RHINO-TO-REVIT AS COLLABORATION:

EVALUATING ALTERNATE WORKFLOWS FOR RHINO-TO-REVIT BIM DATA EXCHANGE IN EARLY DESIGN STAGE

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Abstract. Building Information Modeling (BIM) and Parametric Design Tools (PD) have recently become vital innovation tools for the industry. In a model known as the parametric BIM workflow, concept discovery and building knowledge can be mixed, according to Janssen (2014). To do this, however, it is necessary to enhance BIM interoperability and data transfer capability (Erik 2020). There are major synchronisation difficulties between the PD and BIM platforms. There are also barriers to the smooth and error-free sharing of data between PD and BIM software. This research project conceptualises the relationship between Revit and Rhino, not simply as separate software platforms, but as project collaborators. In doing so, the analysis explores how various data transfer workflow options are collaboratively efficient. As the project continues, for further refining and recording, the Rhino models need to be transferred to Revit. As a result, a Rhino building data model is created to evaluate and assess the workflow from Rhino to Revit across multiple channels (DWG, Conveyor, Rhino.inside.Revit, etc., to achieve the best solutions in various scenarios. Seven factors are the basis of the assessment process: precision, flexibility, expansion, automation, interoperability, time-consuming and necessary expertise. The comparative study will eventually illustrate the benefits and pitfalls of each workflow, even though the end outcome is the same. And based on their individual needs, users may select the most acceptable parameterised BIM workflow solution. Providing designers with a creative approach to contribute to reducing the time and resources expended on non-design and technological interoperability problems by design workers.

Keywords. BIM Collaboration; Methodology; Parametric BIM Workflow; Rhino; Revit

1. Introduction: (Research context and motivations)

The principles of Industry 4.0 have influenced a move to end-to-end digitisation and dynamic interoperability in the architectural field (Maskuriy et al. 2019). Building Information Modeling (BIM) and Parametric Design Tools (PD) have recently become vital engineering tools for the industry. In a model known as the parametric BIM workflow, design exploration and construction information can be mixed, according to Janssen (2014). However, to do this, improving BIM interoperability and data transfer capability is important (Erik 2020). There are major synchronisation difficulties between the PD and BIM platforms, though. There are also barriers to the smooth and error-free sharing of data between PD and BIM software.

There is a full disparity in concept thought between BIM and PD instruments. To enhance design challenges and succinct graphic design processes, BIM resources are dedicated to adding comprehensive details. And the program for PD focuses on the development of more complex solid geometry. This prompted several BIM data sharing and interoperability problems between them. Therefore, parametric modelling approaches, such as building embedded materials, building structural models, engineering details, and links to advanced construction records, are not consistent with the benefits of BIM (Boeykens 2012). Similarly, for the establishment of complex geometric entities and the consistency design process, BIM applications and techniques do not have the benefits of parametric design tools.

This research project conceptualises the relationship between Revit and Rhino, not simply as separate software platforms, but as project collaborators. In doing so, the analysis explores how various data transfer workflow options are collaboratively efficient. This thesis, therefore, examines multiple methods of BIM workflow and methods of model coupling. More precisely, this Project investigates the sharing of data for Rhino between Revit and PD plugins. Through studying and evaluating the mechanism and effects of model transmission coupling for Rhino to Revit from the initial design stage based on different platforms, various parametric BIM workflow approaches are being tested. As the Project continues, for further refining and recording, the Rhino models need to be transferred to Revit. As a result, a Rhino building data model is created to evaluate and assess the workflow from Rhino to Revit across multiple channels (DWG, Conveyor, Rhino.inside.Revit, etc., to achieve the best solutions in various scenarios. Seven factors are the basis of the assessment process: precision, flexibility, extension, automation, interoperability, time-consuming and necessary expertise.

The findings of this analysis help in reducing the time and resources expended on non-design and technological interoperability problems by design personnel. Ultimately, this analysis will provide users with a new method of design that will allow users to choose the appropriate parameterised BIM workflow based on their individual needs.

2. Research Aims and Objectives

This research aims to strengthen the methodology of design and develop the skills of teamwork and data processing between the Parametric Design tool and BIM software. The goal of the Project is to construct a PD architectural model and use it to analyse the various model coupling possibilities in the BIM environment.

3. Research Questions

What is the significant thing between Rhino and Revit for data model transfer?
How do interoperability and workflow apply to BIM?
How to pick the most effective workflow approach for Rhino-to-Revit while faced with multiple cases?

4. Methodology

The method of action analysis is an exploratory method of research that is adaptable to a small-scale approach. Instead, the intervention analysis approach is used to continuously investigate, develop and analyse and offer solutions to real-world challenges of research-related operations and procedures. It is not meant to define theoretical principles and general laws.

According to McNiff (2013), action research is a particular way of evaluating one's activity to decide if it complies with their ideal activity. Therefore it would be beneficial to follow critical self-reflective activity during each point of the analysis process to achieve a thorough understanding to improve the whole analysis.

About the research issue, to evaluate the feasibility of executing the strategy, it is important to integrate expertise in the organisational phase with academic knowledge in research. Also, Hearn and Foth 2005 claimed that in the sense of "layman", some elements of technological expertise should translate imperative ideas so that group members can continue to participate.

Research papers should, however, take non-professionals into account and use non-term explanations (Hearn and Foth 2005)

To acquire knowledge by analysing the technologies of similar hypotheses, action research is highly effective. This can be accomplished by explaining, at each point of the study process, the iterative loop of planning, intervention, observation and reflection (Baskerville, 1999). Four phases of AR will be expressed in particular research ventures, namely, preparation, intervention, reflection, and repetition.

This initial planning stage will be documented utilizing comprehensive documentation, including elucidation of the combination of parameterised BIM workflows in the AEC business. Also, the PD approach and the BIM environment coordination model are still very relevant. Critical reflections on the components and vulnerabilities of current resources will relate to users' explicit requirements, including tacit needs.

The nature and limitations of the research would thoroughly address the actual needs and stakeholders, which is consistent with the concept of people-oriented architecture. The adoption of the perspective sharing approach of the observer and the observed should be considered based on this assumption.

The findings of the tests will be clinically isolated and tested in the subsequent case studies. The therapeutic methods will be reconsidered to maximise and boost effectiveness when improving potential studies of correlation. In compliance with the interaction framework of action testing standards in the design analysis sector, the Project will continue to review and focus on the findings throughout the process (Cole et. 2005).

4.1 SPECIFIC METHODS:

1.Analyzing of problems
2. Effective analysis of current technologies and tools
3. Iterative case study process and Analysis (Test → Reflect → Improve → Repeat)
4. Detailed overview of the functionality and performance of various forms of partnership and a description of the capability and effect of parametric architecture and integration of BIM.

5. Literature review

5.1. INDUSTRIAL 4.0 AND ARCHITECTURAL ENGINEERING CONSTRUCTION INDUSTRY

The Architectural Engineering and Construction (AEC) industry is facing new problems with the advent of technology. The emergence of 'Industry 4.0' has created a unique development opportunity for digitalisation and interoperability in the field of architecture (Maskuriy et al. 2019). Since the AEC industry is still evolving, the "low-profit margin and lack of innovation" is still criticised (Deloitte 2018). Also though emerging technology will transform the whole market, until 2016, the built environment lacked the opportunity to implement new operating methods, which led to the implementation of revolutionary technologies at a slower pace in the built environment than in other manufacturing fields (Bew 2015). Building information modelling (BIM) has currently been one of the main technologies that have captured the industry's interest. In specific, BIM offers a more systematic system of design that promotes the effectiveness, teamwork, and engineering efficiency of architectural design practice (Techel & Nassar 2007). And BIM has made the fourth industrial revolution a central repository for the processing of information about digital ventures (Maskuriy, Selamat, Ali, Maresova, & Krejcar, 2019)

5.2. INTEROPERABILITY AND IMPROVEMENT

There are two influential techniques in this modern industrial revolution that can tackle the digital interoperability and innovation process: building information modelling and parametric modelling. Both also contributed to an intensive and strengthened design process and provide, taking into account the convergence of multiple functions and variables, the underlying purpose of problem-solving (Haliburton, et al. Moreover the growth of these developments in the AEC sector shows that a stable base has been laid for tech and BIM implementations and allows for industry enhancements (Deloitte, 2018). In comparison, the use of BIM lowers cost and time load, improves tremendous efficiency and consistency of workflow (alfabbuild; et al., 2018).

In particular, in various parts of the supply chain, it has been rapidly adopted as a competitive strategy to save money, increase competitiveness and market growth, enhance the quality of infrastructure, and improve environmental performance (Wortmann & Tunçer, 2017). The improvements that should have taken place during the transition from analogue to digital are also mirrored in BIM, which ensures that an unprecedented volume of digital data content is monitored and handled (Van Beusekom, Sarwarzadeh, Sinke, Sturm, & Zegger, 2018). This opens up the opportunities for creativity in parametric architecture, and translating digital data into design parameters can be a valuable BIM tool.

5.3. ISSUES AND THE REASONS

At this point, there is no industry workflow that can simplify the process and be consistent with appropriate bim data under any case usage requirements; that can be imported smoothly and reliably from PD software to BIM tools, and that can help subsequent revisions and further development.

In particular, the advancement of digitalisation and interoperability in the field of architecture, BIM, and the use of the Parametric Design Method (PD) have become recent research topics of great importance. There are great variations between PD and BIM in concept thought. The BIM resources are essentially dedicated to presenting comprehensive knowledge to strengthen design challenges and succinct graphic design processes (Banihashemi 2018). In the other hand, PD software focuses on more sophisticated creation of solid geometry and algorithms, which implicitly causes parametric modelling approaches to be insufficient in building embedded resources, building structure models, engineering details, and ties to advanced building documents (Boeykens 2012). However, because of the absence of BIM data, the coordination between these aspects is inadequate for the next phase of concept parameter work (Wortmann & Tunçer 2017).

5.4. SOLUTION

The construction industry needs full data model transmission tools, as well as digital protocols, according to Pratt et al. (2011), to prevent the impact on the subsequent development of building performance measurement and the interoperability of various architectural design methods. It is important to discover future challenges in advance to avoid construction risks and issues to increase the work performance of collaborative projects on various design platforms. Furthermore, improving BIM interoperability and data transfer capability is also important (Erik 2020). For BIM workflows, there are currently several ways to facilitate data conversion. Nonetheless, each of the strategies has associated benefits and drawbacks. It is also important to select the most appropriate instrument for each form of function.

In brief, this review examines the data transfer and interoperability research between software for parametric modelling and BIM tools. It will support the improvement of the collaboration capabilities and interoperability of BIM's workflow. The effectiveness of collaborative work on multiple design platforms, in particular, can help to identify potential problems in advance to prevent construction risks and problems. As a project matures, it becomes necessary for further refining and documentation to export the Rhino models into Revit. The lack of interoperability in this phase, which is not beneficial to the overall growth of BIM cooperation, has been seen by the uniform conversion and IFC format data model transmission. Still, for the subsequent phase, they have given study directions. It is important to concentrate on composite work forms, cloud storage, and software API interfaces to enhance BIM data transfer and interoperability to realise real-time model alteration in multi-person work. In essence, by study and review of distribution strategies and tools, the right options for each different problem can be obtained.

5.5. PARAMETERISED BIM WORKFLOW - BIM DATA EXCHANGE SOLUTION

This research would analyse current workflow strategies for BIM software from the PD tool (Rhino with Grasshopper) to BIM software (Revit). This means not only investigating data exchange between the two software applications but also exploring the connection between parametric designers, engineers and customers.

