ICCEPM 2024 https://dx.doi.org/10.6106/ICCEPM.2024.0645
The 10th International Conference on Construction Engineering and Project Management
Jul. 29-Aug.1, 2024, Sapporo

Automatic Ductwork BIM Generation System for Analyzing HVAC System Conflicts

Yen-Min HSU[1]* and I-Chen WU[2]

[1]*Department of Civil Engineering, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan.* Email address: meggie040524@gmail.com
[2]*Department of Civil Engineering, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan.* Email address: kwu@nkust.edu.tw

Abstract: Building Information Modeling (BIM) involves the integration of equipment information and component parameters across various engineering disciplines. The complex processes during model construction can lead to human errors. Furthermore, design changes often occur at various stages of the building's lifecycle, requiring designers and modelers to make timely modifications, resulting in significant costs and time consumption. Mechanical, electrical, and plumbing (MEP) design is considerably more complex than architectural design. Therefore, this study focuses on the automatic generation of a heating, ventilation, and air conditioning (HVAC) ductwork model with MEP design through BIM. Dynamo, a visual programming language (VPL), offers features such as arrangement, connectivity, and scalability. Thus, this research applied Dynamo to develop the Automatic Ductwork BIM Model Generation System. The BIM model generated by the system facilitates collaborative efforts and enables the analysis of HVAC System Conflicts. The system extracts coordinates for air handling units, supply air, and exhaust air outlets. The equipment is automatically positioned based on these coordinates, and the corresponding duct paths are generated by reading CAD files. At each duct connection point, appropriate fittings are fabricated according to specifications and dimensions. The duct system is configured with distinct colors, and the results are visualized in Revit, facilitating HVAC system clash detection in the future. This study undertakes a real project to validate the proposed system and processes and assesses its impact on modeling efficiency, real-time responsiveness, and accuracy, realizing automated ductwork generation.

Keywords : BIM, HVAC, Dynamo, Automatic Generation, Conflict Analysis

1. INTRODUCTION

According to statistics, BIM has been used in various countries for decades, but it is rarely used in Taiwan's private sector construction industry, which predominantly relies on traditional 2D drawings. This can be attributed to the high costs of implementing BIM in private construction organizations, a shortage of qualified personnel, limited BIM-related knowledge and skills, and the absence of unified BIM norms and standards [1]. These challenges have impeded the integration of BIM within Taiwan's construction sector.

Fragmented working environment is common in a traditional construction practice. Mechanical, electrical, and plumbing (MEP) systems have become more complex to accommodate sophisticated building designs and requirements, which require more space and coordination for installation [2]. In the absence of BIM applications, manufacturers directly use 2D drawings for construction, and the actual construction conditions are determined by experienced professional technicians. Such an experience-driven, ad hoc decision-making approach frequently results in considerable material waste and on-site rework [3]. Therefore, a collision conflict review must be conducted for BIM application projects to satisfy the space requirements of the original design as well as reduce the cost and delayed schedule by avoiding repeated construction [4].

Traditionally, 2D drawings are converted to BIM models manually, and the information integration of each component (i.e., Duct, Cable Tray, Pipe) in the MEP system is inefficient for manual operation [5]. It requires considerable time and cost and is prone to human errors. Therefore, many researchers have proposed the conversion of CAD drawings to BIM models. Byun and Sohn [6] proposed an ABGS system through which a BIM model can be automatically generated from 2D CAD drawings of concrete structures. The amount of reinforcement can be calculated from the relevant information in the inventory drawing with an accuracy of more than 90%. Gimenez et al. [7] developed a system using C++ language to scan 2D floor plans and automatically generate 3D building models; the 3D building model could be built in less than 3 minutes. Yang et al. [8] used information categorized by CAD layers to generate geometric models of beams, slabs, and columns, and almost all the textual information in the construction drawings was accurately imported into the structural BIM model, with additional parameter space reserved for additional building information. Chi and Liu [9] analyzed the contents and characteristics of mechanical components represented in drawings, developed a classification and algorithm for spatial information and metadata that supports automatic recognition of mechanical systems, and utilized the developed computational method to recognize 2D drawings and build BIM models. The results of the study indicate that more than 80% of the pipes can be recognized from various drawings in DXF format.

To provide a more convenient modeling environment for related enterprises, this study uses Dynamo visual programming language to lower the threshold for BIM technicians to read 2D drawings and automatically generate BIM MEP duct models. It solves the problem of traditional manual modeling and collision detection that are time consuming. In addition, the automated model generation considers the construction problems in the drawings in advance through the BIM model, preventing the wastage of materials and re-construction.

2. METHODOLOGY

2.1 Research Framework

To improve the traditional manual modeling method, this study automates the generation of HVAC ducts through visual programming language to enhance the modeling efficiency for the reference of enterprises or modeling technicians who are not familiar with BIM. The conceptual flow of this approach is shown in Figure 1.

