Journal of Architectural/Planning Research and Studies
(JARS) Vol.22(2).2025

https://doi.org/10.56261/jars.v22.271117

Computer Script Development in Dynamo-Revit Software for Building Foundation Design

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Received 17/6/2024 Revised 21/8/2024 Accepted 6/1/2025

Abstract

Building Information Modeling (BIM) technology has transformed the construction industry, offering efficient data management and design processes. This study focuses on applying BIM to foundation design by developing a scripted prototype in Dynamo and Autodesk Revit to calculate the size of shallow foundations. The research integrates Revit for modeling and Dynamo for weight calculation, with the total weight exported to Microsoft Excel for foundation design based on Terzaghi's bearing capacity theory. A closed-form cubic equation rapidly and accurately determined the foundation size. Unlike traditional hand calculations, the developed script offers faster and more precise results. The study highlights the potential of BIM tools to streamline foundation design processes, with the example case of a square-shaped foundation under vertical load in Chiang Mai, Thailand. Future research could explore the application of this method across various soil types and more complex building models.

Keywords

Autodesk Revit program; Building foundation design; Building Information Modeling; Data exchange unit; Dynamo program

1. Introduction

In recent years, the construction industry has been transformed by technological advances and one of the most impactful developments is Building Information Modeling (BIM). This innovative technology enables the integration of various aspects of construction, from design and analysis to maintenance, into a single cohesive system (Chanpichaigosol et al., 2022; Khanh Phuong et al., 2024). BIM's ability to create detailed 3D models of buildings has revolutionized how information is managed and shared among stakeholders, enhancing collaboration and reducing the likelihood of errors during construction (Ahamadjula & Busayarat, 2024; Blondel, 2019).

Beyond its modeling capabilities, BIM has introduced a new level of transparency and communication, allowing architects, engineers, contractors, and project managers to work together more efficiently. Studies have shown that BIM can reduce cost overruns (Hussain et al., 2024; Sheamar et al., 2024; Yilmaz et al., 2024) and delays by providing real-time updates and accurate design integration (Alnaser et al., 2023; Pérez et al., 2024). This integration helps to mitigate common construction challenges such as miscommunication, outdated schematics, and deviations from original plans, all of which can lead to costly revisions and delays.

The advantages of BIM in construction are well-documented, particularly its ability to streamline operations, improve accuracy, and reduce errors. For example, case studies have demonstrated how BIM has reduced construction errors and improved project efficiency in real-world scenarios (Aziz et al., 2024; Disney et al., 2024). However, despite the widespread use of BIM for designing structural components like beams and columns, there is a notable gap when it comes to foundation design tools. Many existing tools focus primarily on superstructure analysis, leaving foundation design relatively underdeveloped. This gap is noteworthy, as the foundation is critical to the stability and safety of any building, transferring loads to the ground and supporting the entire structure.

Current tools for foundation design often lack integration with other systems, leading to inefficiencies. Studies have highlighted these limitations, underscoring the need for more integrated approaches like BIM (Hong et al., 2024; Xie et al., 2022). This research addresses that gap by developing a computational approach using BIM technologies, specifically Autodesk Revit and Dynamo, to improve the foundation design process. The study focuses on integrating Revit for 3D modeling and Dynamo for automating the calculation of foundation dimensions, with the data being transferred to Microsoft Excel for further analysis (Daria & Philipp, 2019; Thabet et al., 2022).

This research aims to develop a streamlined method for foundation design using BIM tools and demonstrate its speed, accuracy, and resource efficiency advantages. This study analyzes the design of shallow foundations under vertical loads, using Chiang Mai, Thailand, as a case study, and explores how BIM can be used to optimize the design process.

2. Materials and Methods

2.1 Characteristics and Engineering Properties of Soil Layers in Chiang Mai

The soil layers in Chiang Mai exhibit considerable complexity with frequent and unpredictable variations (Chonburi, 2017). This variability is critical for foundation design as it directly impacts the soil's load-bearing capacity, influencing the stability and dimensions of the foundation (Chen et al., 2023). Soils at the same depth in nearby locations may possess different engineering characteristics. Field surveys and laboratory tests were conducted to assess soil properties and the results are summarized in Table 1.

Table 1. Characteristics of the Soils in Chiang Mai (Chonburi, 2017)

Depth (m)	Unit Weight Saturated (kN/m^3)	Unit Weight Unsaturated (kN/m^3)	c (kN/m^2)	ϕ (deg)
0.00 - 1.50	20	16	0	30°
1.50 – 4.90	20.50	17.66	49.05	23°
4.90 – 8.00	21.09	18.25	14.71	32°
8.00 – 18.00	20.01	16.76	29.43	13°

2.2 Foundation Systems and Failures

Building foundations are classified into two primary systems: deep and shallow foundations. Shallow foundations are characterized by a depth less than the width of the foundation and transfer building loads to the soil through bearing pressure. They commonly are employed when the soil at the construction site is firm or consists of compacted sand, as in this study. Deep foundations, such as pile foundations, transfer loads through friction along the pile surface and the bearing capacity at the pile tip.

