plug-in for Revit, PDT enables architects and designers to generate alternative design models during the products selection process design process within the BIM framework. This facilitates material reuse, minimizing waste, and extending the lifecycle of building components.

Another core function of the tool is its carbon emission calculation module, which integrates sustainability considerations into the component matching process. By assessing key dimensions such as 'width' and 'height', this feature estimates the carbon footprint associated with reusing building products, particularly windows, further minimizing environmental impact of construction activities. The initial application of the tool indicates significant CO2 savings potential through the reuse of building components, reinforcing its effectiveness in promoting sustainable construction practices.

The Reincarnate PDT for reused building parts and recycled materials is described in the following sections. First, Section 1 presents a brief introduction and general structure of the proposed framework. Section 2 provides an overview of the parametric modelling tool and its features in carbon emissions calculations such as GWP. Section 3 offers an overview of the parametric modelling tool. Section 4 summarizes the parametric design methods for reusable building components. Section 5 presents UML diagrams for parametric modelling tools from architects' and property owners' perspectives. Section 6 discusses the integration of CP-IM and PDT.

1.1. Objectives

The objective of this deliverable is to provide architects and property owners with a user-friendly parametric design tool that simplifies the use of reusable and recycled components, products, and materials from a hypothetical marketplace. This tool, developed through the extraction of building products’ data from demolished or about to be demolished buildings in the Revit environment, creates a secondary marketplace inventory based on key dimensions such as ‘width’ and ‘height’ as an Excel sheet. The use of key dimensions to extract windows from BIM models in the Revit environment generates a secondary marketplace, a database for the matchmaking process. The synthetic data was used to develop and test the hypothetical marketplace development process. Once developed, an Excel sheet-based inventory is used to generate marketplace with each Excel sheet representing a single building component, such as a sheet for windows. This hypothetical marketplace and matchmaking database can be seamlessly integrated into the Circular Potential Information Management (CP-IM) platform. The tool's dynamic nature ensures high accuracy in matchmaking adjustments to fit individual design processes. It is available on GitHub repository and can be downloaded by interested readers and potential users. This adaptable tool can be customized to suit individual design processes. In the context of the Reincarnate project, the tool will expedite the integration of secondary building products, such as windows, listed at the secondary marketplace, into new design or renovation projects’ product selection phases during the design phase, thereby reducing the need for new products in the Revit environment. The tool integrates BIM-supported modular dismantling with parametric design techniques using Autodesk Dynamo, enabling architects and designers to seamlessly incorporate dismantled construction products into new and refurbished building designs. PDT is developed with active input from architects and designers and enables users to apply architectural design methods while considering the availability of reusable components and recyclable items. Additionally, it supports the creation of databases for secondary building materials and components within BIM models, treating buildings as material banks to promote a circular economy in construction.

1.2. Purpose of the document and audience

Deliverable 3.3, titled 'Parametric Design Tool for Reused Building Parts and Recycled Materials' under Task 3.2, Component and Product Reuse' outlines the development of the Parametric Design Tool. For the remainder of this report, the Parametric Design Tool is referred to as ‘PDT’. This deliverable guides the users and integrates these processes with the BIM-based parametric tool, Dynamo, which is crucial in evaluating and calculating carbon saving. Deliverable 3.3 also includes the matching and comparison of secondary building components as well as visualizations in three-dimensional BIM models. Additionally, it provides Excel sheet-based documentation containing geometric data and carbon estimation for windows. These features help architects make informed decisions to prioritize component reuse based on result of PDT for environmental impact. This tool also helps property owners extract building products from demolished or soon-to-be-demolished buildings to create a secondary marketplace inventory based on geometric data of building components. This work was developed in collaboration with WP2 and WP3, particularly Task 3.2, led by PlanB. The primary audience for this report is Reincarnate project partners. This document will provide a detailed explanation of the PDT, which is developed in the Dynamo, Revit environment, within step-by-step instructions on how to use it to pair secondary windows for new or refurbished building designs.

2. Overview of parametric design tool

This section presents the features of the architectural parametric design tool, detailing its functionality and development process, as well as providing a step-by-step diagram for user guidance. It highlights how architects and property owners can utilize the tool, stressing the empowerment it provides. Architects can utilize the tool to integrate dismantled or soon-to-be-dismantled building components and products into new designs or refurbishment projects rather than relying on new ones. This is possible through informed decision-making once all relevant information related to matchmaking is available. Similarly, property owners, by utilizing the tool for their existing buildings that are slated for dismantling, demolition, or deconstruction to create a secondary marketplace inventory based on key dimensions such as 'width' and 'height' within carbon emission calculations' data which is stored in an Excel file play a crucial role in the sustainable construction process. Therefore, this tool enables both user profiles to develop a secondary database of materials and components, allowing architects to integrate secondary construction items into new building designs and renovation projects. Ultimately, PDT encourages collaboration between architects and property owners to develop a secondary marketplace development, facilitating the effective reuse of building materials and components while promoting sustainable construction practices.

2.1. PDT development and implementation

To address the supply-demand challenge in the secondary construction item use, existing digital tools can be leveraged by developing sector-specific algorithms within the construction industry. These tools can serve as 'matchmakers' across the value chain, connecting stakeholders such as owners, designers, suppliers, and workers (De Wolf et al., 2023). In this context, which aligns with the scope of the PDT development and implementation, parametric design tools hold great potential for enabling integrated collaboration among all stakeholders such as property owners and architects by promoting the reuse of construction items. PDT extracts building components to generate secondary hypothetical marketplace database. PDT also allows users to match components in hypothetical marketplace by adjusting tolerance input, enabling the identification of more variations during the matching process. PDT provides accurate and dynamic matching by excluding components that have already been matched based on 'width' and 'height' dimensions of construction items and prioritizing those closest to the target dimensions. This matchmaking process adjusts and verifies the working progress BIM model within the Revit environment, and once matching is complete, it creates an alternative BIM model that aligns with set tolerance input. Upon successful matchmaking, a final BIM model is generated with corresponding Excel sheet (Figure 1).