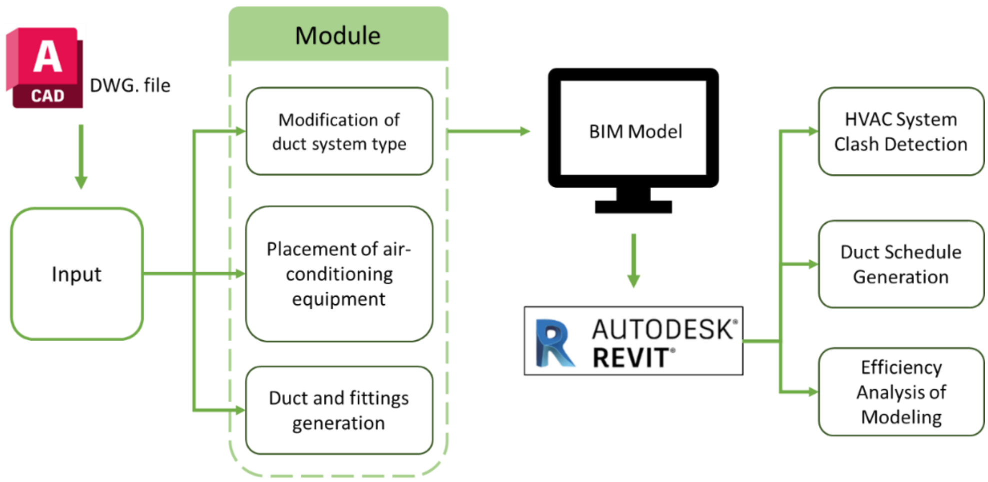


Figure 1. Flowchart of this study

The research process can be primarily divided into three stages. First, the AutoCAD dwg file is linked into Revit, extracting the coordinates of HVAC equipment placement points and exporting them to an Excel file. Based on these data, the program locates equipment and generates ducts and their air duct fittings. Users must perform a "cleanup" action before importing a CAD drawing to eliminate unnecessary elements, such as blocks, lines, and text, which may interfere with the drawing layer. Furthermore, non-essential materials are read in Dynamo, causing the failure of the subsequent program.

Modelers can customize scripts according to project-specific conditions, including duct elevation position and system type color configuration, which can be adjusted to meet the requirements of the project. Second, using the above three programs, the HVAC ducts are automatically generated and presented in the Revit3D window, and the ducts can be adjusted slightly. Based on the visualization in the Revit 3D view, modelers can make adjustments to reducers and tees by selecting connecting fittings that align with the project specifications. Third, after the automated generation, a duct interference check is performed in Revit. Subsequently, a material list detailing duct materials and dimensions is created, and modeling efficiency is analyzed. In Revit, conflict detection is conducted to fine-tune the ductline, minimizing uncertainties stemming from on-site experience judgment by construction workers. The bill of materials for ducts and fittings is generated to effectively control the material budget. Finally, a comparison between traditional modeling efficiency and this study is presented for the reference of relevant users.

2.2 Relating Dynamo Programs

The programs are developed based on Autodesk Revit and Dynamo to generate air ducts, duct fittings, and air-conditioning equipment in Revit. Users have the flexibility to customize duct system types, including width, color, and line configuration for visualization. This program not only reduces the time and cost associated with the manual modeling complexities of MEP systems but also identifies shortcomings in MEP design. CAD drawings can then be updated and corrected manually. Finally, the program can regenerate BIM model based on the updated CAD file, enhancing the efficiency of BIM model generation.

2.2.1 Modification of duct system type

The first module, "Modification of duct system type," can set the linestyle and color for the duct system type automatically. The handling process can be divided into three steps. The first step is to connect to the customized node "Width" for setting the width size of the sideline for each duct system type, as shown in Figure 2. The second step is to use a customized node "Color" to give the duct system type color configuration as shown in Figure 3. Finally, users connect the extracted duct system type to the custom node "Style" to set the required line styles, such as dashed lines or single-point lines. This system streamlines the repetitive task of configuring each duct system type, as presented in Figure 4.