The soil deformation beneath a shallow foundation, known as general shear failure, illustrates how the building's weight is transferred to the foundation. During this process, soil subsidence remains minimal, gradually increasing until the soil reaches its ultimate bearing capacity (q_u). Beyond this point, the soil's ability to support the load decreases significantly, resulting in notable subsidence.

In this study, Terzaghi's general shear failure theory (Das, 2010) was used to determine the ultimate bearing capacity of soil under a shallow foundation (Figure 1). The bearing capacity formula proposed by Terzaghi is:

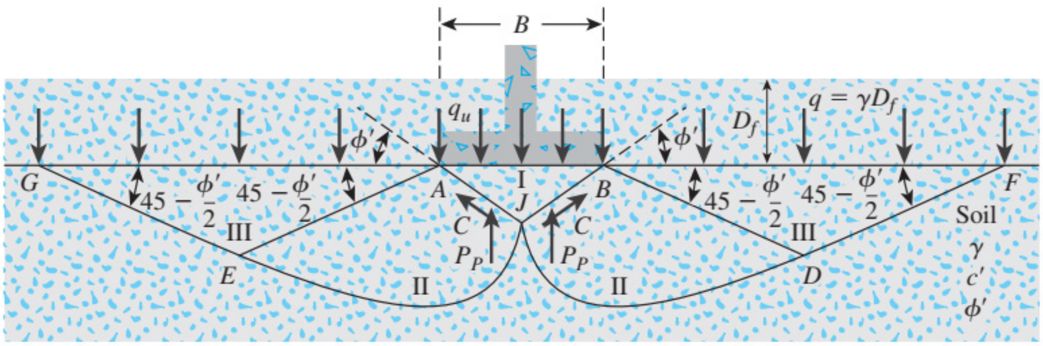


Figure 1. Soil force distribution arising from general shear failure (Das, 2010)

$$q_u = 1.3cN_c + \gamma D_f N_q + 0.4\gamma B N_\gamma \tag{1}$$

where q_u is the ultimate bearing capacity of the soil, and the parameters *c* and *γ* are soil cohesion and soil unit weight, respectively. The variable D_f represents the foundation depth, measured from the ground's surface. The width of the square foundation, which must be solved in the present study, is denoted by ร. The bearing capacity factors of soil, N_c, N_q, and N_γ, depend on the internal friction angle of soil (ɸ).

The allowable bearing capacity q_a is the ultimate bearing capacity q_u divided by an appropriate factor of safety, (*FS*) presented in Eq. (2):

$$q_a = q_u/FS \tag{2}$$

where q_a is an allowable bearing capacity while*FS* denotes the factor of safety. Table 2 outlines the safety factors used for various structures, typically ranging from 2 to 4, to ensure settlements remain within acceptable limits (U.S. Army Corps of Engineers, 1992).

Table 2. Factors of Safety for Various Structures (U.S. Army Corps of Engineers, 1992)

Structure	Factor of Safety (FS)
Retaining Wall	3.0
Earth Excavation	3.0
Bridge	4.0
Highway	3.5
Office Building	3.0
Public Building	3.5
Shallow Foundation	3.0
Mat Foundation	3.0
Deep Foundation with pile load testing	2.0
Deep Foundation with wave reflection testing	2.5
Deep Foundation with dynamic load testing	3.0

2.3 Building Information Modeling

Building Information Modeling (BIM) transcends being a mere software application; it is a comprehensive procedural framework designed for seamless integration within the construction industry. BIM integrates various stages of construction, from design to maintenance, into a cohesive workflow, enhancing accuracy and reducing errors. This process begins with architectural drawings and extends throughout the entire construction lifecycle, as illustrated in Figure 2 (Blondel, 2019).

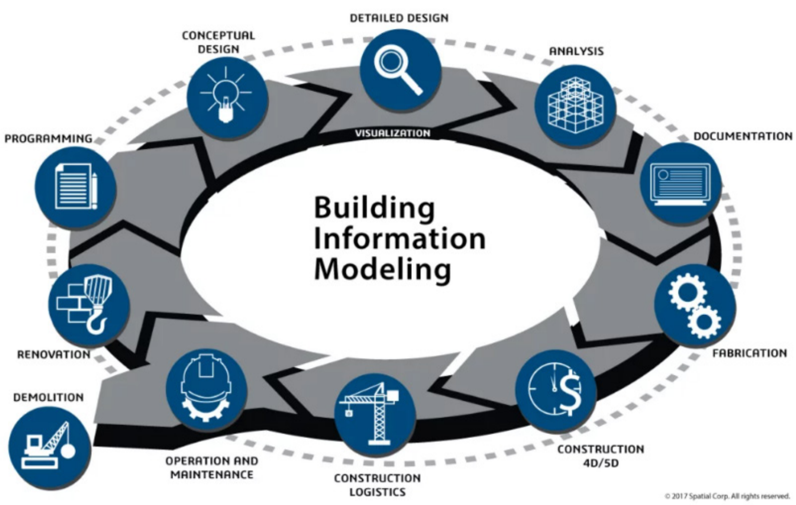


Figure 2. BIM Cycle (Blondel, 2019).