5.5.1. Classification of workflow solution based on the final product.

The Project aims to build a PD tool architectural model (Rhino6) and use it to test the various model coupling possibilities in the BIM context. Through observing the various methods of transmission between PD and BIM systems, the workflow strategies under analysis could be classified by the outcome and mechanism into three groups.

Manual DWG files import solution (Manual import method)
Manual ACIS SAT files import solution (Manual import method)
Manual Rhino-3dm files import solution (Manual import method)
Conveyor Direct Shapes import solution (Direct Shapes import method)
Rhino.Inside.Revit Direct Shapes import solution (Direct Shapes import method)
Conveyor Loadable Families import solution (Loadable Families import method)
Rhino.Inside.Revit Loadable Families import solution (Loadable Families import method)

With the aid of other platforms, the manual transmission scheme is substantially different from the transmission mechanism, and its influence is always proportional to the time spent. The limit is only related to the information the file can carry.

A fast minimally ordered method of transmission is Direct Form. Restricted organisation and speed, such as early concept presentations and categories that do not need to be modified, render DirectShapes best for transient drawing sets. And it is unquestionably not appropriate for later project phases that are more complete.

For individual components or special projects that need to be customised in the architectural model, the Loadable Families approach is sufficient. As part of the Revit family, by using various family models, you can streamline the workflow. These artefacts will also have their sketches and support the editing of Revit, in addition to being part of the whole project painting.

In addition to this certain basic elements can be manually or automatically modified into Revit current Native categories, such as walls and floors.

5.5.2 Classification of workflow solution based on Collaboration effect

Centred on the likelihood that future project creation will be provided by the workflow, such as:

1. Editing capabilities required for subsequent revisions.
2. For the interoperability between PD and BIM
3. Management capabilities of the data model.
4. Collaboration for other software development.

The three classifications of the workflow are

Manual import method (Low collaboration solution)
Direct Shapes import method (Medium collaboration solution)
Families import method (High collaboration solution)

5.5.3. DWG files

Autocad's DWG exports geometry, which is undeniably the quickest way, from rhino to Revit. In Revit, the model is shown as Mass. In this manner, certain unimportant contexts, individual forms and landscapes such as sculptures can be imported easily. In Autodesk's AutoCAD software, DWG applies to both a technology setting and .dwg files, the native file format. In 1982, with the very first launch of AutoCAD software, Autodesk founded .dwg. DWG files contain all the data entered by a user in a CAD drawing. The following data may include diagrams, geometric data, maps and photographs.

One of the most widely used design data formats is the .dwg file format, found in almost every design world (Autodesk, 2020)

5.5.4. ACIS SAT files

The type of SAT file is linked primarily to ACIS. The 3D ACIS Modeler (ACIS Modeler, ACIS) is a kernel geometric model developed by Spatial Corporation and is part of Dassault Systems. Many software engineers, such as computer-aided design, computer-aided manufacturing, computer-aided engineering (CAE), architecture, engineering and construction, use ACIS in industrial fields. ACIS is also used by industry-standard applications such as AutoCAD, Briscad and Cimatron as a geometry kernel. Revit can translate item collections in the SAT file into objects, 3D entities and areas (3D ACIS MODELER, 2007).

5.5.5. Rhino 3dm files

For the 3D graphics file format created by the openNURBS Project, the .3dm file extension is used. These 3DM files are also categorised as files for CAD (Computer-aided Design). These .3dm files are often referred to as CAD files of 3D NURBS and can be created by different CAD applications. There are 3D graphics and other CAD-related artefacts in these 3DM files. You can read and write Rhino 3DM files without Rhino in other 2D and 3D CAD/CAM/CAE and image programs. These .3dm files may contain specifics of the metadata and format attributes as well. To open and view the contents of these .3dm files, designed by Robert McNeel & Associates, which is a CAD technology, Rhino 3D software can be used (Associates, 2020).

5.5.6 Conveyor

For user-friendly synchronisation between Rhino and Revit software applications, Conveyor is a geometry and data processing plugin. To translate geometric figures into Revit components by reading Rhino's open-source 3DM scripts. And there are no intermediate files, no cloud storage, no confusing device settings. It is possible to perform object recognition and data delivery for users who understand basic 3D modelling and architecture (P.G, 2020).

5.5.7 Rhino.Inside.Revit

A new project created by Robert McNeel & Associates that will load Rhino7 into other applications is the Rhino.Inside Project. As part of the initiative, Rhino.Inside.Revit will prove to users a better way to place Rhino7 and GH into the Revit memory to run as additional components. Using the API to convert the data type from Rhino and the data type from Revit to each other (Rhino.Inside®.Revit, 2020).

```
# adding references to the System, RhinoInside
import clr
clr.AddReference('System.Core')
clr.AddReference('RevitAPI')
clr.AddReference('RevitAPIUI')
clr.AddReference('RhinoInside.Revit')

# now we can import symbols from various APIs
from System import Enum

# rhinoscript
import rhinoscriptsyntax as rs

# rhino API
import Rhino

# grasshopper API
import Grasshopper

# revit API
from Autodesk.Revit import DB

# rhino.inside utilities
import RhinoInside API
from RhinoInside.Revit import Revit, Convert
# add extensions methods as well
# this allows calling .ToXXX() convertor methods on Revit objects
clr.ImportExtensions(Convert.Geometry)

# getting active Revit document
doc = Revit.ActiveDBDocument
```

Figure 1. Rhino.Inisde.Revit API set

6. Case Study

From parametric modelling tools (Rhino & Grasshopper) to BIM platform, this chapter examines numerous parametric BIM workflow solutions (Revit). First, identify an architectural model with adequate information to represent the parametric architecture thinking, and then let it flow through various link methods into the BIM sector to calculate the actual results of the various workflow methods currently available. This chapter includes seven workflow solutions that will help to move data as a bridge between BIM and PD. Each extension will push the same model from Rhino and its additional details to the BIM platform (Revit), and seven separate BIM models constructed from the same building model data will be obtained after the transition process is over. But they can have varying levels of meaning and information effects, and the best transmission result as an element may be a native element that can be edited in Revit. This will supplement and enhance the interoperability between PD and BIM. While each parametric BIM workflow solution will attempt to accomplish the same result, each solution will relay data differently. The following would clarify in depth the various forms and methods of transmission of each scheme. As an important measurement criterion for the potential of the workflow, the degree of detail, versatility, and scalability of the model data to be distributed will be used for this case study. Similarly, the extent of model coupling and accuracy is also an integral aspect.

6.1. Establishment of a building model for evaluation

The preparation of the model is essential as the first phase of this comparative assessment study. Therefore an architectural model has been established that conforms with the thinking of machine architecture. The test model has typical graphic elements and complex personalised elements after in-depth creation, as well as detailed material details and classification of the structure. Finally, the concept of all components flows directly into Revit after the parametric BIM workflow is finished. All elements, therefore, contain useful information which in the BIM setting, can be ordered, grouped, organized, counted, and categorised by a schedule.

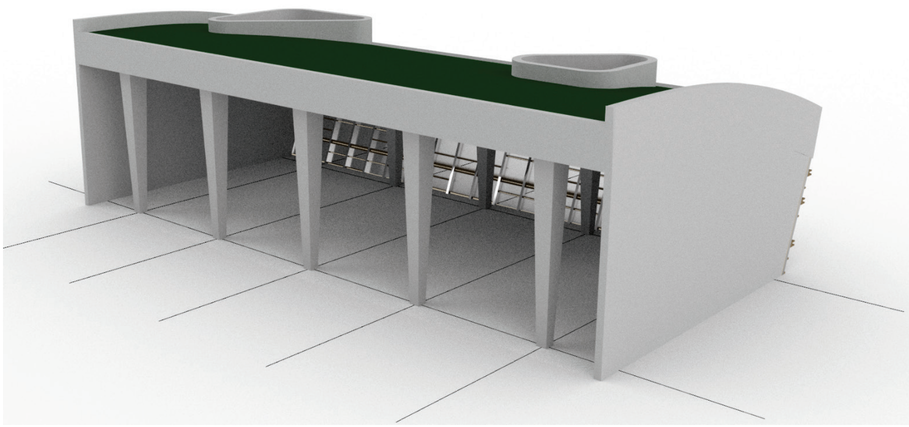


Figure 2. Overview of Rhino Architectural Model for the Evaluation

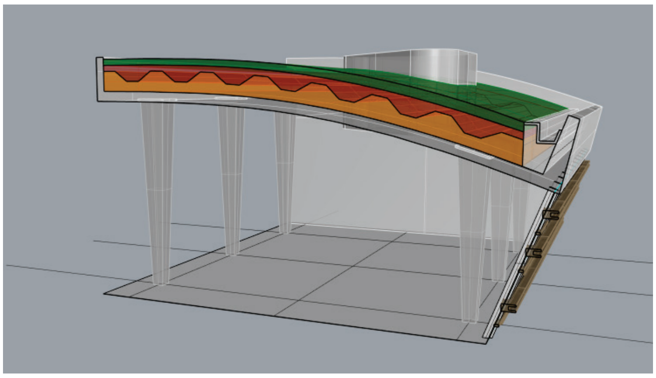


Figure 3. Section View

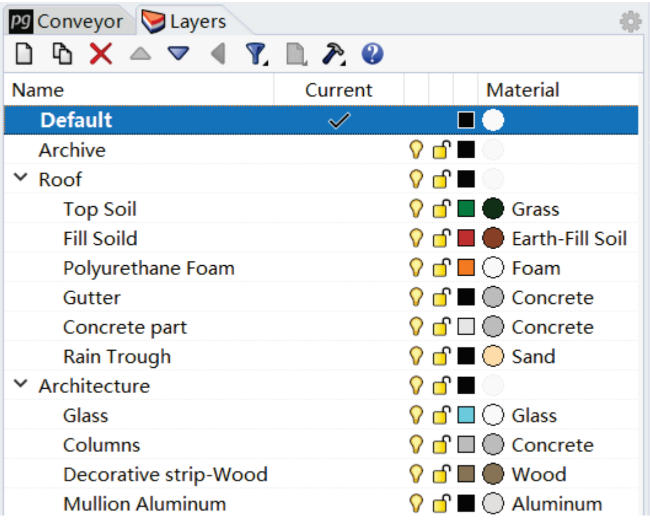


Figure 4. Layer information

The model includes typical architectural elements for RHINO-TO-REVIT BIM data exchange valuation, and complex or custom architectural elements.

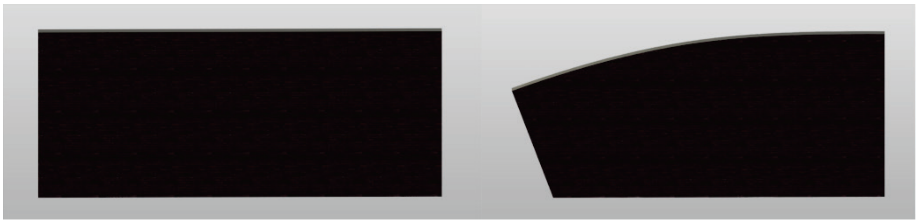


Figure 5. Wall example for element type

6.2. MANUAL .DWG FILES IMPORT WORKFLOW SOLUTION

DWG files' manual import scheme has the highest transfer speed and the most succinct method of operation. Basically, the method can be explicitly broken into two steps: export and import. At the same time, in this project, it is also the least structured data model.