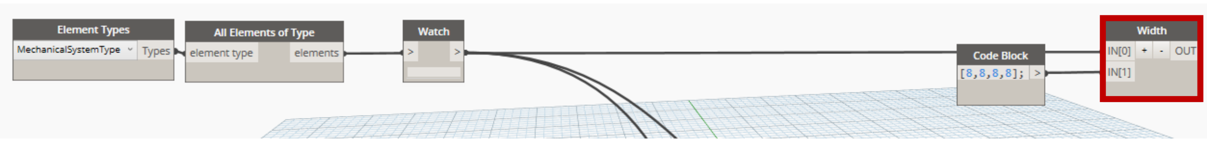


Figure 2. Duct System Type – Width

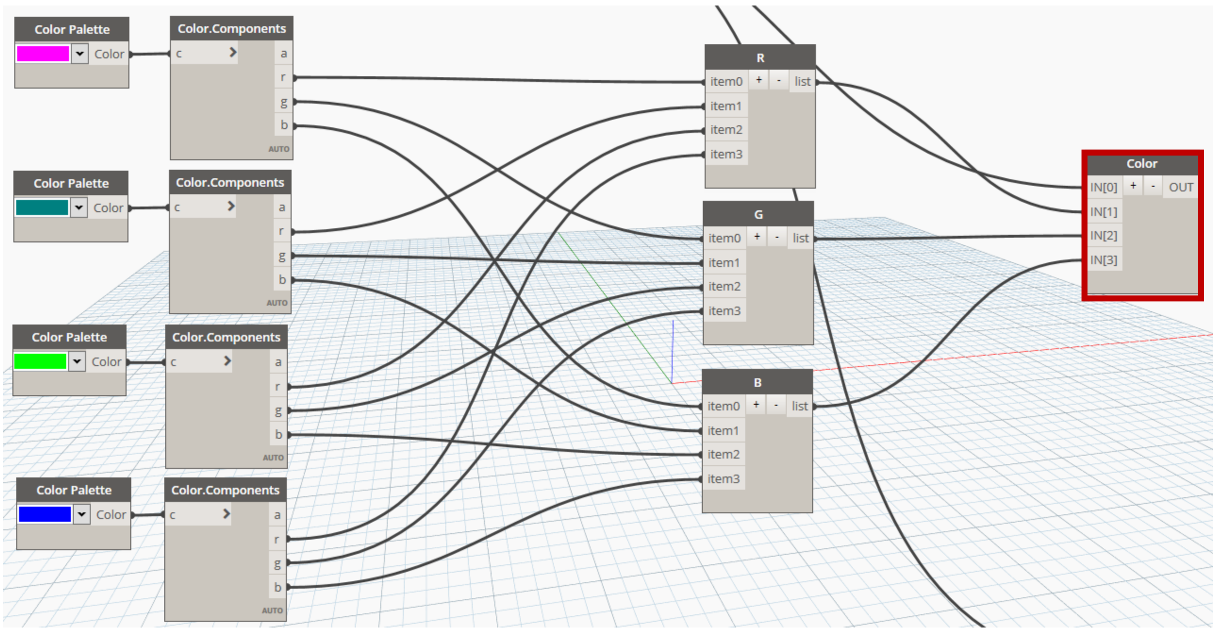


Figure 3. **Duct System Type – Color**

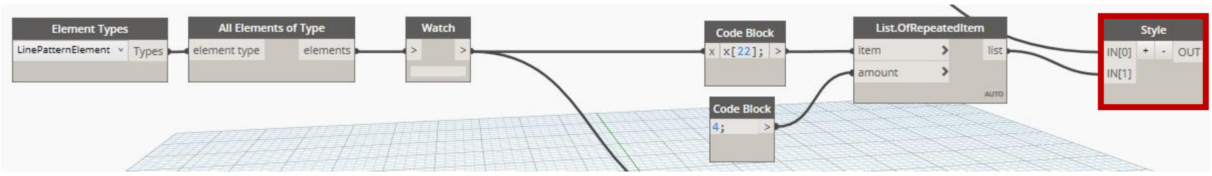


Figure 4. Duct System Type – Style

2.2.2 Placement of air-conditioning equipment

The second module, "Placement of air conditioning equipment," encompasses two steps. In Step 1, Excel is linked, containing XYZ points for equipment placement, as depicted in Figure 5. Step 2 involves utilizing the "FamilyInstance.ByPointAndLevel" node to automatically position a Revit FamilyInstance based on the provided FamilyType (Equipment), coordinates from Step 1, level(floor) and FamilyType(Equipment) for this node to position equipment automatically, as shown in Figure 6.

By placing the equipment automatically at the point determined through the aforementioned process, it can reduce the errors caused by manually placing the equipment and increase the modeling efficiency. Moreover, the modeler is spared the need to repeatedly switch the view screen when placing equipment.