Numerous software programs contribute to enhancing BIM workflows, including SketchUp, ArchiCAD, Tekla, Vectorworks Architect, Autodesk Revit, and Dynamo. In this study, Autodesk Revit was utilized for detailed building modeling. At the same time, Dynamo was employed to automate data extraction and calculations, linking the information to Microsoft Excel for foundation design analysis based on Terzaghi's theory. The flowchart of the calculation procedure is shown in Figure 3.

Autodesk Revit facilitates the creation of detailed structural models, enabling the simulation of three-dimensional representations of architectural, structural, and system-related components. Dynamo, a visual programming tool integrated with Revit, automates complex calculations and data processing tasks, enhancing the efficiency and accuracy of the design process (Pierson, 2019; Pratansup, 2022). Through this integrated approach, all parties can access real-time updates, ensuring awareness of ongoing modifications and developments within the project (Association of Siamese Architects Under the Royal Patronage, 2015).

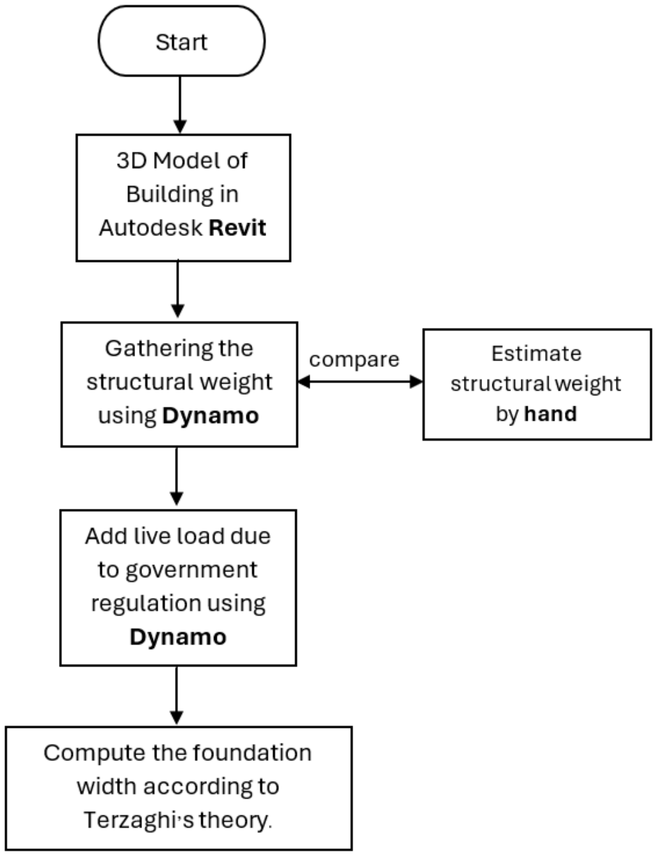


Figure 3. Calculation procedure of foundation width.

2.4 Solution of Required Foundation Width

The required foundation width (*B*) is determined by solving a cubic equation derived from Terzaghi's ultimate bearing capacity formula. The process begins with calculating the total weight from the building model using Dynamo, which includes both the dead load (*DL*) and the live load (*LL*), as specified by Ministerial Regulation (Ministerial Regulation No.6, 1984). This total design load is denoted by Q_a. The cubic equation used to solve for B is expressed as:

$$B^3 + a_1 B^2 - a_2 = 0 \tag{3}$$

where the coefficients a_1 and a_2 are computed as follows:

$$a_1 = \left(1.3cN_c + \gamma D_f N_q\right)/(0.4\gamma N_\gamma) \tag{4}$$

$$a_2 = (FS \cdot Q_a)/(0.4\gamma N_\gamma) \tag{5}$$

Equation (3), with positive coefficients as per Eqs. (4) and (5), is solved analytically using the solution for cubic equations (Spiegel et al., 2018). The factors Q and R are defined as:

$$Q = a_1^2/9 \tag{6}$$

$$R = (27a_2 - 2a_1^3)/54 \tag{7}$$

The discriminant (D) determines the nature of the roots:

$$D = R^2 - Q^3 \tag{8}$$

If the value of the discriminant is negative ($D < 0$), the solution of Eq. (3) is:

$$B = 2\sqrt{Q}\cos\left(\frac{1}{3}\cos^{-1}\left(R/\sqrt{Q^3}\right)\right) - \frac{1}{3}a_1 \tag{9}$$

If the discriminant is positive ($D > 0$), the solution of Eq. (3) is:

$$B = \sqrt[3]{R + \sqrt{D}} + \sqrt[3]{R - \sqrt{D}} - \frac{1}{3}a_1 \tag{10}$$

This method accurately and efficiently determines the foundation width, leveraging the integration of Dynamo and Excel for computational tasks.