6.2.1. Import process

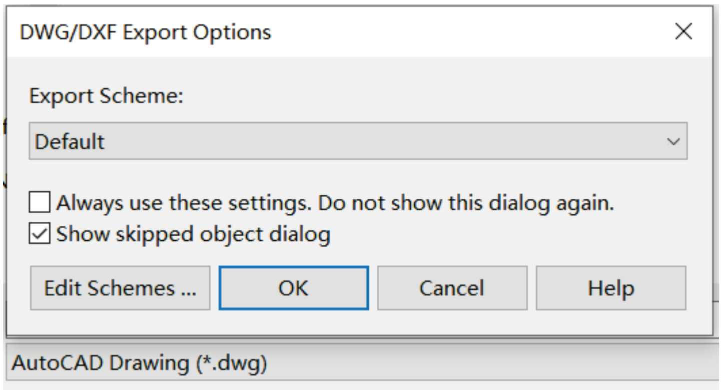


Figure 6. Rhino export window for DWG files.

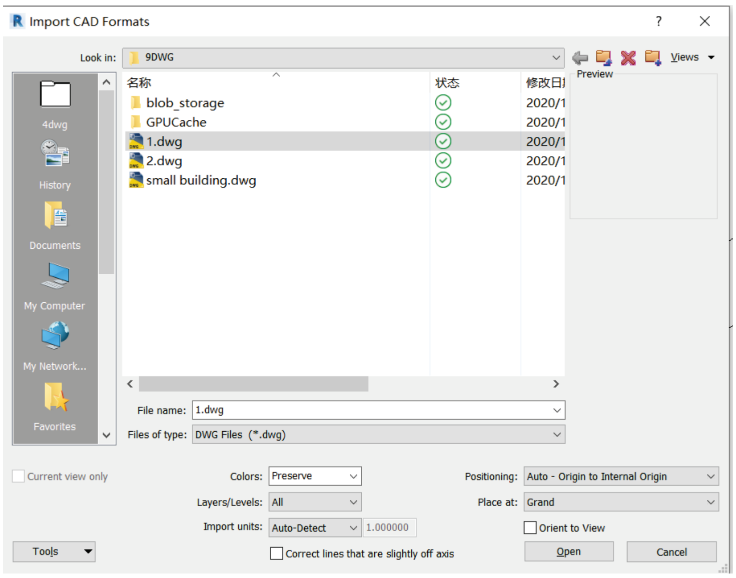


Figure 7. Revit import window for DWG files.

6.2.2. Import result

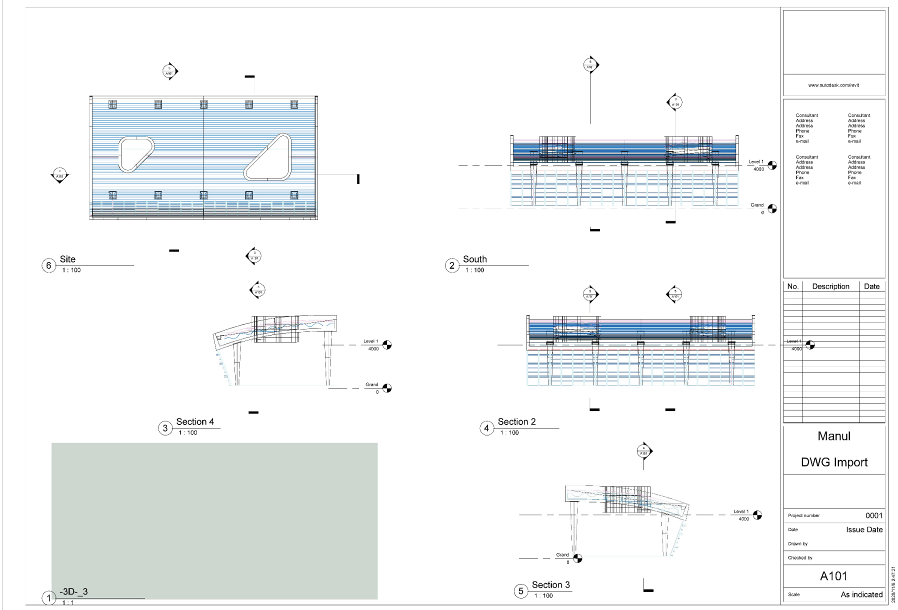


Figure 8. DWG format file import result drawing.

6.2.3. Analysis

TABLE 1. DWG solution summary.

Workflow		DWG
Accuracy	Geometry import	**0.5**
	Location	**1**
	Manually adjust requirements	**Lowest**
Flexibility	Editability of geometry in Revit	**0**
	Editability of Material in Revit	**0**
	Texture addition	**1**
	Rendering	**0**
Expansibility	Material Import	**0**
	Independent sheet set (Family)	**0**
	Constraints(Elevation…)	**0**
	Identity Data, Phasing	**1**
Automation	Automatic recognition and conversion of common elements	**0**
Interoperability	Automatically update the model	**0**
	Possibility of subsequent changes	**0**
Time-consuming		**lowest**
Skills requirements	Rhino & GH skills requirements	**Low**
	Revit skills requirements	**Low**

0: Not supported at all; 0.5: Barely supported; 1: Excellent effect.

6.3. MANUAL ACIS .SAT FILES IMPORT WORKFLOW SOLUTION

The most fundamental stability and scalability can be given by this approach. Rhino6 has a built-in sat file export feature in the AUTODESK format, and Revit also offers the option of provisional classification according to the model section. The model needs to be separated into several parts in the transmission method according to the functions and materials of the parts, and they are imported and specified separately.

6.3.1. Import process

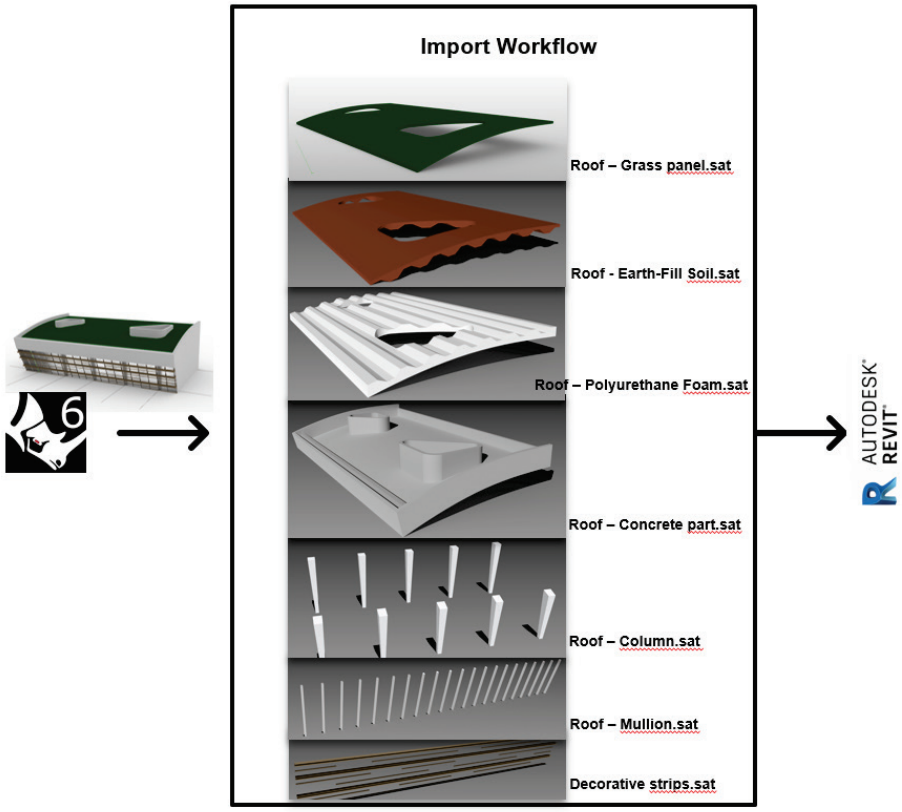


Figure 9. Import workflow for .SAT files.

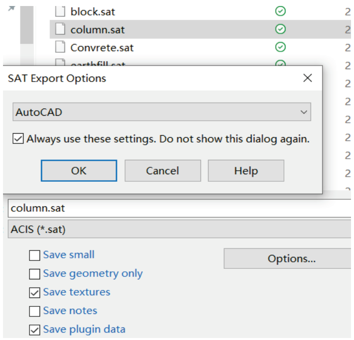


Figure 10. Rhino export window for .sat files.

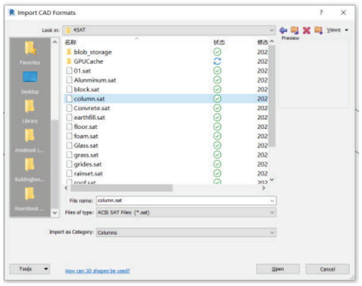


Figure 11. Revit import workflow for .SAT files.

6.3.2. Import result

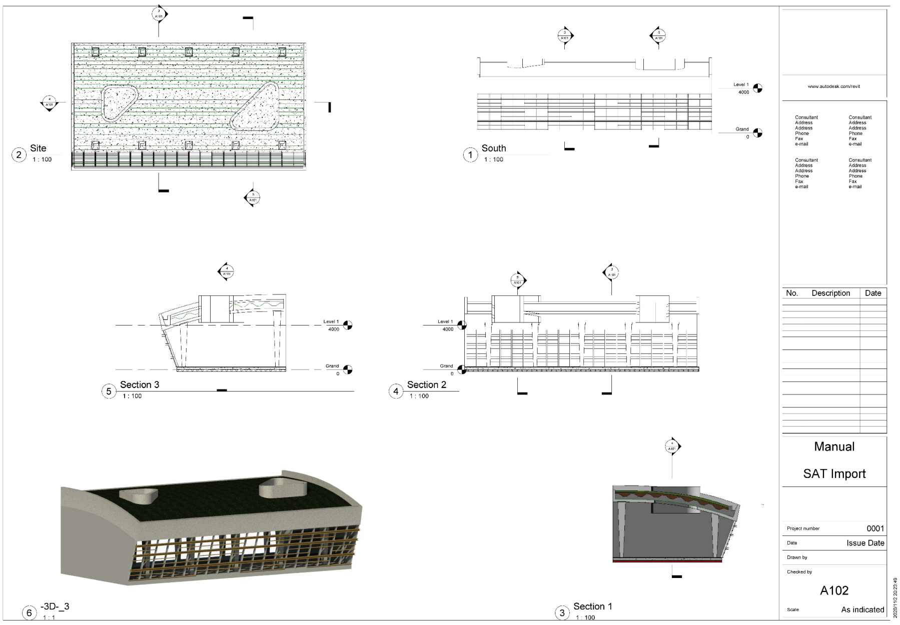


Figure 12. SAT file import result drawing.

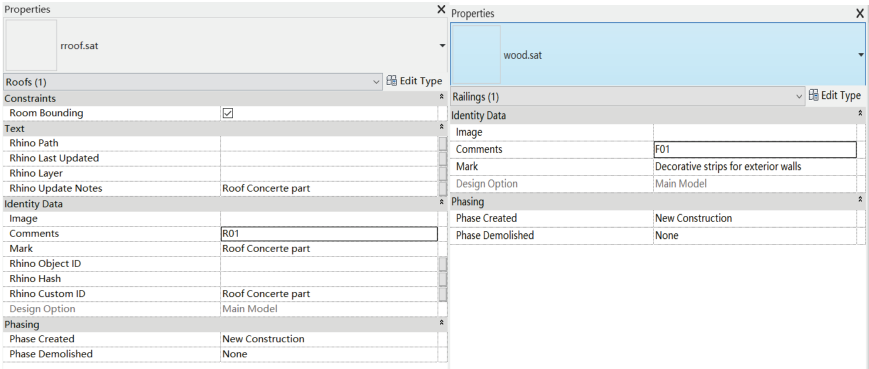


Figure 13. SAT file import additional BIM information.