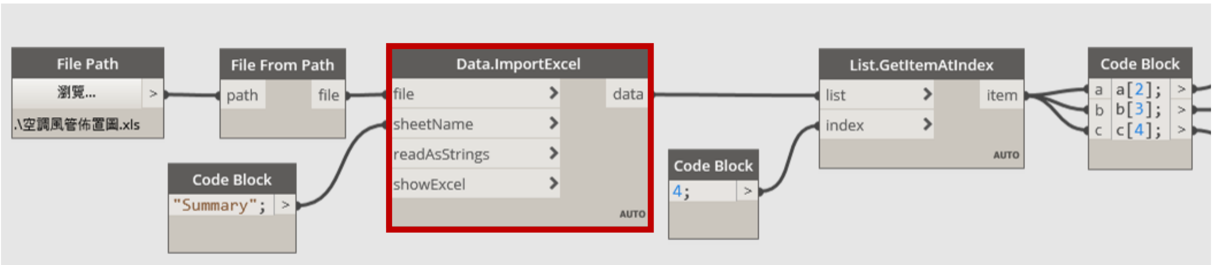


Figure 5. Importing coordinates of the air-conditioning equipment

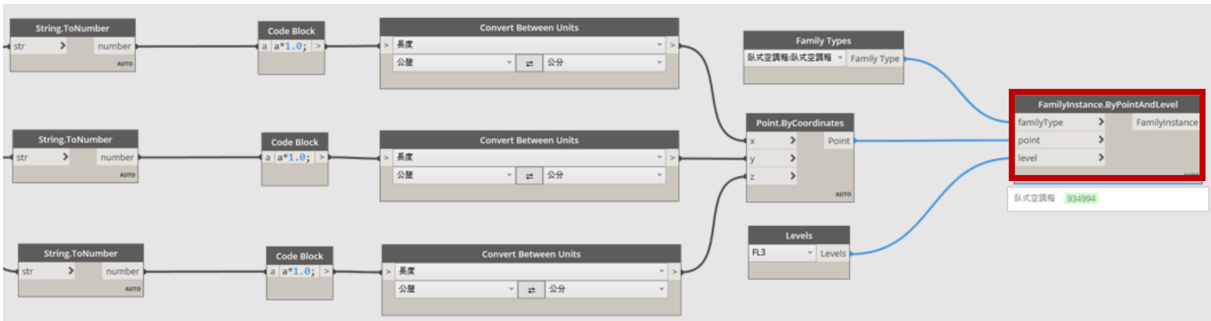


Figure 6. Placing Air Conditioning Equipment

2.2.3 Duct and fittings generation

The third module, "Ducts and fittings generation," is divided into three steps. The first step involves reading duct dimensions, utilizing the Third-party package "bimorphNodes" to link the CAD drawing into the Dynamo Environment. The "CADTextData.FromLayers" node establishes a connection with the selected CAD drawing, specifying the layer to be read. Subsequently, the dimensions of the ducts on this layer are extracted as text using the "CADTextData.TextValue" node. The "CADTextData.TextValue" node reads this layer for the text of the ductline size and converts it into numbers and units into millimeters, in line with the Revit ductline units. These numbers are assigned to the "width" and "height" of the "Duct.CreatByLine" node, as shown in Figure 7.

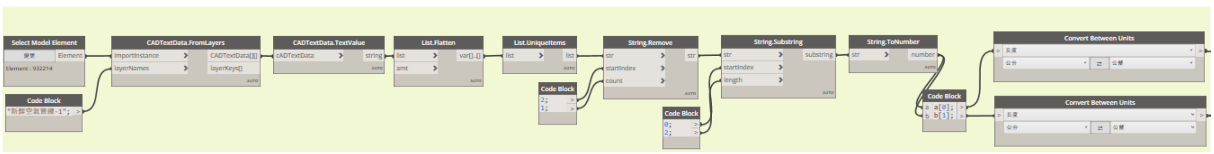


Figure 7. Reading the air duct dimensions from CAD layer

The second part involves duct generation. This research employs the "CAD.CurveFromCADLayers" node from the bimorphNodes package to read the required line from the CAD drawing. Subsequently, the "Duct.CreateByLine" node from the OpenMEP package is connected to generate ducts along the specified lines. Some parameters are assigned at the same time. The "level" parameter designates the floor where the duct should be placed. The square duct extracts through the "Element Types" and "All Elements of Type" nodes, set as "ductType." "systemType" is selected as fresh air. Duct generation proceeds based on these settings, as depicted in Figure 8. Following duct generation, the module employs the "Element.SetParameterByName" node to adjust the elevation position of the ductline.