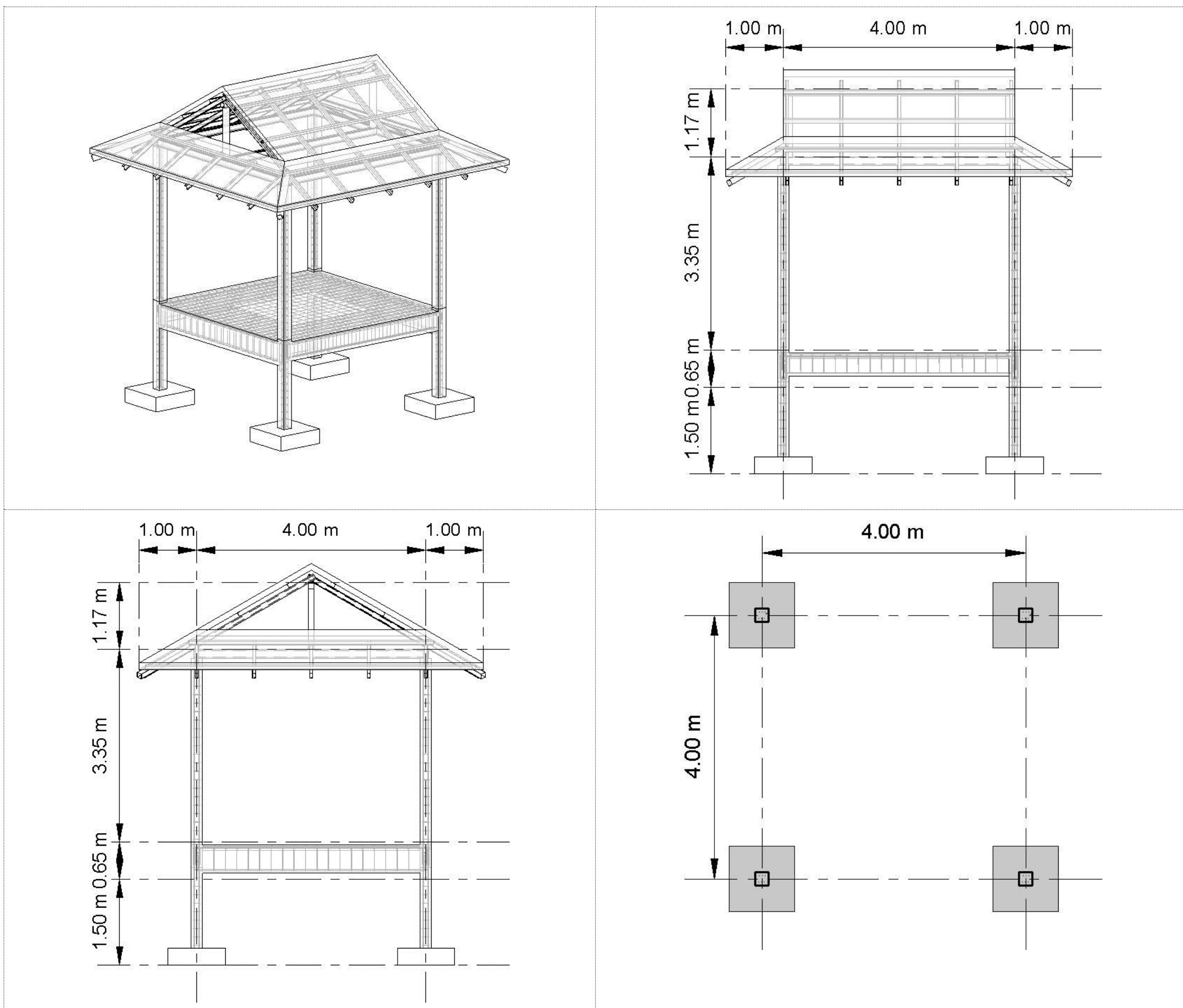


Figure 4. Three views of buildings and foundation plan.