6.3.3.Analysis

TABLE 2. ACIS SAT solution summary.

Workflow		**SAT**
Accuracy	Geometry import	**0.5**
	Location	**1**
	Manually adjust requirements	**Medium**
Flexibility	Editability of geometry in Revit	0
	Editability of Material in Revit	**0.5**
	Texture addition	**1**
	Rendering	**0.5**
Expansibility	Material Import	0
	Independent sheet set (Family)	0
	Constraints(Elevation…)	**1**
	Identity Data, Phasing	**1**
Automation	Automatic recognition and conversion of common elements	0
Interoperability	Automatically update the model	0
	Possibility of subsequent changes	0
Time-consuming		**Medium**
Skills requirements	Rhino & GH skills requirements	**Medium**
	Revit skills requirements	**High**

6.4. MANUAL RHINO .3DM FILES IMPORT WORKFLOW SOLUTION

Between Rhino and Revit, Rhino 3DM files have the highest compatibility. It also has graphics and details support in Revit as Rhino's native file format. The import workflow is somewhat similar to the SAT file, but it can also produce families using Revit Family templates. At the same time, with the aid of Revit's Mass import feature, model parts could be imported into the Mass setting, and elements such as walls and floors can be reconstructed in BIM by choosing surfaces and lines.

6.4.1. Import process

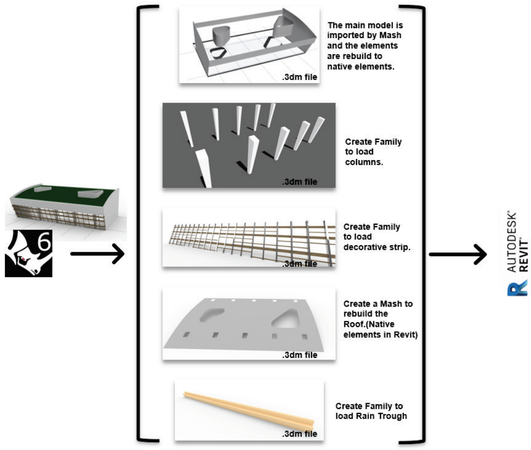


Figure 14. Import workflow for .3DM files.

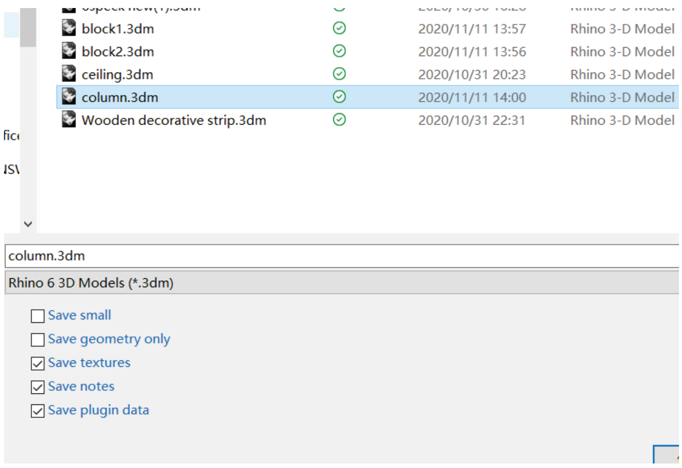


Figure 15. Rhino export window for .3DM files.

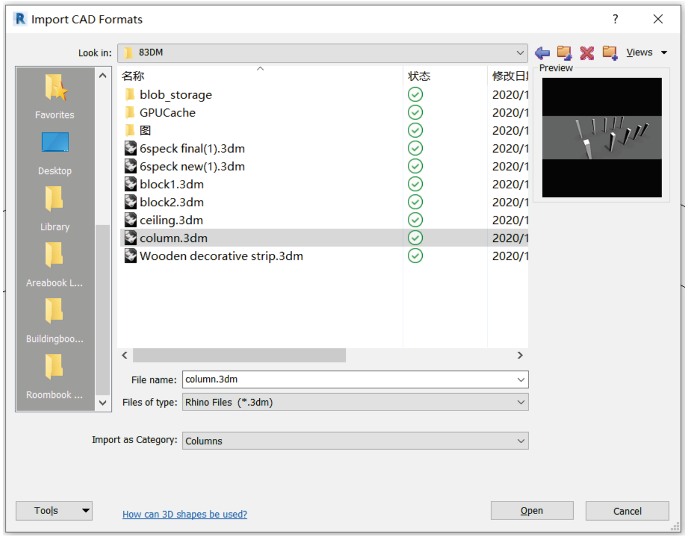


Figure 16. Revit import window for .3DM files.

6.4.2. Import result

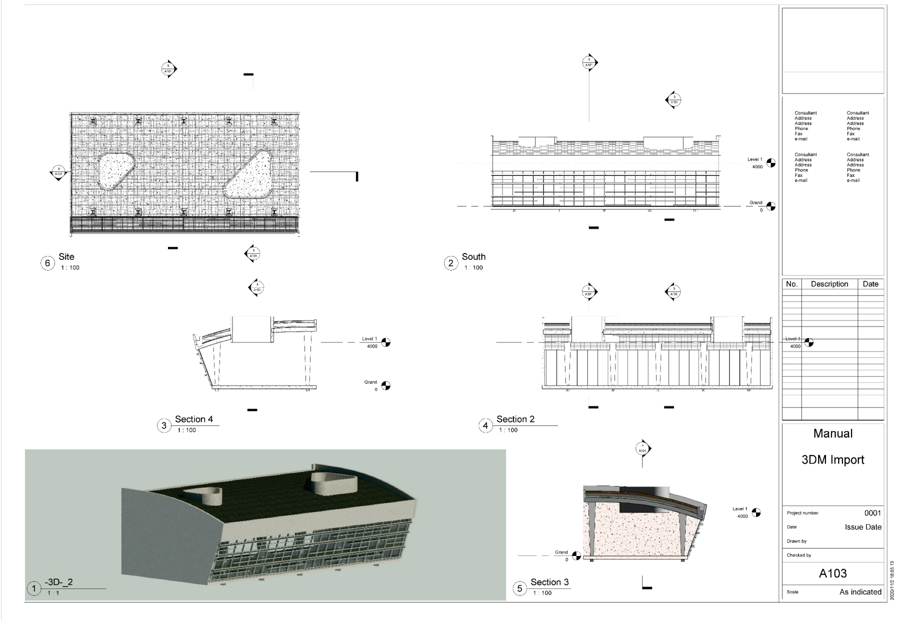


Figure 17. 3DM file import result drawing.

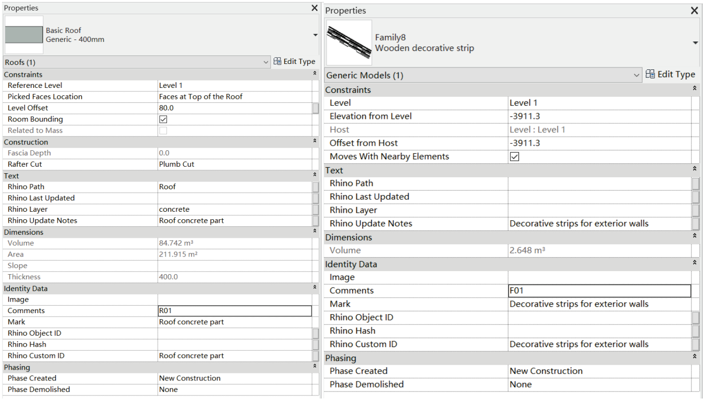


Figure 18. 3DM file import additional BIM information.

6.4.3.Analysis

TABLE 3. Rhino 3DM solution summary.

Workflow		Rhino 3dm
Accuracy	Geometry import	**1**
	Location	**1**
	Manually adjust requirements	**High**
Flexibility	Editability of geometry in Revit	0
	Editability of Material in Revit	**0.5**
	Texture addition	**1**
	Rendering	**1**
Expansibility	Material Import	0
	Independent sheet set (Family)	**1**
	Constraints(Elevation…)	**1**
	Identity Data, Phasing	**1**
Automation	Automatic recognition and conversion of common elements	**0**
Interoperability	Automatically update the model	**0**
	Possibility of subsequent changes	**0**
Time-consuming		**High**
Skills requirements	Rhino & GH skills requirements	**Medium**
	Revit skills requirements	**High**

6.5. CONVEYOR DIRECT SHAPES IMPORT WORKFLOW SOLUTION

As the carrier for geometric model conversion, Conveyor uses Rhino's open source 3DM file format, which is why this analysis chose 3DM files for comparative research. The Conveyor Direct Form import is much simpler than the manual import process, and it's excellent at handling and restoring the native components. It helps users to pick and identify what they need in the rhino, and then the item travels from the usual layer to the layer of the Conveyor Belt. If the layer has the right material content, it will be imported to Revit automatically. Most typical elements are immediately modified to Revit native elements, such as walls, floors, and curtain walls.

6.5.1. Import process

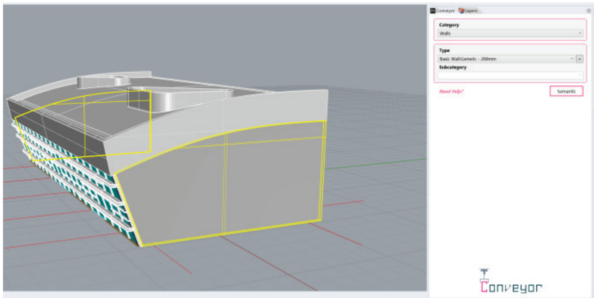


Figure 19. The interface of Conveyor plugin for Rhino.

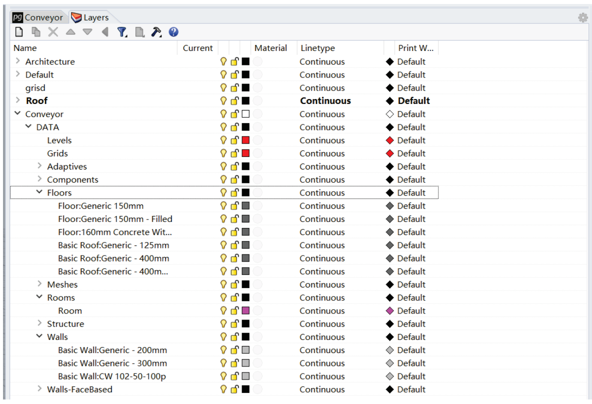


Figure 20. Conveyor layers.

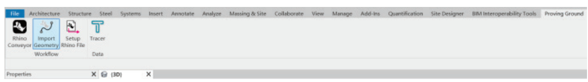


Figure 21. The window of Conveyor plugin for Revit.