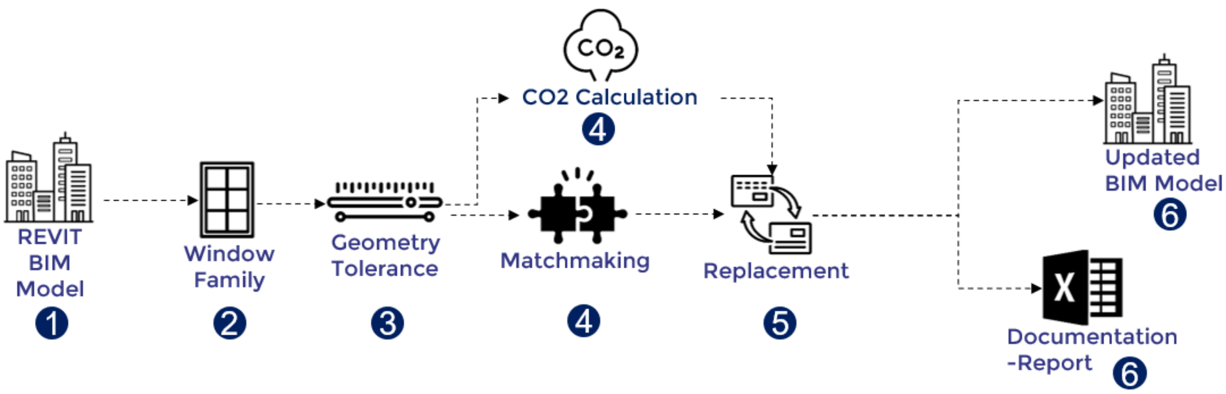

Figure 1: Simplified PDT pipeline in the Dynamo, Revit environment.

The matching algorithm calculates the Euclidean distances between component dimensions and pairs the closest match for each component, in this case, windows, by considering adjusted tolerance input (Figure 2). If no match is found within the specified tolerance or original dimensions of components, the PDT outputs a 'no match' result, indicating that component could not be integrated into current BIM-model. As a result of the PDT matching process, two outcomes are generated: firstly, successful matches where secondary components closely aligned with original dimensions of the windows, and secondly, unmatched cases, where no suitable alternative is found. These results are recorded in Excel datasheets.

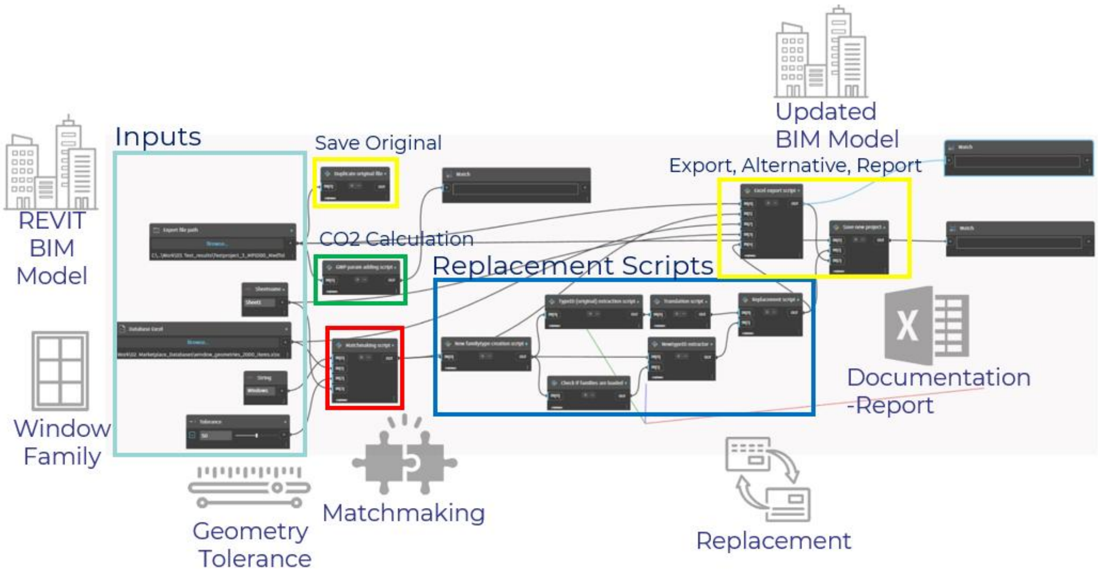

Figure 2: Pipeline of PDT in the Dynamo, Revit environment.

Initially, the PDT prototype was developed using a small-scale architectural project, such as the Tiny House concept BIM model where windows served as the primary building product. By streamlining geometric matching and data processing through Dynamo nodes and scripting for Tiny House case, the PDT reduces manual effort, enhances accuracy, and facilitates real-time decision-making in the use of secondary components. This approach enables the tool's potential to implement workflows and supports broader application across various building products such as doors, HVAC systems, and windows which serve as the demonstration case of this PDT development.

1. The pipeline developed for the PDT involved creating scripts to automate the management of building components in Revit, utilizing API references as explained by Revitapidocs.com (Talarico, 2024). The process included the following steps: Development of Matchmaking Logic: Scripts are created to extract building components from Revit and match them with marketplace data stored in an Excel file. The comparison is based on 'width' and 'height' parameters,

with allowances for minor variations using a tolerance input. The tolerance input ranges 0 to 100, providing maximum dimension tolerance of 10 cm for each window along each edge. The logic excludes previously matched windows to ensure reliability and prioritizes components closest to the specified dimensions.