The building analyzed in this study, shown in Figure 4, is a one-story structure with reinforced concrete columns, slabs, and floor beams. The roof structure is constructed from structural steel. The imposed live loads are 150 kg/m^2 for the floor structures and 30 kg/m^2 for the roof structures, per Ministerial Regulation (Ministerial Regulation No.6, 1984).

2.5 Building Information Modeling utilizing Autodesk Revit

The simulation of BIM requires meticulous data input into the model. The process is as follows:

1. **Initiate a New Model:** Start by generating a new model file using Revit's "New" command, selecting the Structural Template to align with the intended simulation model.
2. **Foundation Design:** Fabricate a square foundation design.
3. **Concrete Column Design:** Craft concrete columns with a square cross-section of 0.2 m, using both pier and column types.
4. **Concrete Beam Design:** Develop concrete beams following the construction drawings, specifying cross-sectional dimensions for each beam type.
5. **Concrete Slab Plan:** Formulate a comprehensive cast-in-place concrete slab plan by determining slab types, thicknesses, and materials, creating distinct slab areas across various locations.
6. **Reinforcement Measures:** Specify the type of steel reinforcement, incorporating each designated reinforcement type into beams, floors, and columns while determining the concrete cover distance as indicated in the construction drawings.
7. **Steel Roof Structure:** Create steel forms by specifying each variant's type and cross-sectional dimensions, then use these forms to construct the roof structure following the design blueprints.

This systematic approach ensures that all structural components are accurately modeled (Figure 4?), facilitating precise data extraction and subsequent analysis using Dynamo.

2.6 Creating a Command Set for Data Linkage within the Dynamo Program.

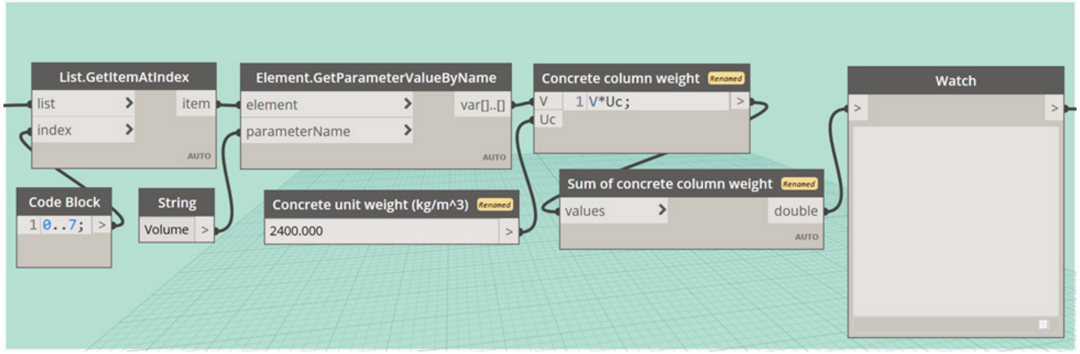
To perform foundation design computations, understanding the weights of the building components is essential. It includes dimensions such as size, volume, and length. Dynamo automates the extraction and aggregation of these data, linking them to Microsoft Excel for further analysis. The integration between Dynamo and Excel improves the speed and accuracy of calculations compared to manual methods. The process involves the following steps:

1. **Column Weight Calculation:**
   - ***Classification:*** Classify column weights into concrete and steel columns (used in the roof structure) using the List.GetItemAtIndex command.
   - ***Parameter Extraction:*** Determine the volume for concrete columns and the length for steel columns using the Element.GetParameterValueByName command.
   - ***Total Weight Calculation:*** Aggregate the weights based on the extracted data, as shown in Figure 5.
2. **Beam Weight Calculation:**
   - ***Classification:*** Classify beam weights into concrete and steel beams (used in the roof structure) using the List.GetItemAtIndex command.
   - ***Parameter Extraction:*** Determine the volume for concrete beams and the length for steel beams using the Element.GetParameterValueByName command.

- ○ ***Total Weight Calculation:*** Aggregate the weights based on the extracted data, as shown in Figure 6.

3. **Reinforcement Weight Calculation:**
   - ○ ***Reinforcement Type Identification***: Use the Element.GetParameterValueByName command to identify specific reinforcement types.
   - ○ ***Index Location:*** Employ the List.AllIndicesOf command to locate the positions of each reinforcement type.
   - ○ ***Length Extraction:*** Extract the length of each reinforcement using the Element.GetParameterValueByName command.
   - ○ ***Total Reinforcement Weight:*** Use the List.GetItemAtIndex command to determine the length of each reinforcement type and calculate the comprehensive reinforcement weight, as illustrated in Figure 7.
4. **Floor Weight Calculation:**
   - ○ ***Floor Type Specification:*** Use the Element.GetParameterValueByName command to specify the floor type.
   - ○ ***Index Location:*** Utilize the List.AllIndicesOf command to locate the positions of the specified floor type.
   - ○ ***Volume Extraction:*** Extract the floor volume using the Element.GetParameterValueByName command.
   - ○ ***Reinforcement Length:*** Use the List.GetItemAtIndex command to determine the length of each type of steel reinforcement.
   - ○ ***Total Floor Weight:*** Compute the comprehensive floor weight, as demonstrated in Figure 8.
5. **Live Load Calculation:**
   - ○ ***Component Division:*** Divide the live load into roof and floor components.
   - ○ ***Parameter Extraction:*** Use the Element.GetParameterValueByName command to extract space-related parameters.
   - ○ ***Area Data Utilization:*** Utilize the acquired area data to perform live load calculations, as shown in Figure 9.