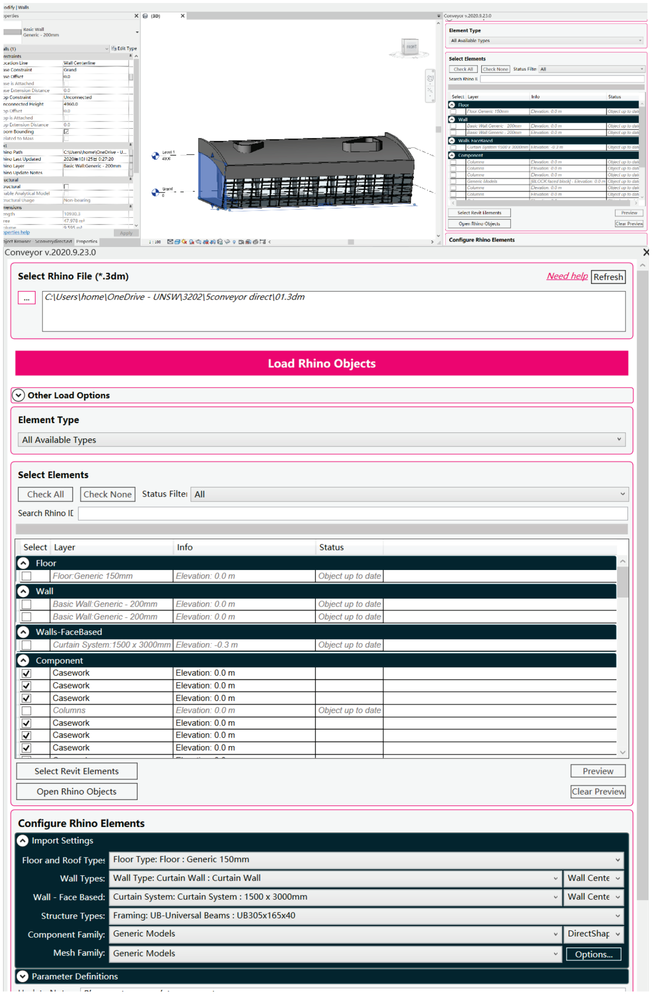


Figure 22. The interface of Conveyor plugin for Revit.

6.5.2. Import result

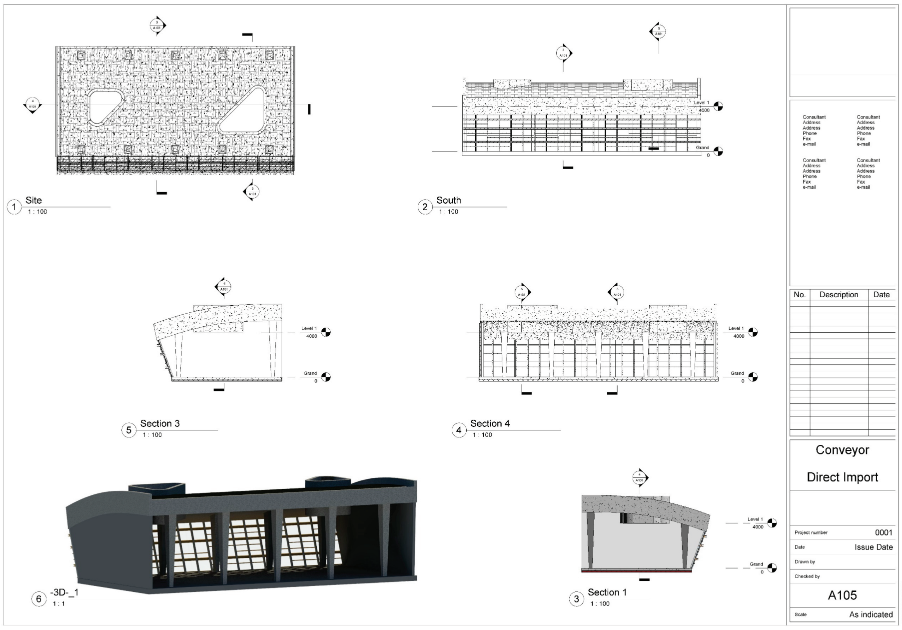


Figure 23. Conveyor direct shapes import result drawing.

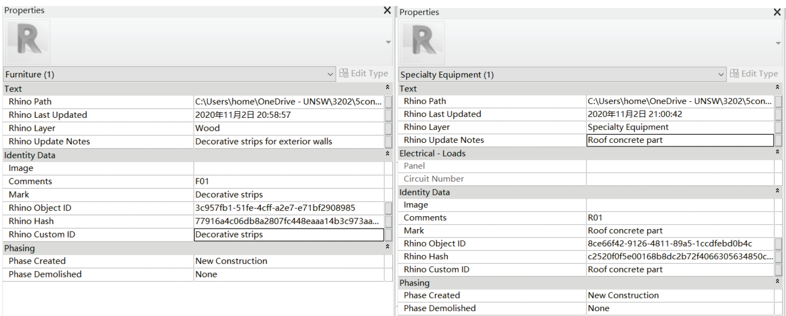


Figure 24. Conveyor direct shapes import additional BIM information.

6.5.3.Analysis

TABLE 4. Conveyor Direct Shapes solution summary.

Workflow		C. D.S
Accuracy	Geometry import	1
	Location	1
	Manually adjust requirements	Low
Flexibility	Editability of geometry in Revit	0
	Editability of Material in Revit	0.5
	Texture addition	1
	Rendering	0.5
Expansibility	Material Import	0
	Independent sheet set (Family)	0
	Constraints(Elevation…)	1
	Identity Data, Phasing	0
Automation	Automatic recognition and conversion of common elements	1
Interoperability	Automatically update the model	1
	Possibility of subsequent changes	1
Time-consuming		Low
Skills requirements	Rhino & GH skills requirements	Medium
	Revit skills requirements	Medium

6.6. CONVEYOR LOADABLE FAMILY IMPORT WORKFLOW SOLUTION

The formation of the Revit Family is the key distinction between the Conveyor Loadable Family import scheme and the previous one. To build an editable family, this solution will add a selection belonging to the Rhino block and import it into the BIM environment. In most instances, it already has all of the native Revit Family's functions and information. Its gain lies in the ability to read the Rhino layer's information (like material details) and handle sub-categories.

6.6.1. Import process

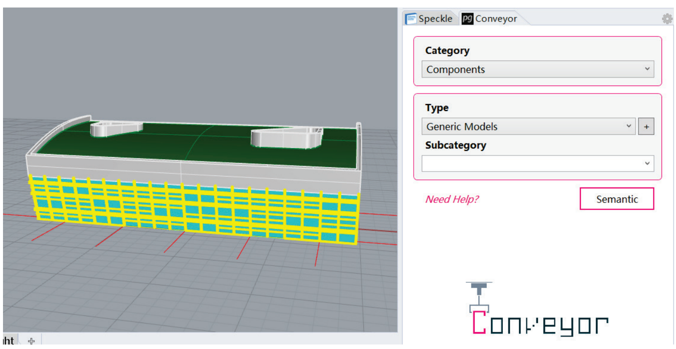


Figure 25. The process of creating a family by Conveyor with Rhino blocks..

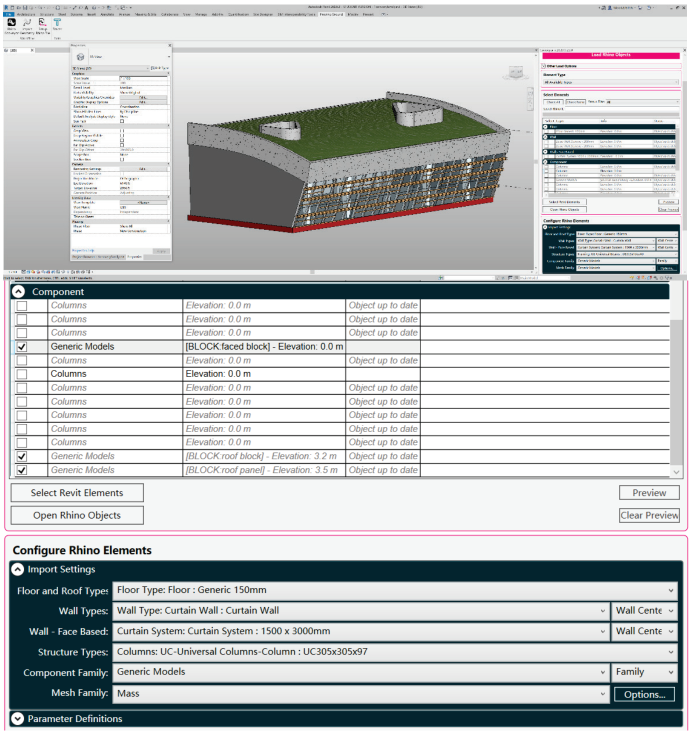


Figure 26. Import of families established by Conveyor.

6.6.2. Import result

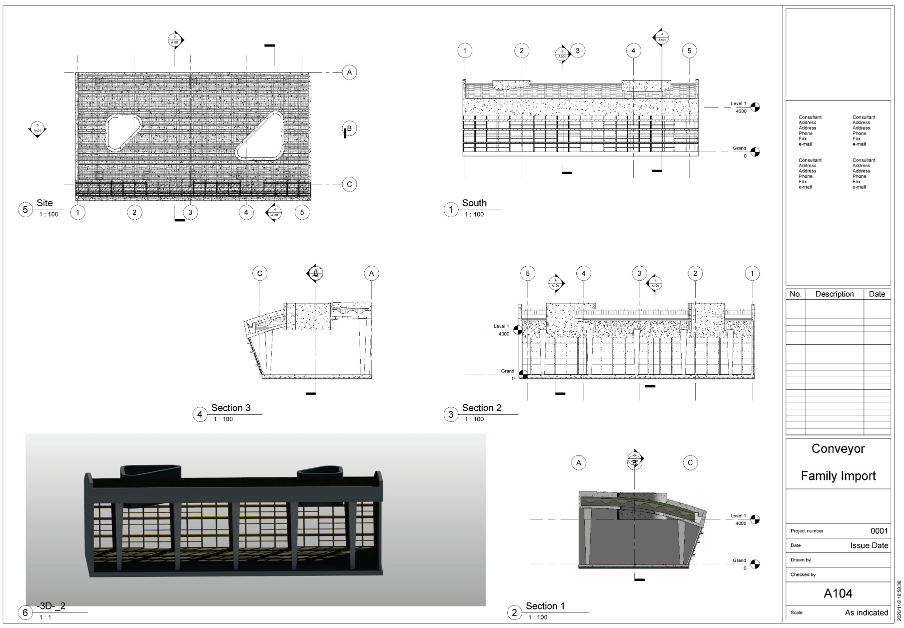


Figure 27. Conveyor loadable family import result drawing.

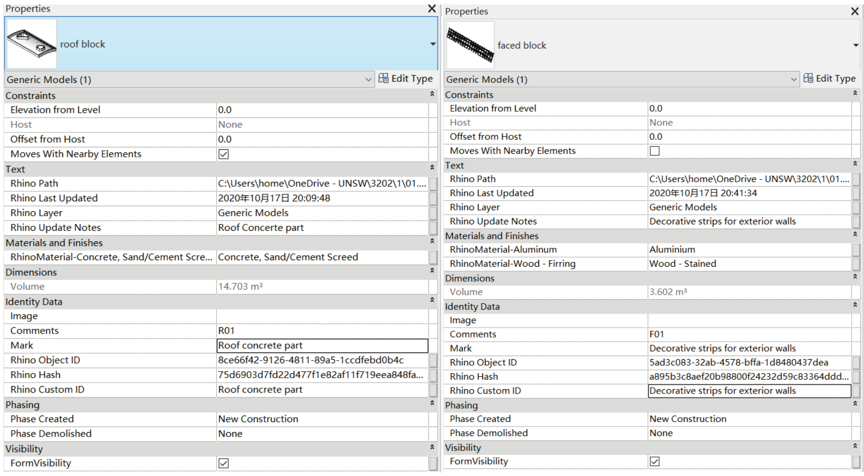


Figure 28. Conveyor loadable Family import additional BIM information.