2. Creation of New Family Types: The tool automatically generates new family types in Revit for matched components, overwriting parameters to maintain data integrity. Each new type is uniquely named and based on the window in the marketplace.
3. Verification of Family Types: A script is implemented to confirm that new family types were properly loaded into the Revit project. It also produced a detailed status report, ensuring completeness and accuracy in the verification process.
4. Updating FamilyInstance Objects: The tool updates FamilyInstance objects to reflect new FamilySymbols into the Revit model while managing errors and generating a report on the updates.
5. Final Export to Excel: The final script ensures the completion of the process by exporting all changes to an Excel file, documenting new family types and matched window data, and providing a comprehensive record of the automation process.

2.2. Global warming carbon emissions calculation technique

The Global Warming Potential (GWP) associated with carbon emission is included in this deliverable for comparative assessment purpose. GWP data are stored as family-type parameters, labelled "Global Warming Potential (kg-CO2-eq)" within the window families in the Revit environment (Figure 3). The GWP calculation is based on geometric dimensions of windows, with the formula (Height*Width)/1000000mm2) * 7.9 used for the computation.

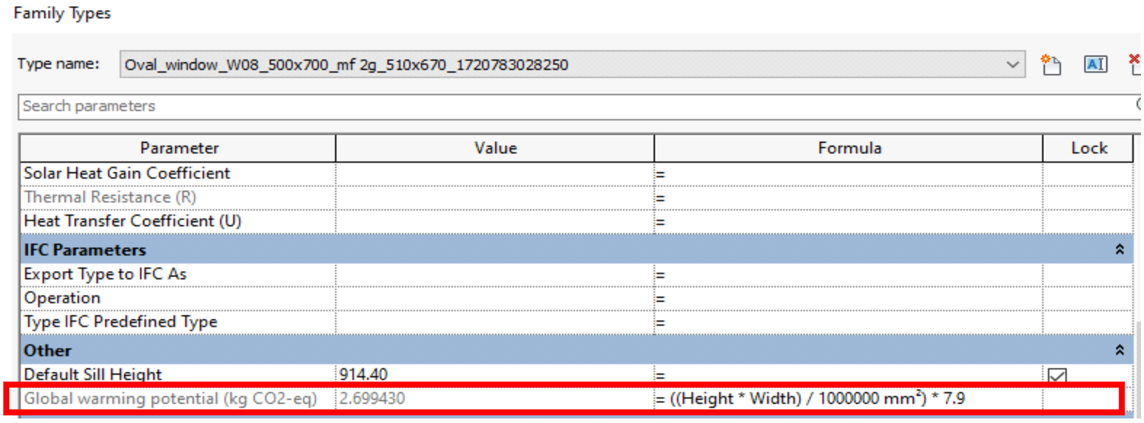

Figure 3: Carbon Estimation Calculation Technique in IFC Data Format

For the GWP calculation of windows, we rely on a standard wooden, double-glazed window with an area of one square meter is assumed. The GWP values for producing wooden frames and glass were sourced from previous studies (Sinha and Kutnar, 2012; Grané Anglarill, 2018) and adjusted according to the window dimensions.

Additionally, certain key assumptions are made in the GWP calculation for windows: secondary windows are assumed to have no additional carbon emissions, which facilitates the direct estimation of CO2 savings when replacing secondary components with new ones. Also, the transportation impacts and installation are excluded from the GWP calculation due to their variability. While this assumption simplifies the comparison, it may not fully account for variations in material quality or specific construction conditions.

2.3. Parametric design tool user manual

The diagram on the left illustrates the procedure for architects using the Autodesk Revit Dynamo platform. The process is divided into two main steps: the Revit phase, where the modelling phase is implemented, and the Dynamo phase, where the matchmaking phase occurs. In the Revit phase, the user can either open the existing Revit Model as (as-is) BIM model or import the BIM model into the Revit environment, ensuring that all necessary families are included, and the model is up to date. In the Dynamo phase, the Dynamo script is opened within the environment, which is used to automate the GWP calculation and manage geometry-based parameters to extract window data to generate a hypothetical marketplace and match the windows.

Once the matching process is complete, the matching data, along with geometric dimension details and the GWP results of Windows, are written to Excel spreadsheets within the updated BIM model (Figure 4). This process allows users to use their Revit Model to be accurately configured for carbon emission calculations and a list of reusable building components through new family data, which is properly integrated. The parametric modelling tool user manual, available via the GitHub link, is designed to guide users, with basic knowledge of Revit and the Dynamo platforms. The following fifteen steps are presented through the window case, starting within the Revit environment and followed by Dynamo script utilization.

Step 1: Open or upload the BIM model in the Revit (Architectural) environment, which contains information on the dimensions of building components.

Step 2: Save all Window families to a directory or any relevant families used in the model in a directory, which enables users to access them for later use and calculations like carbon emissions in the next steps.

Step 3: Insert saved families as current families: After saving the model in a directory, reinsert these window families into the Revit Model, which ensures the project contains the most up-to-date families.

Step 4: Open Dynamo: Starting from this phase, the next steps are utilized in the Dynamo platform, a visual programming tool that interacts with Revit to perform tasks, particularly parametric tasks like automating workflows and carbon calculation in the scope of this deliverable. The user opens the Dynamo script that is developed and provided to you.

Step 5: Set a directory to find families for carbon emissions calculations. In the Dynamo Script, the user sets the file path to where the user saved the families earlier, which allows Dynamo to locate and reference the families for carbon emissions calculations.