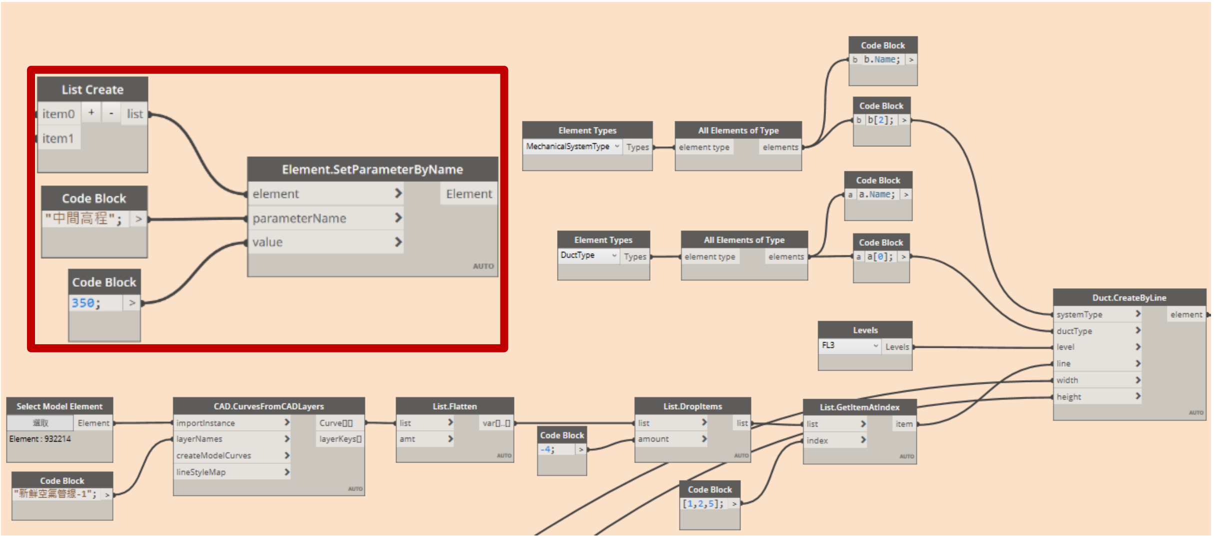
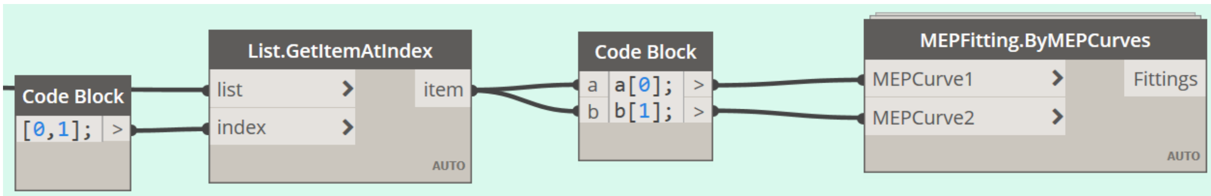
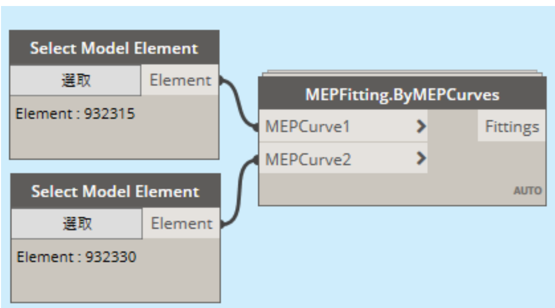


Figure 8. Air duct generation

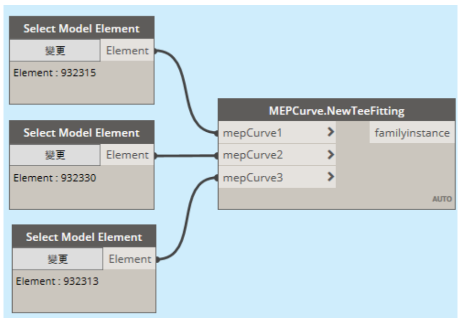
The third part involves the automatic generation of duct fittings. This segment utilizes the Third-party package "MEPover" to create duct fittings. The "MEPFitting.ByMEPCurves" node connects two ducts and generates fittings based on the original routing preference in Revit. The generated fittings may be bends or reducers, as depicted in Figure 9(a) and 9(b). Another scenario involves connecting three ducts, for which the "MEPCurve.NewTeeFitting" node is used to generate tee fittings, as illustrated in Figure 9(c).



(a) Bend



(b) Reducer



(c) Tee

Figure 9. Creative Duct Fittings – Bend, Reducer, and Tee Fittings

These three components focus on duct generation based on CAD Drawings. The module extracts precise information from CAD drawings, such as size and line details, to generate corresponding ducts automatically. Modeling technicians do not require to manually adjust the duct sizes, and the distance between ducts can be neglected if the distance between ducts is considerably short and the fittings cannot be connected.

3. DEMONSTRATION

In this study, a hospital operating room relayout project served as the experimental site to demonstrate and validate the auxiliary program (Figure 10).