6.6.3.Analysis

TABLE 5. Conveyor loadable Family solution summary.

Workflow		**C. L.F**
Accuracy	Geometry import	**1**
	Location	**1**
	Manually adjust requirements	**Medium**
Flexibility	Editability of geometry in Revit	**1**
	Editability of Material in Revit	**1**
	Texture addition	**1**
	Rendering	**1**
Expansibility	Material Import	**1**
	Independent sheet set (Family)	**1**
	Constraints(Elevation…)	**1**
	Identity Data, Phasing	**1**
Automation	Automatic recognition and conversion of common elements	**1**
Interoperability	Automatically update the model	**1**
	Possibility of subsequent changes	**1**
Time-consuming		**Medium**
Skills requirements	Rhino & GH skills requirements	**Medium**
	Revit skills requirements	**High**

6.7. RHINO.INSIDE.REVIT DIRECT SHAPES IMPORT WORKFLOW SOLUTION

Using Rhino.Inside.Revit to load Rhino7 and Grasshopper into Revit memory to run as an additional program. Use its attached Grasshopper battery to classify the model according to layers and add BIM information. The geometry of the Rhino will then be submitted to Autodesk Revit, and eventually the shape and details of the Rhino will be converted to Revit components.

6.7.1. Import process

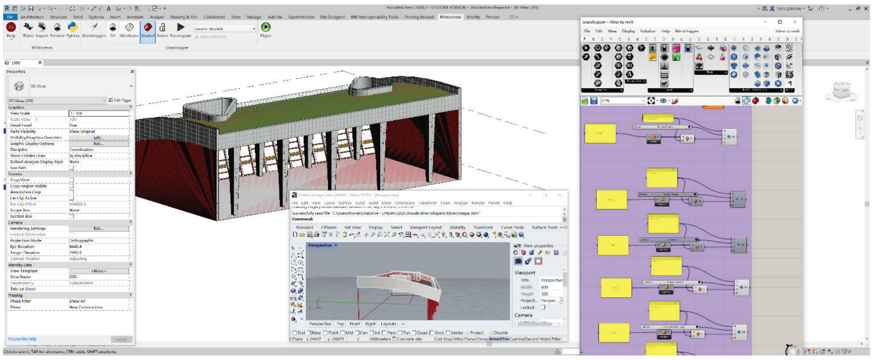


Figure 29. R.I.R work interface overview

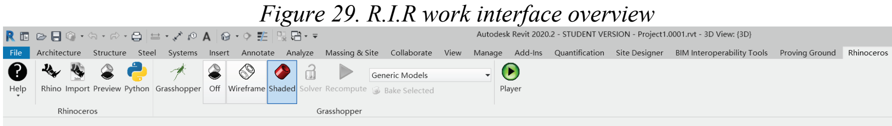


Figure 30. R.I.R add-in window of Revit.

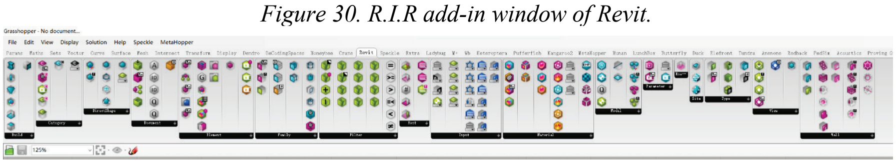


Figure 31. R.I.R Grasshopper library.

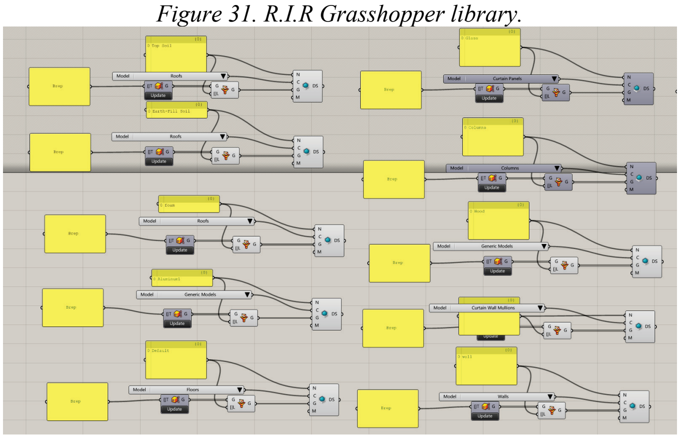


Figure 32. Use Grasshopper to select and define the architectural model for BIM data exchange, R.I.R Direct Shapes.

6.7.2. Import result

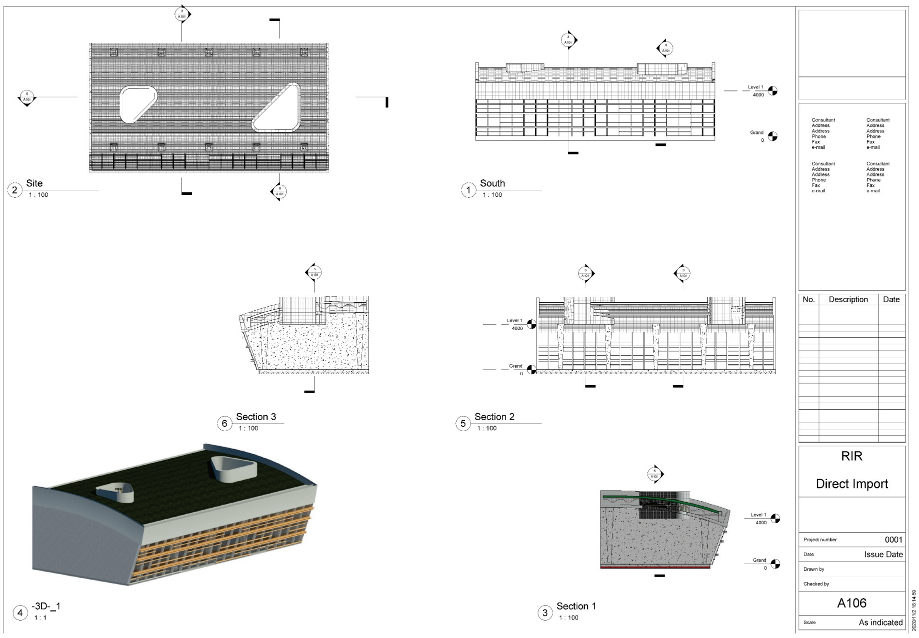
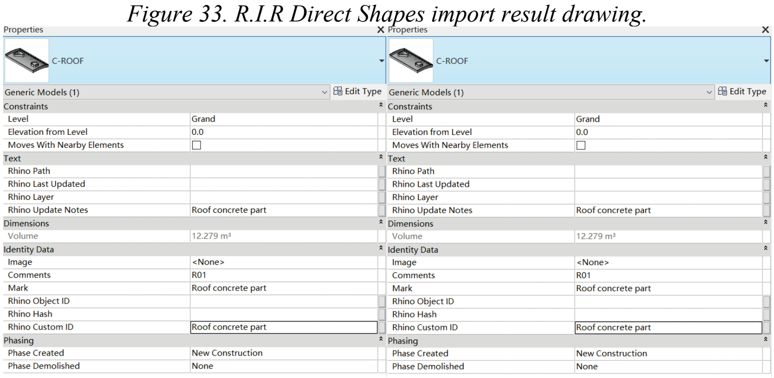


Figure 33. R.I.R Direct Shapes import result drawing.



Properties		Properties	
C-ROOF		C-ROOF	
Generic Models (1)	Edit Type	Generic Models (1)	Edit Type
Constraints		Constraints	
Level	Grand	Level	Grand
Elevation from Level	0.0	Elevation from Level	0.0
Moves With Nearby Elements	☐	Moves With Nearby Elements	☐
Text		Text	
Rhino Path		Rhino Path	
Rhino Last Updated		Rhino Last Updated	
Rhino Layer		Rhino Layer	
Rhino Update Notes	Roof concrete part	Rhino Update Notes	Roof concrete part
Dimensions		Dimensions	
Volume	12.279 m³	Volume	12.279 m³
Identity Data		Identity Data	
Image	<None>	Image	<None>
Comments	R01	Comments	R01
Mark	Roof concrete part	Mark	Roof concrete part
Rhino Object ID		Rhino Object ID	
Rhino Hash		Rhino Hash	
Rhino Custom ID	Roof concrete part	Rhino Custom ID	Roof concrete part
Phasing		Phasing	
Phase Created	New Construction	Phase Created	New Construction
Phase Demolished	None	Phase Demolished	None

Figure 34. R.I.R Direct Shapes import additional BIM information.

6.7.3.Analysis

TABLE 6. R.I.R Direct Shapes solution summary.

Workflow		R.I.R D.S
Accuracy	Geometry import	0.5
	Location	1
	Manually adjust requirements	Medium
Flexibility	Editability of geometry in Revit	0
	Editability of Material in Revit	1
	Texture addition	1
	Rendering	1
Expansibility	Material Import	1
	Independent sheet set (Family)	0
	Constraints(Elevation…)	0
	Identity Data, Phasing	1
Automation	Automatic recognition and conversion of common elements	0
Interoperability	Automatically update the model	0.5
	Possibility of subsequent changes	1
Time-consuming		Medium
Skills requirements	Rhino & GH skills requirements	High
	Revit skills requirements	Medium

6.8. RHINO.INSIDE.REVIT LOADABLE FAMILY IMPORT WORKFLOW SOLUTION

By reading the Revit Family Templates file, the Loadable Family import method could create Revit families. Compared to the R.I.R Direct Shapes import method, this solution has higher integration capabilities and compatibility. And it also supports the development of subcategories. In Grasshopper, all of the work above will be done.

6.8.1. Import process

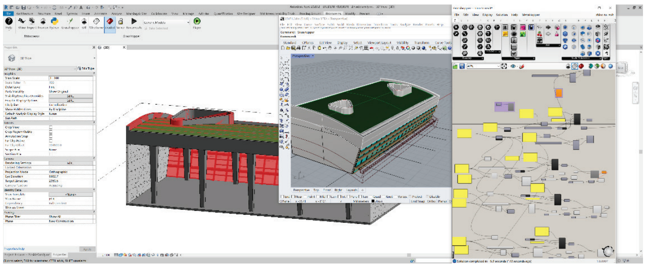


Figure 35. Work interface overview for R.I.R Loadable family import solution.

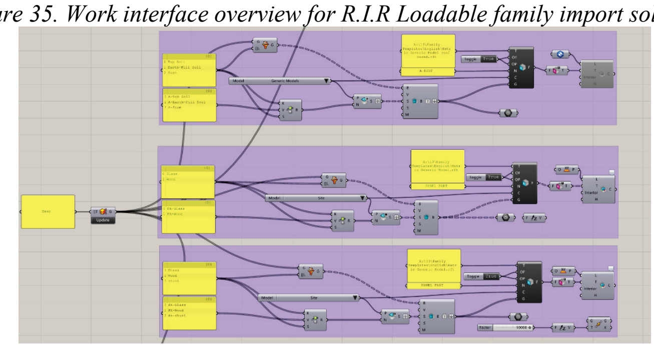


Figure 36. Establishment of Revit family.