Step 6: Insert the families again and choose the overwritten parameters: This time, users decided to overwrite parameters to reinsert the saved families into the Revit Model. This is important because it updates any pre-existing parameters with new values to ensure accuracy for the calculations.

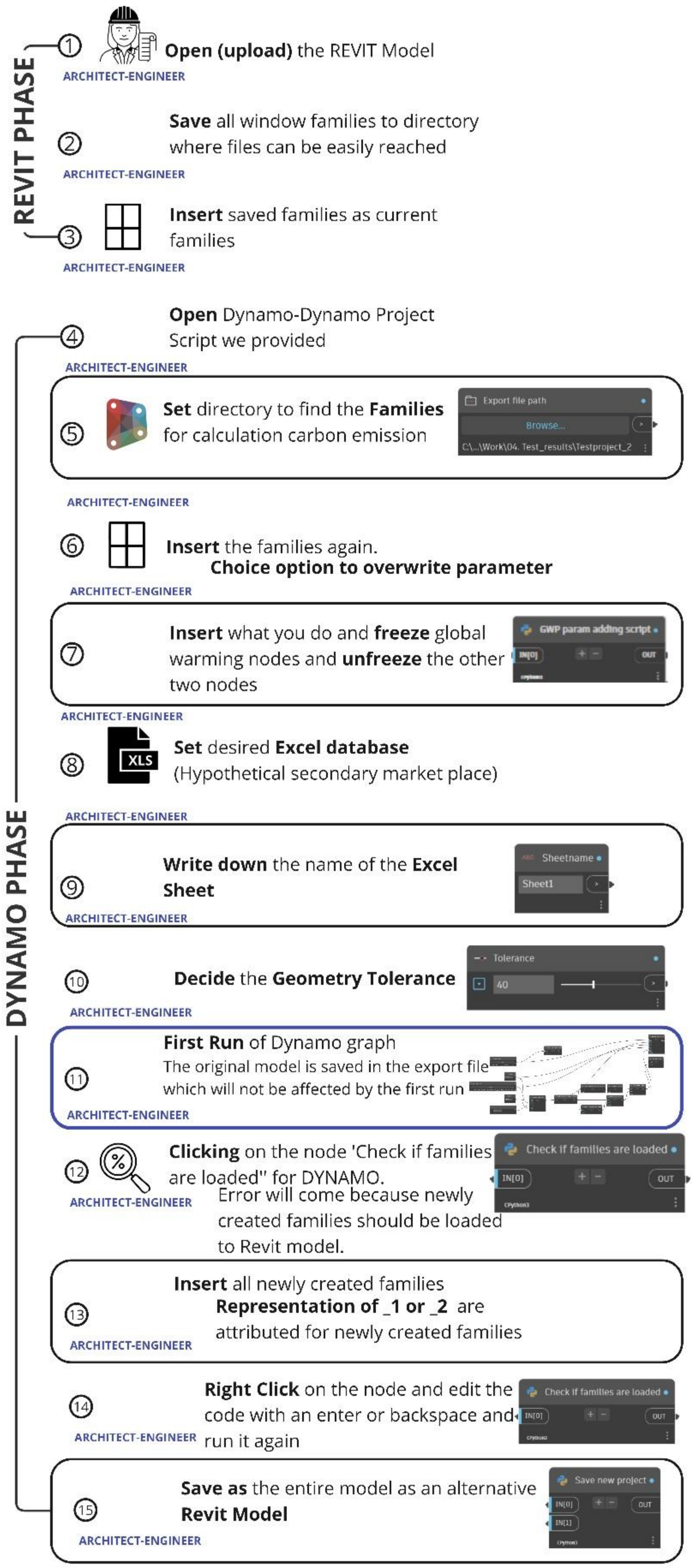

Figure 4: Diagram of parametric modelling tool

Step 7: Insert what you do and freeze global warming nodes and unfreeze other nodes: In this step, Dynamo-- global warming potential (GWP) nodes allow the user to make carbon emissions calculations while unfreezing the remaining nodes to ensure proper data processing.

Step 8: Set desired Excel Database (Hypothetical Secondary Marketplace): The user defines where to set up an Excel Database where results or outputs from the Dynamo. This Excel sheet acts as a hypothetical secondary marketplace where data is stored for further analysis.

Step 9: Write down the name of the Excel spreadsheet: The user notes the exact name of the Excel spreadsheet that is being used, which will be crucial to ensure the data is exported to the correct location.

Step 10: Decide the geometry tolerance: The user, in this case, the architect, sets a geometry tolerance in the Dynamo script using a slider node which determines how accurately the geometry in the Revit Model should be represented and calculated during the matchmaking process. The geometry tolerance is set between 0 to 100, allowing for a maximum 10-centimeter adjustment along all window edges. At that point, a higher tolerance results in a larger set of possible matches, while a lower tolerance provides more precise results.

Step 11: First run of Dynamo Graph (script): User will run the Dynamo script for the first time after following the steps. Runing the Dynamo scripts will trigger the script by calculating the values and making necessary changes to the Revit Model. The original model that the user uploads is saved in an export file to ensure that this first run does not affect it.

Step 12: Check if families are loaded: After the first run, the user can check if the families are correctly loaded through this node named “Check if families are loaded”. Dynamo might throw an error at this stage as newly created families may not be inserted in the Revit environment yet. If the user encounters an error, the user should proceed with the next step.

Step 13: Insert all newly created families: The user should insert the new families generated by Dynamo back into the Revit Model. Newly generated families often have a suffix like_1 or _2 that helps differentiate them from the original ones.

Step 14: Right-click on the component and edit the code (via clicking the enter or backspace button): The user, if needed, should right-click on the Dynamo node to make small adjustments like adding or removing an enter/backspace and rerun the script that helps to clear any potential errors or glitches in the workflow.