6. **Total Design Load Calculation:**
   - ○ ***Summation:*** Sum the total weight and live load to calculate the load exerted on the building foundation.
   - ○ ***Data Export:*** Use the Data.ExportExcel command to generate Excel files for further analysis, as depicted in Figure 10.



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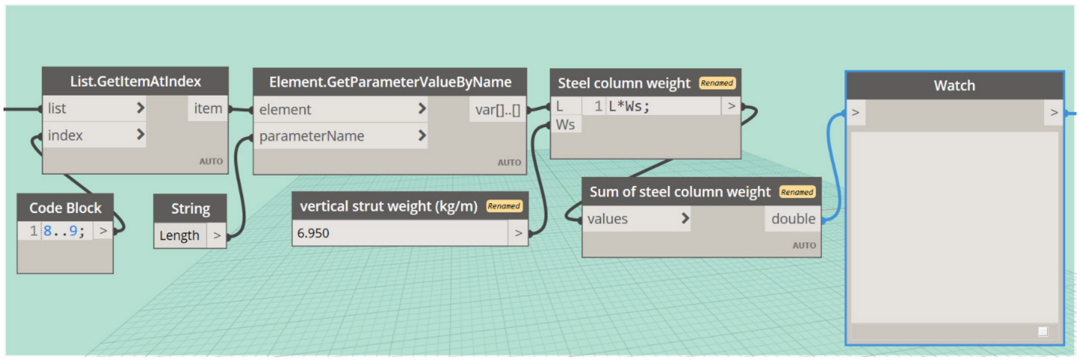
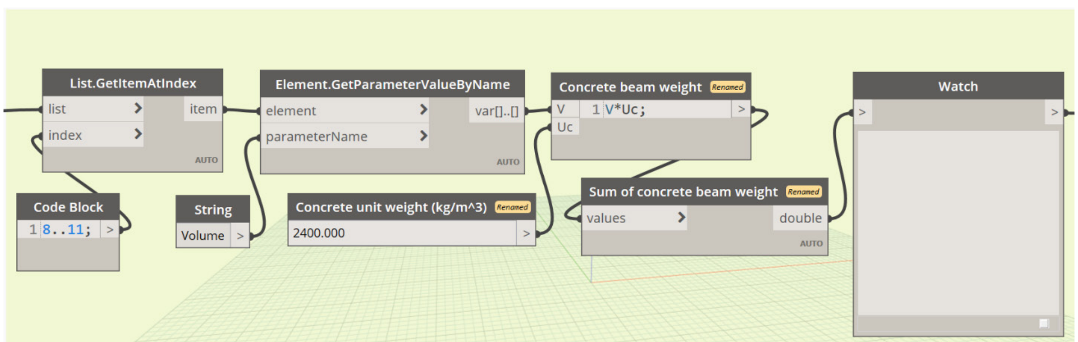


b)

Figure 5. Column weight determination process, a) concrete column, and b) steel column.