6.8.2. Import result

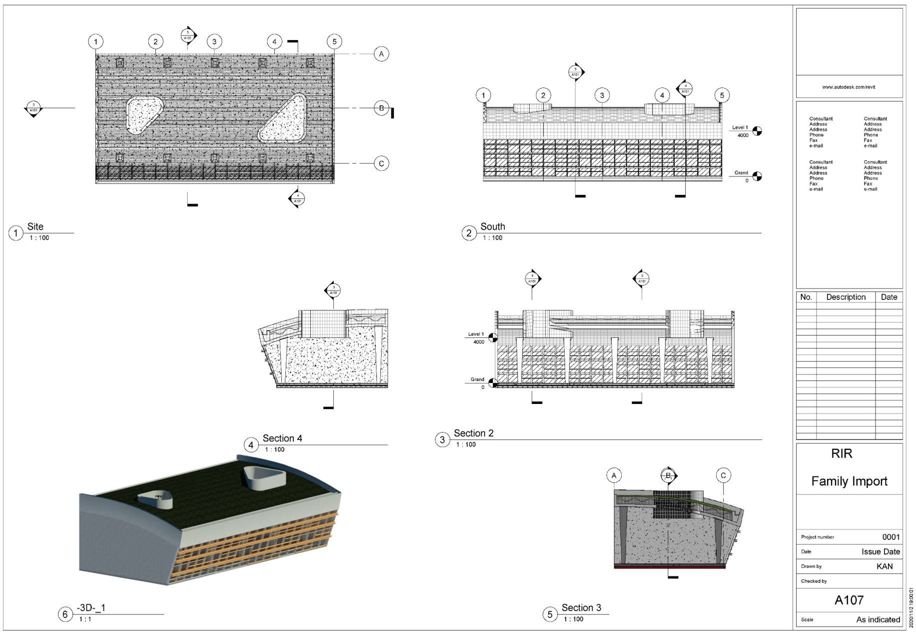


Figure 37. R.I.R Loadable family import result drawing.

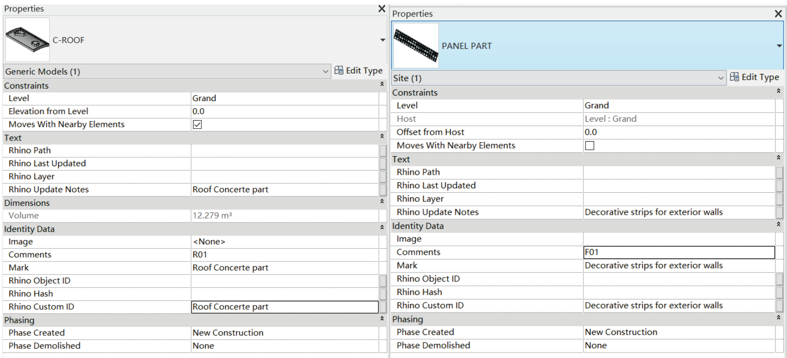


Figure 38. R.I.R loadable Family import additional BIM information.

6.8.3.Analysis

TABLE 7. R.I.R loadable Family solution summary.

Workflow		R.I.R L.F
Accuracy	Geometry import	**1**
	Location	**1**
	Manually adjust requirements	**High**
Flexibility	Editability of geometry in Revit	**1**
	Editability of Material in Revit	**1**
	Texture addition	**1**
	Rendering	**1**
Expansibility	Material Import	**1**
	Independent sheet set (Family)	**1**
	Constraints(Elevation…)	**1**
	Identity Data, Phasing	**1**
Automation	Automatic recognition and conversion of common elements	**0.5**
Interoperability	Automatically update the model	**1**
	Possibility of subsequent changes	**1**
Time-consuming		**High**
Skills requirements	Rhino & GH skills requirements	**High**
	Revit skills requirements	**High**

7. Compare & Evaluation

This chapter analyzes various facets of the efficiency of the seven transmission schemes in the previous chapter and considers seven different metrics for study. Its key aim is to offer convenience for individuals in the industry to select the most acceptable workflow approach for each project according to the project and model's real needs.

7.1. EXPLANATION OF THE EVALUATION ITEM

Accuracy

- Geometry import:
  It determines the quantity and quality of the correctly structured transmission of PD information in the BIM context.
- Location
  Accuracy of location information
- Manually adjust requirements
  Manual corrections required to achieve the desired effect.

Flexibility

- Editability of geometry in Revit
  The ability to change graphics for subsequent projects.
- Editability of Material in Revit
  Material editing capabilities for subsequent projects.
- Texture addition
  Additional information editing capabilities.
- Rendering
  Effect of renderings.

Expansibility

- Material Import
  Support for importing Rhino materials into the BIM environment.
- Independent sheet set (Family)
  About the ability to create and edit family sub-drawing sets.
- Constraints (Elevation…)
- Identity Data, Phasing

Automation

- Automatic recognition and conversion of common elements from PD to BIM environment.

Interoperability

- Automatically update the model

The ability to automatically or semi-automatically upload elements from PD to the BIM environment.

- Possibility of subsequent changes

  Regarding the likelihood of the modification being synchronised to the BIM environment in the later PD environment.

Time-consuming

Actual time consumption

Skills requirements

- Rhino & GH skills requirements
- Revit skills requirements

7.2. SUMMARY TABLE

TABLE 8. Overview of test results.

Workflow		DWG	SAT	3dm	Conveyor		Rhino.Inside.Revit	
Category		DWG	Manual import		Direct Shape	Loadable Families	Direct Shape	Loadable Families
Accuracy	Geometry import	0.5	0.5	1	1	1	0.5	1
	Location	1	1	1	1	1	1	1
	Manually adjust requirements	Lowest	Medium	High	Low	Medium	Medium	High
Flexibility	Editability of geometry in Revit	0	0	0	0	1	0	1
	Editability of Material in Revit	0	0.5	0.5	0.5	1	1	1
	Texture addition	1	1	1	1	1	1	1
	Rendering	0	0.5	1	0.5	1	1	1
Expansibility	Material Import	0	0	0	0	1	1	1
	Independent sheet set (Family)	0	0	1	0	1	0	1
	Constraints(Elevation…)	0	1	1	1	1	0	1
	Identity Data, Phasing	1	1	1	0	1	1	1
Automation	Automatic recognition and conversion of common elements	0	0	0	1	1	0	0.5
Interoperability	Automatically update the model	0	0	0	1	1	0.5	1
	Possibility of subsequent changes	0	0	0	1	1	1	1
Time-consuming		lowest	Medium	High	Low	Medium	Medium	High
Skills requirements	Rhino & GH skills requirements	Low	Medium	Medium	Medium	Medium	High	High
	Revit skills requirements	Low	High	High	Medium	High	Medium	High

TABLE 9. Simplified overview table.

	DWG	SAT	3dm	Conveyor Driect	Conveyor Family	RiR Direct	RiR Family
Accuracy	1.5	1.5	2	2	2	1.5	2
Flexibility	1	2	2.5	2	4	3	4
Expansibility	1	2	3	1	4	2	4

Automation	**0**	**0**	**0**	**1**	**1**	**0**	**0.5**
Interoperability	**0**	**0**	**0**	**2**	**2**	**1.5**	**2**
Time-consuming	**0.25**	**1**	**1.5**	**0.5**	**1**	**1**	**1.5**
Skills requirements	**1**	**2.5**	**2.5**	**2**	**2.5**	**2.5**	**3**

For the unity of the chart, the time costing and required skills are changed to the time saving and ease of use in the score statistics table. The specific method is to subtract the original score from the total score to get the new result.

TABLE 10. Final statistics table.

Score								
	DWG	**SAT**	**3dm**	**Conveyor Driect**	**Conveyor Family**	**RiR Direct**	**RiR Family**	**Full marks**
Accuracy	**1.5**	**1.5**	**2**	**2**	**2**	**1.5**	**2**	**2**
Flexibility	**1**	**2**	**2.5**	**2**	**4**	**3**	**4**	**4**
Expansibility	**1**	**2**	**3**	**1**	**4**	**2**	**4**	**4**
Automation	**0**	**0**	**0**	**1**	**1**	**0**	**0.5**	**1**
Interoperability	**0**	**0**	**0**	**2**	**2**	**1.5**	**2**	**2**
Time-saving	**1.25**	**0.5**	**0**	**1**	**0.5**	**0.5**	**0**	**1.5**
Accessibility (skills)	**2**	**0.5**	**0.5**	**1**	**0.5**	**0.5**	**0**	**3**

TABLE 11. Final statistics of % table.

% of Score							
	DWG	**SAT**	**3dm**	**Conveyor Driect**	**Conveyor Family**	**RiR Direct**	**RiR Family**
Accuracy	**75%**	**75%**	**100%**	**100%**	**100%**	**75%**	**100%**
Flexibility	**25%**	**50%**	**63%**	**50%**	**100%**	**75%**	**100%**
Expansibility	**25%**	**50%**	**75%**	**25%**	**100%**	**50%**	**100%**
Automation	**0%**	**0%**	**0%**	**100%**	**100%**	**0%**	**50%**
Interoperability	**0%**	**0%**	**0%**	**100%**	**100%**	**75%**	**100%**
Time-saving	**83%**	**33%**	**0%**	**67%**	**33%**	**33%**	**0%**
Accessibility (skills)	**67%**	**17%**	**17%**	**33%**	**17%**	**17%**	**0%**

7.3. COMPARISON CHART

TABLE 12. Comparison chart of transmission solutions based on aspects.

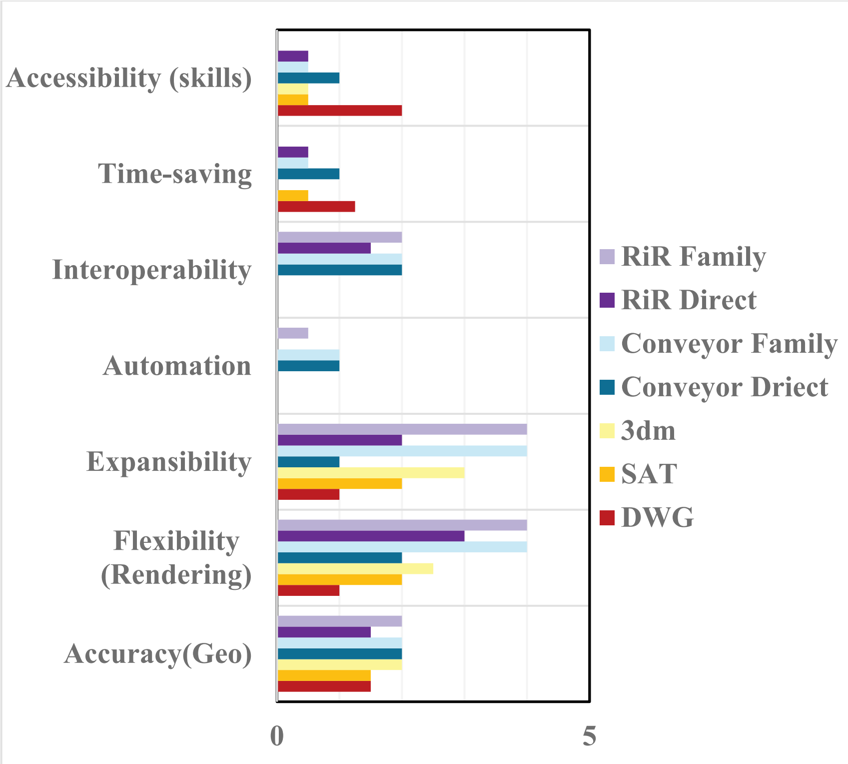
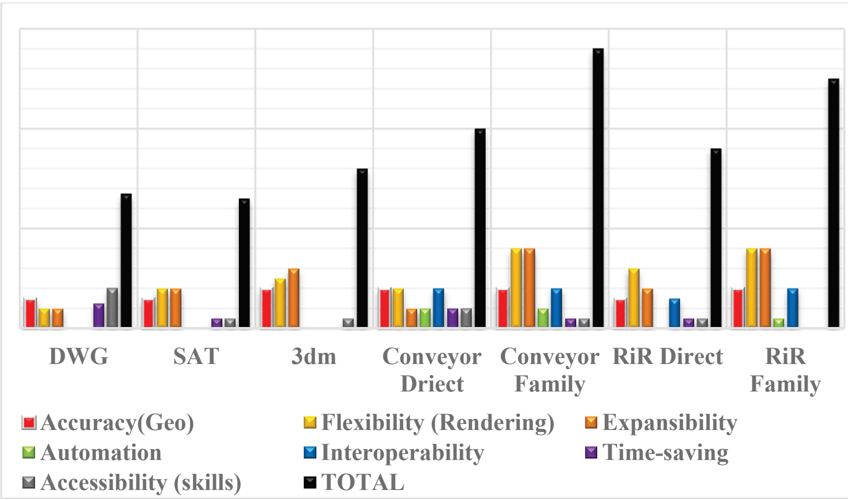