Step 15: Save the entire model as an alternative Revit Model: At this final step, the user should save the whole Revit model under a new name to ensure the user has a backup of the updated model with all new families and parameters by Excel spreadsheets that show the carbon emissions calculations.

3. Workflow and Stakeholder Interaction in the Parametric Desing Process

The flowchart diagram, shown in Figure 4, illustrates how designers and property owners interact with stakeholders through the parametric modeling tool. It details the sequential processes integrated with BIM data management and analysis. The diagram provides a structured approach to managing and analyzing BIM data, enhancing parametric design methods for reusable components while incorporating carbon emission calculations to assess environmental impact.

The process begins with the “Architect,” a key figure in the process, uploading the current (as-is) BIM model into the system and preparing it for transformation and analysis. Once uploaded, BIM components are converted into “Component-Parameter Data” and exported to an Excel file. At the same time, the “Property Owner” follows the same steps, generating two separate Excel sheets, one from the property owner and another from the architect.

A critical next step involves evaluating the model’s environmental impact, specifically calculating carbon emissions related to global warming potential. If the assessment yields unsatisfactory results, the process triggers further evaluation. The architect then defines the “geometry tolerance range” for component matchmaking. This phase ensures the BIM model is adjusted and verified, creating an “alternative BIM model” that aligns with the specified tolerance range. Finally, the “Final BIM Model” is generated after a successful evaluation. This final model integrates the updated BIM data and the corresponding Excel sheet, completing the collaborative process.

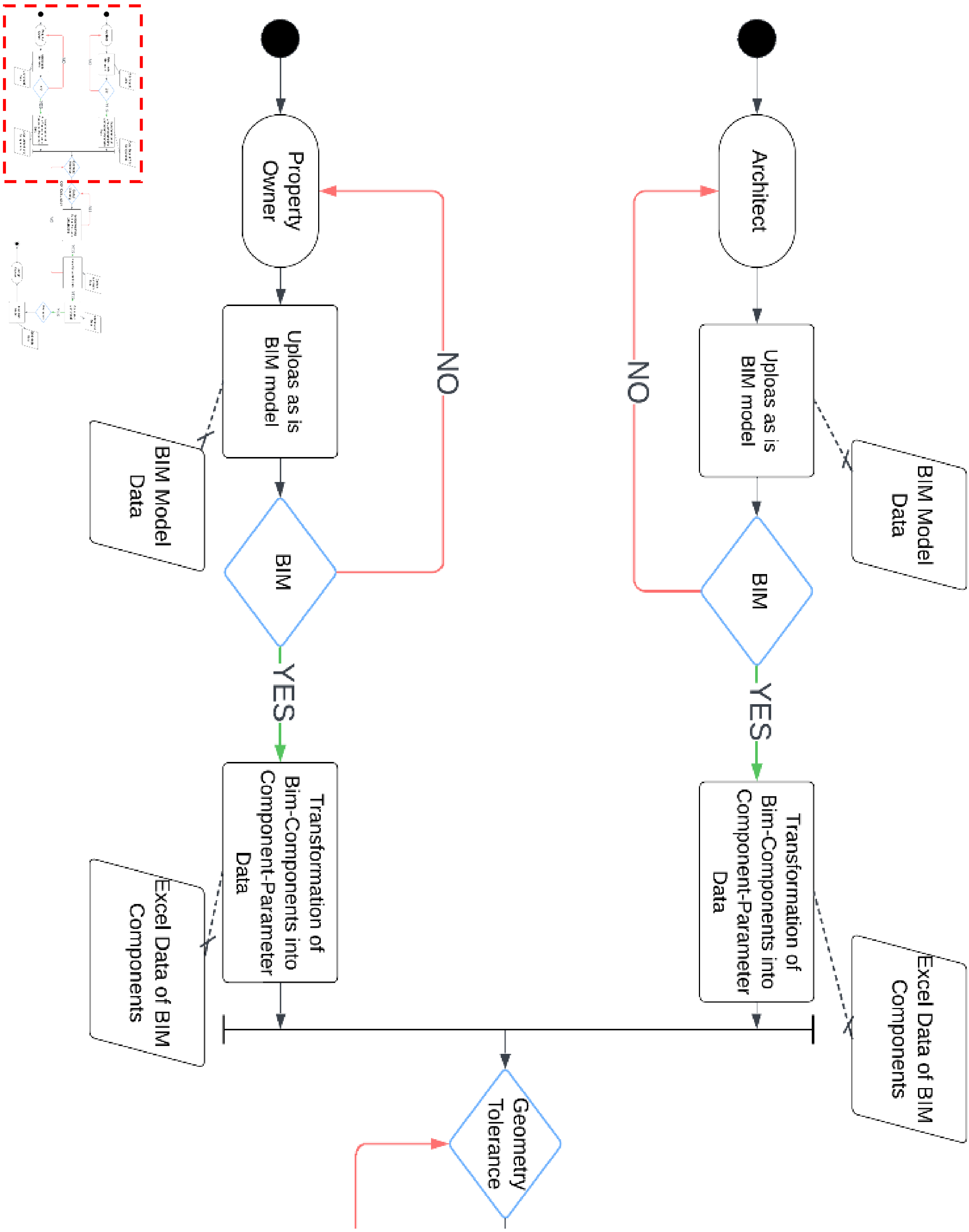

Figure 5: Flow chart diagram of the structure process diagram of parametric design tool.