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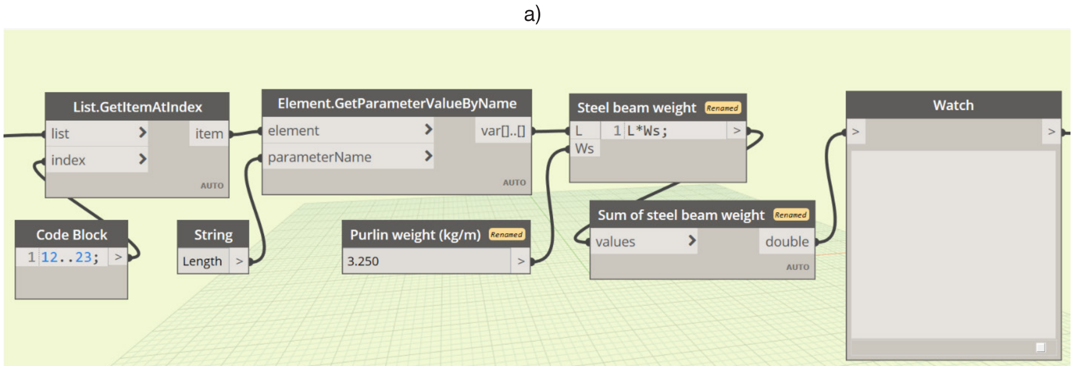
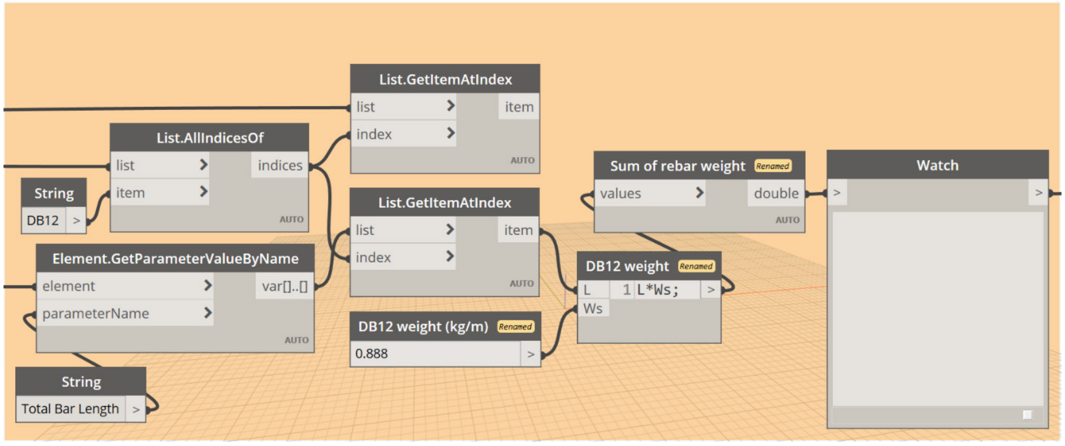


b)

Figure 6. Beam weight calculation process, a) concrete beam, and b) steel beam (roof).



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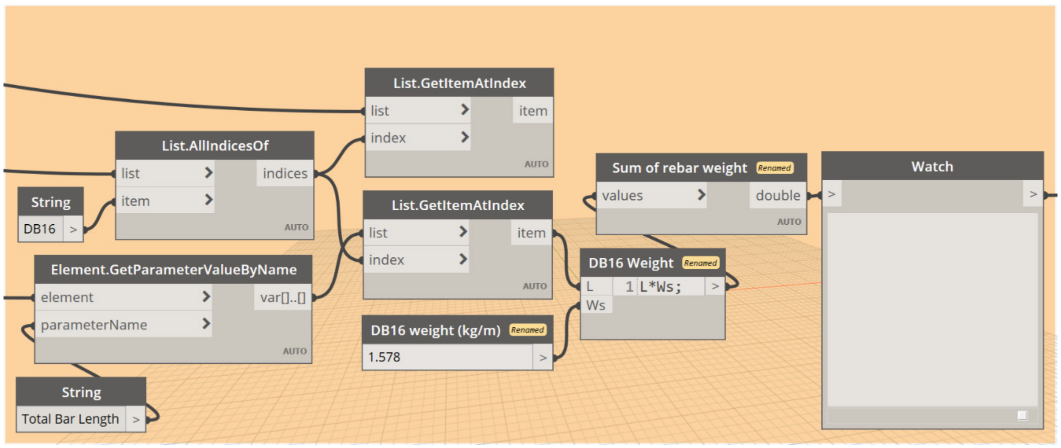


b)

Figure 7. Reinforcement weight calculation, a) DB12, and b) DB16 steel.

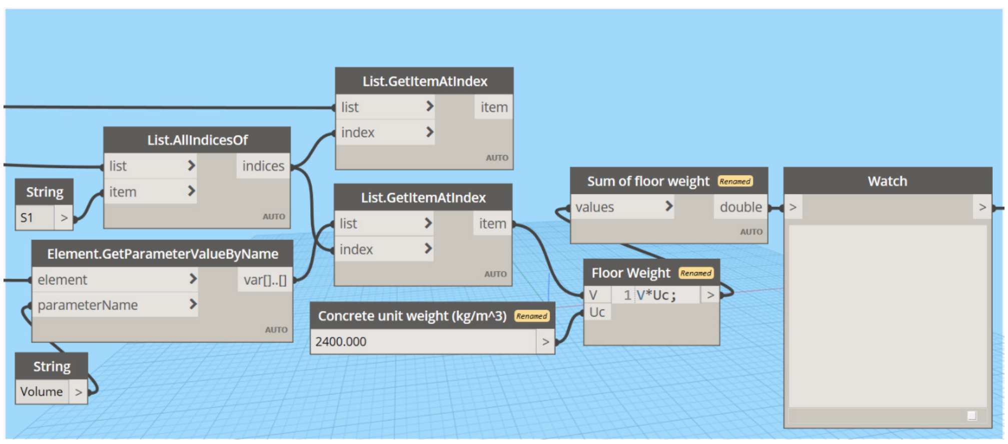
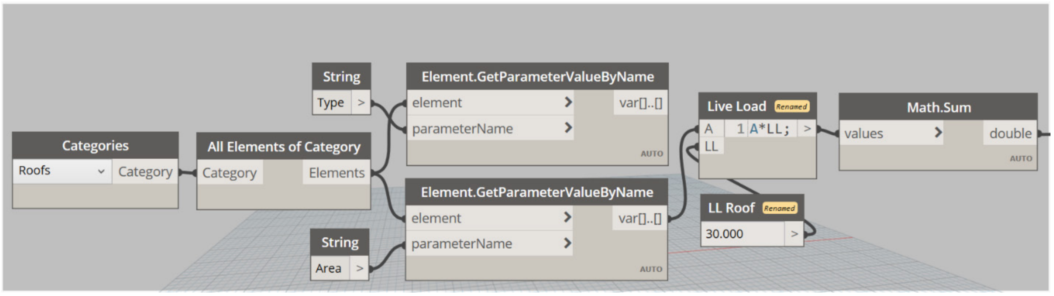