TABLE 13. Comparison of aspects based on transmission solutions



7.4. RADAR CHART

TABLE 14. Overall Radar chart

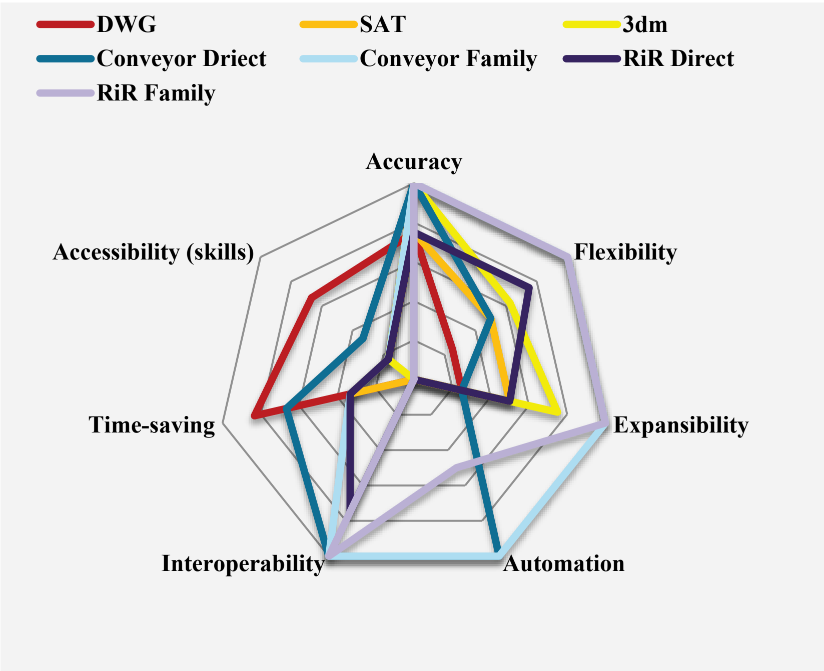


TABLE 15. Manual import Radar chart.

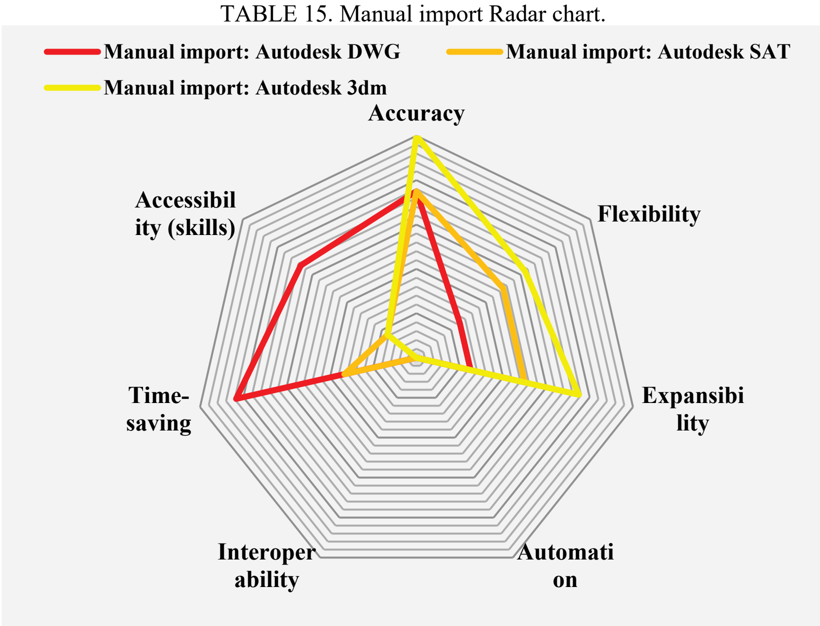
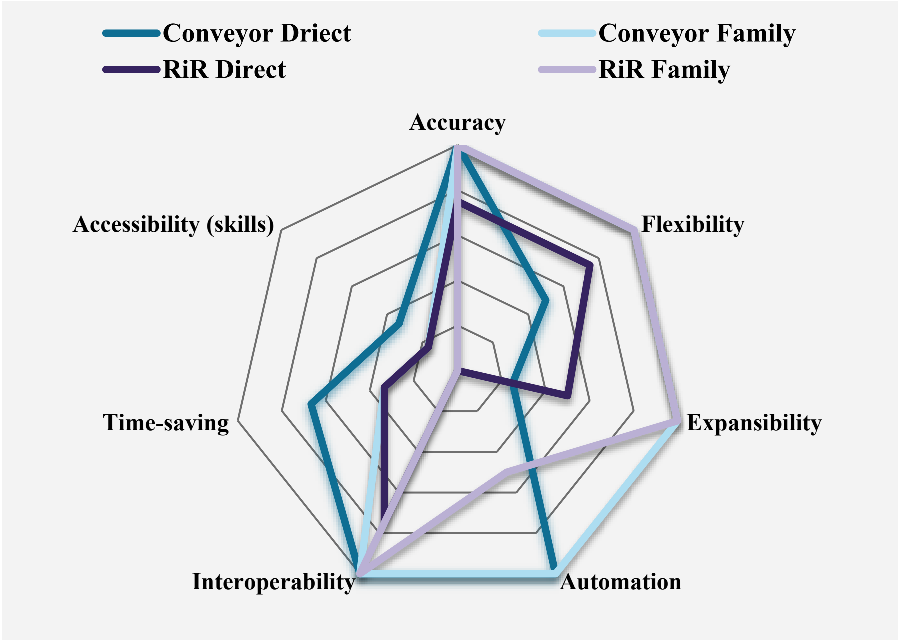


TABLE 16. Platform import Radar chart



From the chart, manually import methods could provide support with blueprint for the early stages, the transmission quality and expandable items are mainly affected by file compatibility. However, further research in order to deepen the follow-up design requires more skill requirements, including data processing and other IT knowledge. Taking Conveyor as an example, this method of creating Revit elements by reading the Rhino native file format model could provide a user-friendly operation interface and operation mode. At this stage, R.I.R has further integrated the entire design process. Although its work efficiency needs to be improved, the software version in this project is still a test version.

In general, each solution has different advantages and shortcomings. In order to maximize the strengths and avoid weaknesses, we need to consider the actual project conditions to make choices. For example, Conveyor's performance in automation is excellent, which also means that can automate more processes. And in terms of flexibility, R.I.R can provide more possibilities for subsequent modifications to the native Revit family.

However, the comparison shows that the solution based on the native data format has better performance. This applies not only to Rhino and Revit, but also to other possible tools and platforms which is consistent with the concept of Industry 4.0.

8. Discussion and Conclusion

This thesis analyses and evaluates the mechanism of seven parametric BIM workflow model coupling schemes and the findings available. To better explore and evaluate collective processes from Rhino to Revit, a Rhino building data model that follows real expectations was built at the beginning. Then from a functional viewpoint, typical use criteria were classified as assessment objects. Seven factors are the basis of the assessment process: precision, flexibility, extension, automation, interoperability, time-consuming and necessary expertise. As a consequence, each workflow has its deficiencies and benefits, even though the end outcome is the same. And on the basis of their individual needs, users may select the most acceptable parameterized BIM workflow solution.

Parametric design and BIM are completely different. The workflow approach used in this research does not replicate as a generic model the models of both parties, but links the data models across the bridges. In these seven examples, the rhino geometric model is transformed into BIM components. The larger the degree of automation, the less human interference in the workflow, which would also increase work performance and precision substantially. It also offers a new paradigm as the final research study that enhances the process of design. Not only does it allow more user-friendly and direct transfer of information, but it also increases the interoperability of the industry. For eg, from parametric modeling data, non-parametric workers have the ability to add model information. The results leads to reducing the time and resources expended by production workers on non-design and technological interoperability problems. Particularly to improve the communication, teamwork and data management between architecture, engineering and construction of the parametric BIM design workflow. Regarding collaboration, if the file locations of Conveyor and R.I.R are changed to a cloud drive such as Onedrive or Google Drive, it will meet the needs of team collaboration in most projects.

Study requires only evaluating and incorporating existing technologies for the sharing of BIM data, rather than creating a new transmitting solution. However no further expanded studies and supplements have been carried out because of the impact of time and paper length.

About this research's potential course of growth. A safer alternative should be to use a blueprint from a real project for research for a more detailed measurement and study. Rhino Inside is still in the stage of production in this report, and additional testing should be carried out after the official version is released.

While abandoned cloud-based collaboration applications such as Gevit and Speckle performed poorly in the complex solid geometry, the operating mode of the cloud-based collaboration platform is more compatible with the IoT goals of Industry 4.0. So it is essential to carry out further research and study.

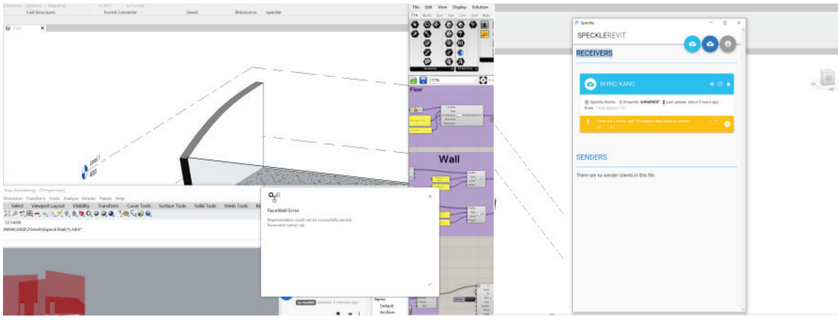


Figure 39. About Speckle and Grevit's problems in the research process.

This empirical research enhances the collaborative feasibility of the Computational design sector by evaluating and examining current job procedures, taking into account the real needs of customers, and moving cooperation closer to the IoT priorities of Industry 4.0. This will help refine communication practices and allow us to concentrate more on addressing practical issues and the design itself.

Acknowledgements

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