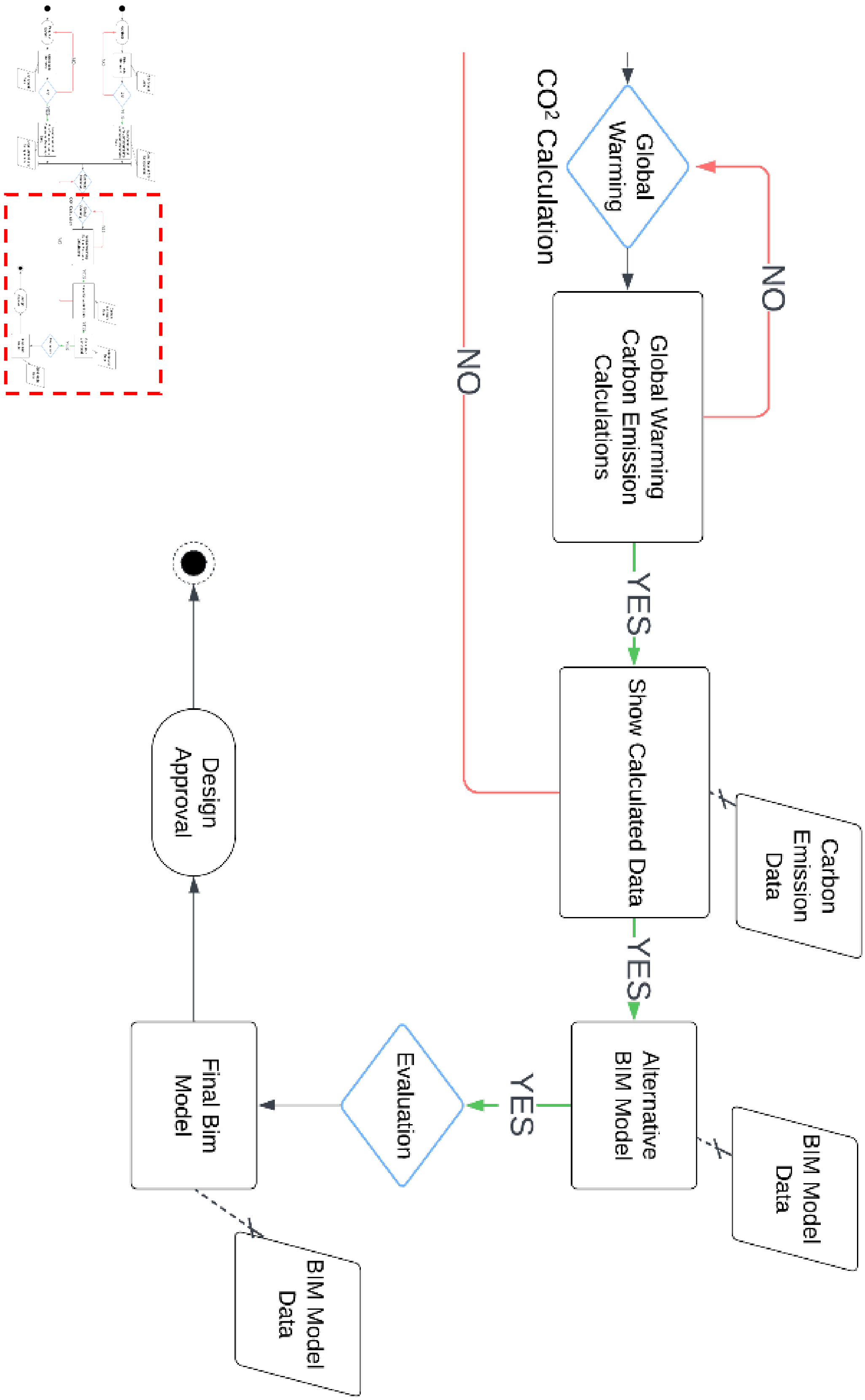

Figure 5: Flow chart diagram of the structure process diagram of parametric design tool.

4. UML Illustrations for Parametric Design Tool

The Unified Modelling Language (UML) diagrams are detailed on page 28 of Deliverable 3.2, Methods for BIM supported dismantling,' where they define the categorization and statements of the UML diagrams. Since Deliverable 3.3 builds on the close collaboration between PlanB and TUB, it does not explain the UML diagrams. The UML diagrams from Deliverable 3.2 have been merged and adapted for Deliverable 3.3. Instead, the following section emphasizes the pivotal role of architects and property owners in using and integrating the PDT into their processes through UML diagrams and the integration of PDT to CP-IM within its features as storage and microservices. This integration highlights the collaborative nature of the projects and the importance of stakeholders' involvement in the design process.

4.1. UML for parametric design tool from the architect's perspective

This section illustrates the UML Use-case diagram framework for architects' case scenarios. The diagram, shown in Figure 6, illustrates the integration of the CP-IM, micro-service, and storage, which is detailed in D3.2, further bolsters the architects' confidence in their project design and construction management. The initial step for architects is to import or open the BIM model on the Revit platform, as stated in the previous chapters. This crucial step sets the foundation for the entire process, which was previously explained by the Flow chart diagram of the structure process diagram which is illustrated in figure 5. Once the BIM model is imported and opened, the next step is to transform BIM-model component information into geometry based-parameter data by saving all window families to a directory where files can be easily reached. In the meantime, secondary material data will be generated, stored, and accessed in Excel through the micro-service of storage in the CP-IM platform. The impact of the BIM environment on GWP carbon emissions underscores the importance of every decision made by architects in this process.