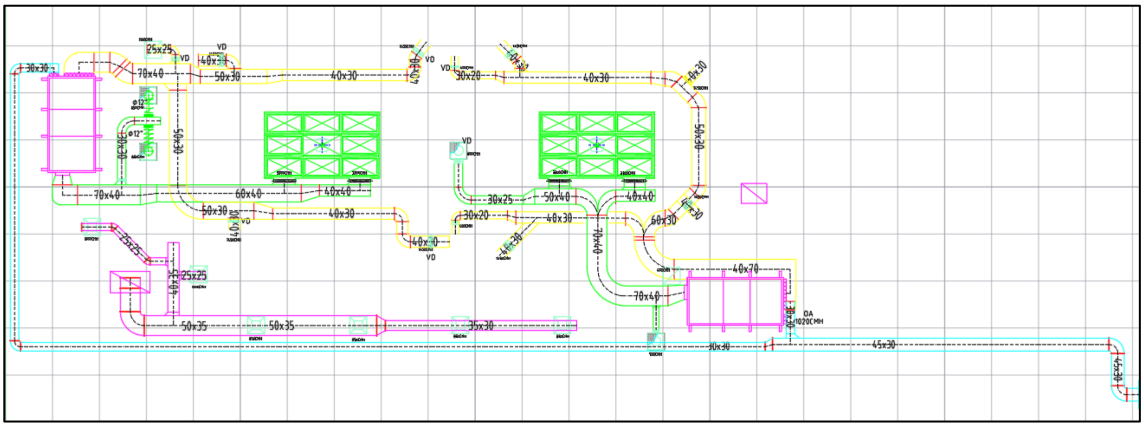


Figure 10. 2D Plan Drawing is about an experimental site

First, this study cleaned up the CAD dwg file, organized layers, and removed unnecessary lines, text, blocks, etc. Subsequently, a Revit project is created to set up all the duct system types for the project. The auxiliary program "Modification of duct system type" is used in this study to promptly adjust the style, color, and line thickness of the duct system line to match the color plan specification.

Thereafter, users can use the study's auxiliary program "Placement of air-conditioning equipment" to position the equipment in accordance with the specified coordinates of the XYZ position that is generated based on CAD drawings. Therefore, the repetitive actions of placing each equipment is minimized, and human errors are prevented by positioning the equipment precisely, as shown in Figure 11.

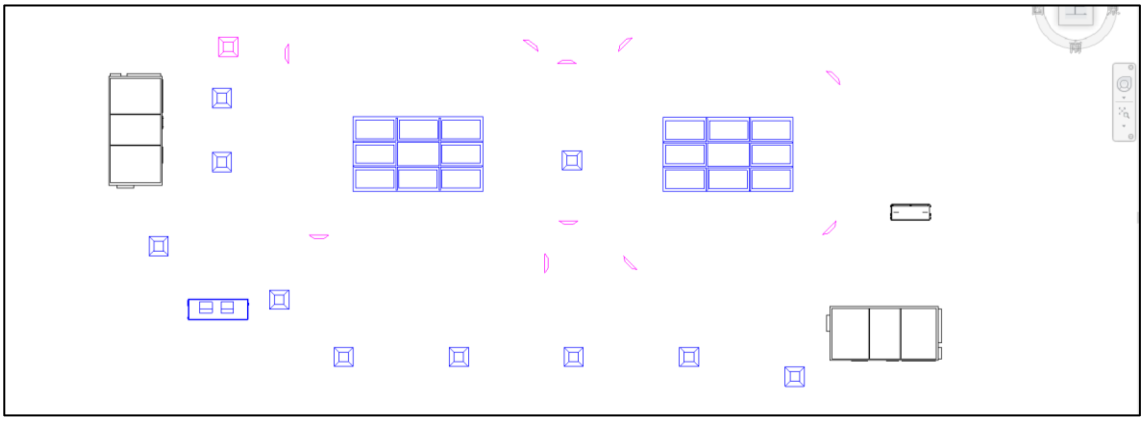


Figure 11. Results of placing air-conditioning equipment by coordinates

Next, the auxiliary program "Ducts and fittings generation" reads CAD drawings and generates corresponding ducts according to the layers, including duct sizes, bends, reducers, and tees. This can promptly generate ducts and save the complicated manual operation steps of view switching, as shown in Figure 12.

Through Revit's internal functions, the duct systems are integrated together for interference check and early detection of conflicts through visualization, mitigating the loss of heavy materials and time caused by conflicts during construction, as shown in Figure 13.

After the review of conflict and collision, users can use the Autodesk Revit internal functions to generate a schedule of materials, the function can rapidly and accurately calculate the cost of materials for reducing the error of manual calculation. The model information can be updated more efficiently than the traditional 2D drawings, as shown in Figure 14.