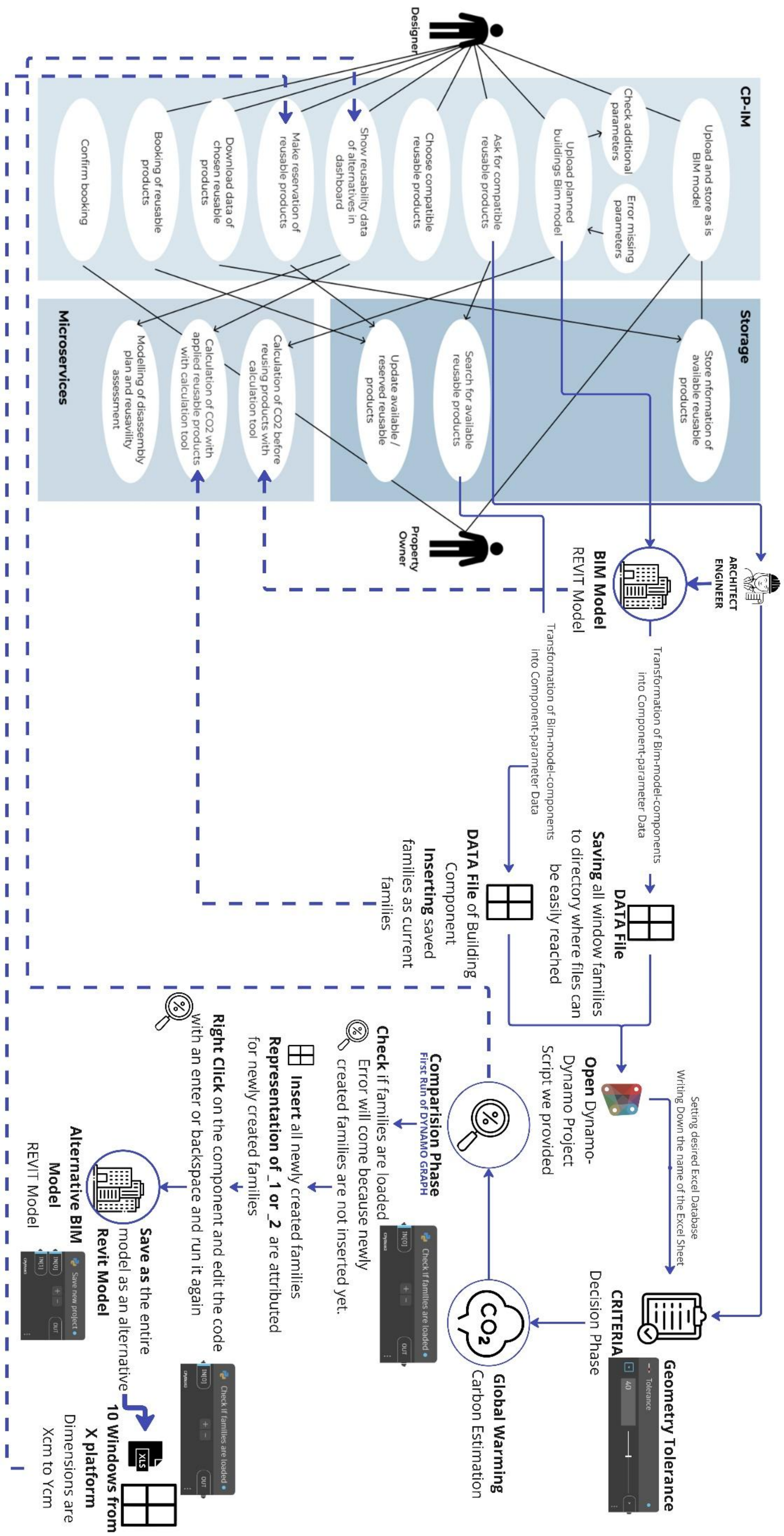

Figure 6: Use case-diagram for PDT from the designer's perspective.

4.2. UML for parametric design tool from the property owner's perspective

The Unified Modelling Language (UML) use-case diagram framework demonstrates how property owners, empowered by the PDT, can take controls of their projects. Figure 6 showcases the integration of CP-IM, micro-services, and storage, as detailed in Deliverable 3.2, further reinforcing owners' confidence in project management process.

The diagram illustrates what property owners can access through UML within the scope of micro-services and storage, both with and without PDT, as well as their interaction with architects. The steps for utilizing PDT in the Revit environment have already been explained in the above-mentioned section. All steps remain the same, except for how property owners access CP-IM and how CP-IM based accessibility to micro-services, and storage is structured. Additionally, both adapted UMLdiagrams illustrate the potential relationship between architects and property owners.

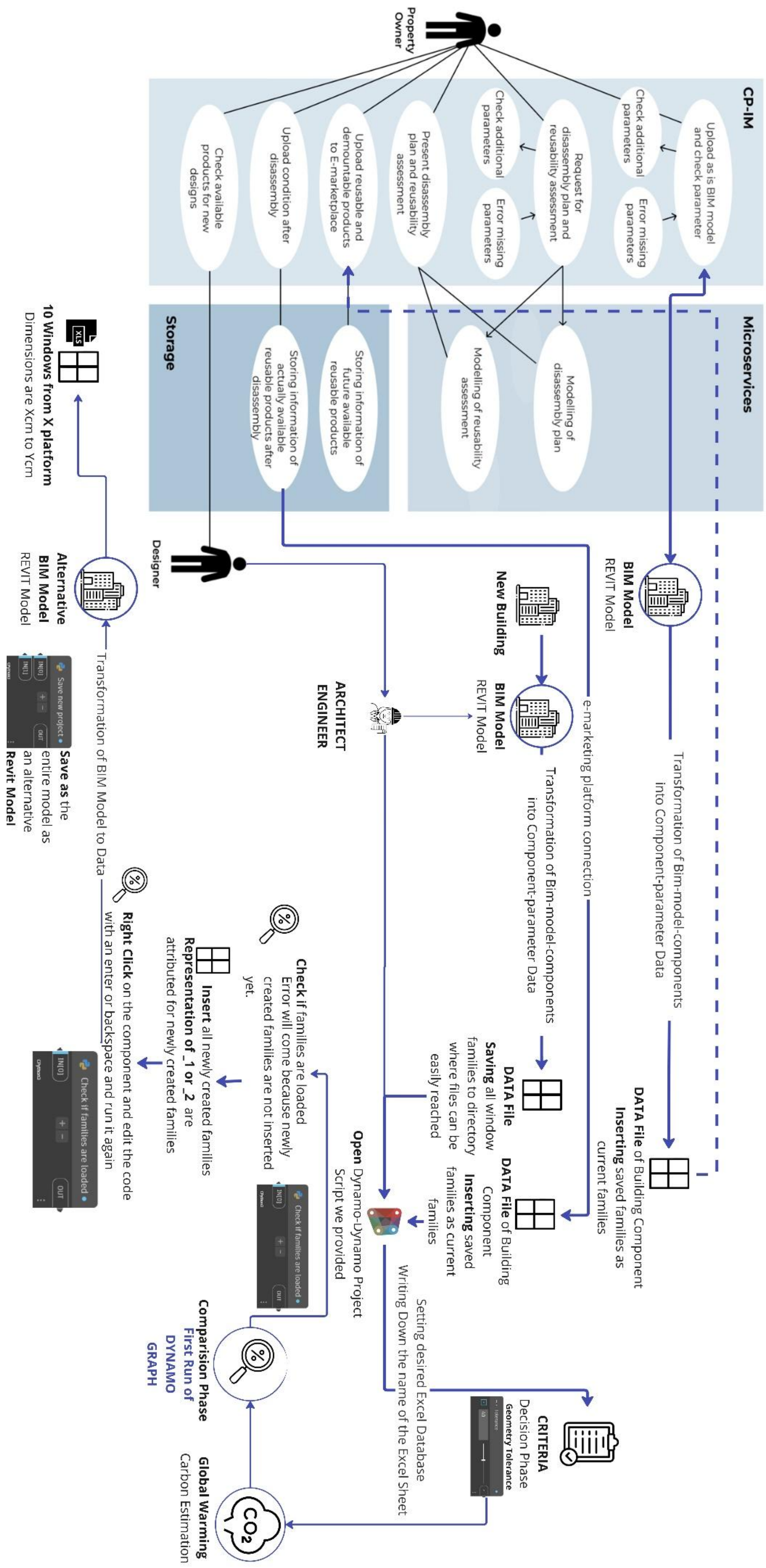

Figure 6: Use case-diagram for PDT from the property owners' s perspective.

5. Integration of CP-IM and Parametric Design Tool

The parametric modelling tool is integrated with the CP-IM platform, as explained through UML-based diagrams adapted from the Deliverable 3.2 to this deliverable. As illustrated in both UML diagrams, PDT integrates with CP-IM platform through different actors such as "Architects" and "Property Owners ". This integration creates a marketplace for material exchange and fosters a collaborative environment.

The "Upload as-is BIM Model and check the parameters" step in the CP-IM platform enables user to interact with both CP-IM and PDT. Additionally, CP-IM's "Storage Services" allow users to store hypothetical marketplace data for future use and upload reusable and demountable products to e-marketplace.

As a final step, CP-IM and PDT integration enable users to check available products for new designs with both architects and property owners have access. The main difference between their access levels is that architects have more features available, while property owners have limited access. The integration of the CP-IM platform is a key outcome of Deliverable 3.3 and is set to become an essential resource, facilitating collaboration and material exchange and inspiring new ways of circular construction thinking.

6. Conclusion

This report introduces the REINCARNATE PDT, a good resource for reusing building parts and recycled materials. It is designed to guide interested readers, project partners, and potential users. PDT, whether used independently by external users or within REINCARNATE demonstration projects, offers a promising future for sustainable construction. Its flexibility allows stakeholders to participate actively in construction material and product selection, leveraging the secondary materials marketplace within the BIM environment.

This report underscores the significant potential of automation scripts for integrating second-hand windows into Revit models. The Dynamo-based PDT demonstrates that substantial CO_2 savings are achievable by reusing building items, optimizing the design process, and reducing environmental impact. This PDT enhances efficiency and promotes environmentally friendly circular design and construction practices by automating the integration of windows from a hypothetical marketplace into Revit models.

Our key findings highlight the crucial role of flexibility in circular design and construction. The REINCARNATE PDT's tolerance levels for matching windows directly influence CO2 savings, emphasizing the need for adjustable criteria. Larger and more diverse marketplace inventories amplify environmental benefits, whereas rigid criteria (zero tolerance) result in minimal or no savings, underscoring the importance of adaptability in circular construction.

Despite these positive outcomes, challenges remain. Future efforts should focus on improving the user interface, expanding the PDT's capabilities to include additional components (e.g., doors, prefabricated elements, HVAC systems), and refining CO2 impact estimations by incorporating transportation and logistics factors. Enhancing IFC format integration will allow users to store and calculate data across BIM environments. Evaluating the feasibility of large-scale second-hand marketplaces, especially in less populated regions, is critical, as government incentives may be needed to ensure their viability. Further research into the logistic-related CO2 impact is essential for a comprehensive assessment of material reuse.

In conclusion, this tool supports environmental sustainability and offers economic and social benefits. The prototype represents an initial step toward increasing the use of secondary building products in renovation and new construction products. It enables small-scale projects struggling to compete in a resource-intensive industry to increase productivity and reduce costs by up to 40%. Continued tool development, alongside supportive policies and evolving industry practices (e.g., wider adoption of BIM and increasing awareness of sustainability), could further accelerate the adoption of circular construction practices.

7. References

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