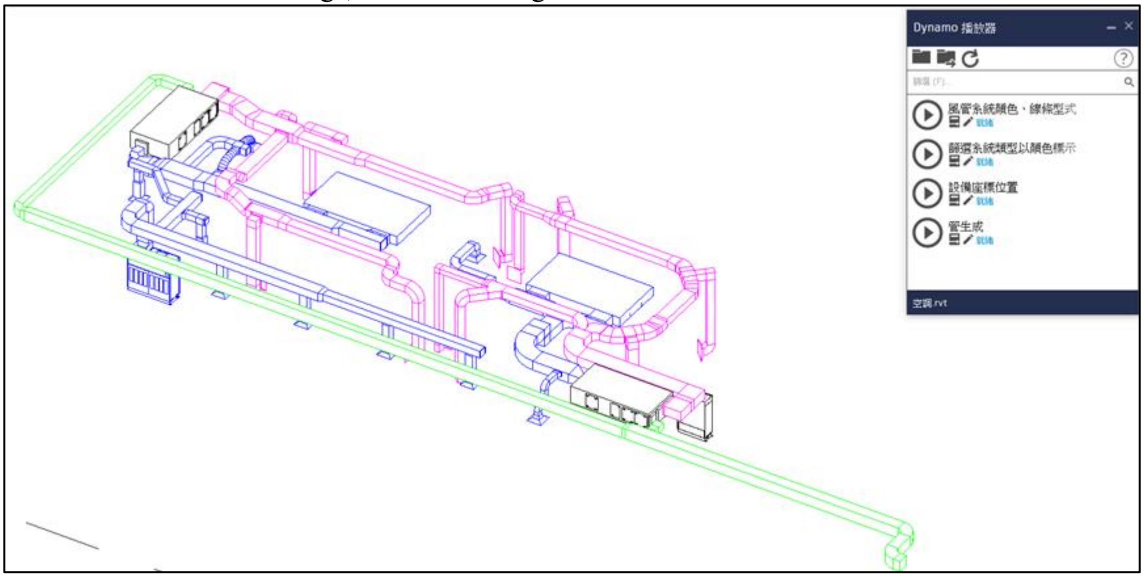


Figure 12. Results of ducts and fittings generation

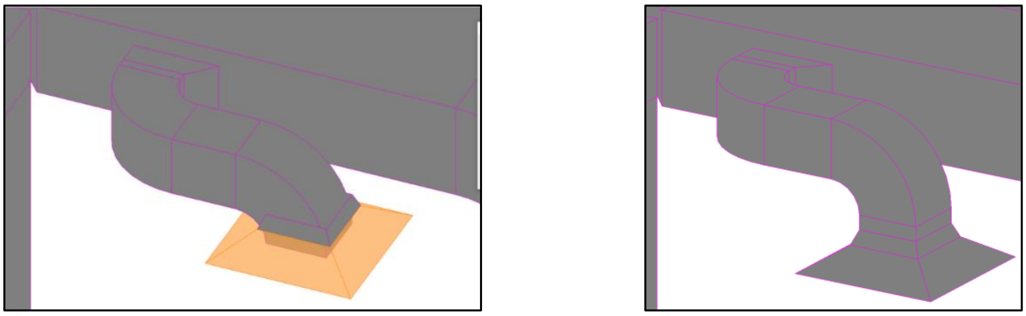
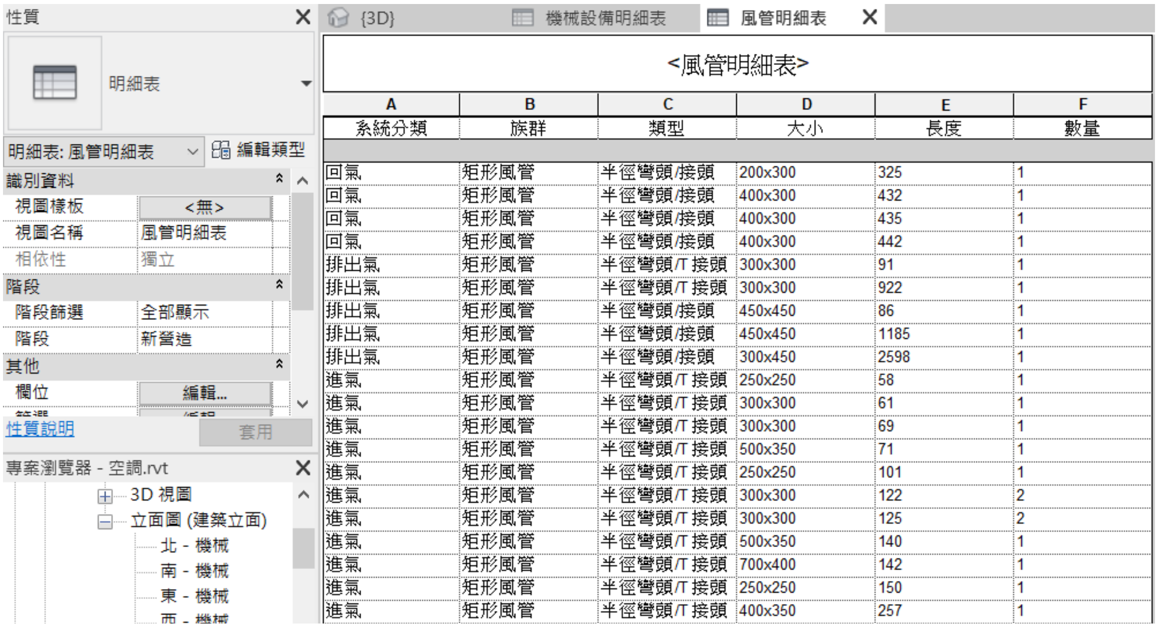


Figure 13. Interference review in Revit



<風管明細表>

A	B	C	D	E	F
系統分類	族群	類型	大小	長度	數量
回氣	矩形風管	半徑彎頭/接頭	200x300	325	1
回氣	矩形風管	半徑彎頭/接頭	400x300	432	1
回氣	矩形風管	半徑彎頭/接頭	400x300	435	1
回氣	矩形風管	半徑彎頭/接頭	400x300	442	1
排出氣	矩形風管	半徑彎頭/T 接頭	300x300	91	1
排出氣	矩形風管	半徑彎頭/T 接頭	300x300	922	1
排出氣	矩形風管	半徑彎頭/接頭	450x450	86	1
排出氣	矩形風管	半徑彎頭/接頭	450x450	1185	1
排出氣	矩形風管	半徑彎頭/接頭	300x450	2598	1
進氣	矩形風管	半徑彎頭/T 接頭	250x250	58	1
進氣	矩形風管	半徑彎頭/T 接頭	300x300	61	1
進氣	矩形風管	半徑彎頭/T 接頭	300x300	69	1
進氣	矩形風管	半徑彎頭/T 接頭	500x350	71	1
進氣	矩形風管	半徑彎頭/T 接頭	250x250	101	1
進氣	矩形風管	半徑彎頭/T 接頭	300x300	122	2
進氣	矩形風管	半徑彎頭/T 接頭	300x300	125	2
進氣	矩形風管	半徑彎頭/T 接頭	500x350	140	1
進氣	矩形風管	半徑彎頭/T 接頭	700x400	142	1
進氣	矩形風管	半徑彎頭/T 接頭	250x250	150	1
進氣	矩形風管	半徑彎頭/T 接頭	400x350	257	1

Figure 14. Duct Schedule Generation

After the actual implementation of the aforementioned case, the auxiliary program written in this study was compared with traditional manual modeling. The implementation included modifying the duct system type color, line type, placing the air conditioning equipment and ducts according to the coordinates to generate and connect the duct fittings, and understanding the results of the comparison from Table 1 to effectively improve the modeling efficiency. The application of Dynamo reduced the time required by the technician to produce drawings and effectively optimized BIM.

Table 1. Efficiency analysis for case modeling

Project	Manual mode of operation	Dynamo Program
Modification of duct system type color, line style	Manual operation 90 s	Set the add-on program to run for 20 s
Placement of air-conditioning equipment according to the coordinates	Manually operated 30 min.	Set up the add-on program to run for 14 min.
Duct Generation and Duct Fitting Connections	Manual operation 2 h	Set up the add-in program to run for 1 h.

4. CONCLUSIONS

This research leveraged Dynamo to develop the Automatic Ductwork BIM Model Generation System to analyze HVAC system conflicts. This program can read CAD drawings to rapidly generate ducts with the appropriate size and elevation according to CAD drawings and constructs suitable duct fittings. It not only shortens the time and cost of BIM modeling but also minimizes manual error. The result of the auxiliary program are presented in Revit 3D, enabling users to use the Revit built-in "interference review" function for conflict collision review, as well as executing rapid correction of the conflict part, in advance to resolve the situation of the reconstruction. Moreover, generating material schedule within Revit, providing precise control over the quantity of fittings and budget management, thereby reducing material wastage. Based on the testing results for the aforementioned features, the modeling speed increased approximately 2 times compared with the previous manual modeling, substantially improving the modeling efficiency for technicians and mitigating the risk of possible omissions associated with manual modeling.

REFERENCES

[1]Chen, C.-C., & Wang, W.-C. (2020). Survey on the Supply and Demand of Professional Manpower in Building Information Modeling (BIM) Technology in Taiwan. *Architecture and Building Research Institute, Ministry of the Interior Collaborative Research Report.* https://www.abri.gov.tw/News_Content_Table.aspx?n=807&s=213927

[2]Wang, J., Wang, X., Shou, W., Chong, H.-Y., & Guo, J. (2016). Building information modeling-based integration of MEP layout designs and constructability. *Automation in construction, 61*, 134-146.

[3]Liu, H., Singh, G., Lu, M., Bouferguene, A., & Al-Hussein, M. (2018). BIM-based automated design and planning for boarding of light-frame residential buildings. *Automation in construction, 89*, 235-249.

[4]Wang, H.-P., Huang, S.-C., Wang, S.-H., & Wang, W.-C. (2022). Case Studies of BIM Applications in Taiwan. *Construction Management Journal, 113*, 1-33.

[5]Wang, D., & Hu, Y. (2022). Research on the Intelligent Construction of the Rebar Project Based on BIM. *Applied Sciences, 12*(11), 5596.

[6]Byun, Y., & Sohn, B.-S. (2020). ABGS: A system for the automatic generation of building information models from two-dimensional CAD drawings. *Sustainability, 12*(17), 6713.

[7]Gimenez, L., Robert, S., Suard, F., & Zreik, K. (2016). Automatic reconstruction of 3D building models from scanned 2D floor plans. *Automation in construction*, 63, 48-56.

[8]Yang, B., Liu, B., Zhu, D., Zhang, B., Wang, Z., & Lei, K. (2020). Semiautomatic structural BIM-model generation methodology using CAD construction drawings. *Journal of Computing in Civil Engineering, 34*(3), 04020006.

[9]Cho, C. Y., & Liu, X. (2017). An automated reconstruction approach of mechanical systems in building information modeling (BIM) using 2D drawings. In *Computing in Civil Engineering 2017* (pp. 236-244).