Figure 8. Floor weight calculation.



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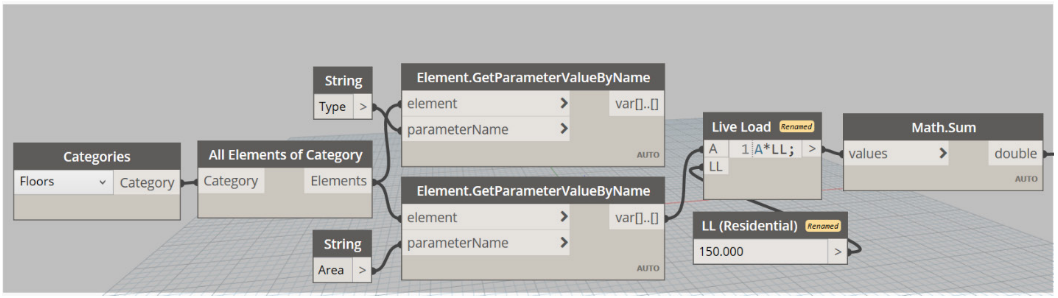

b)

Figure 9. Live load calculation process, a) live load on the roof, and b) live load on the floor.

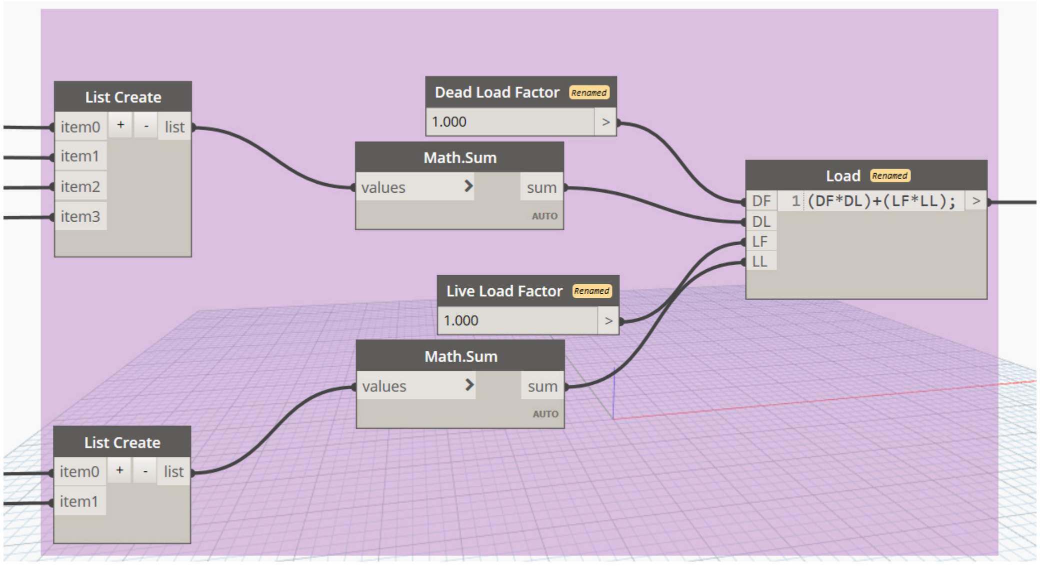

Figure 10. Computation of total design load.

2.7 Foundation Width Determination using the Microsoft Excel Program.

After obtaining the required allowable load (Q_a) from the Dynamo program, additional data are input into Microsoft Excel to compute the foundation dimensions, as illustrated in Figure 11. Terzaghi's Ultimate Bearing Capacity equation and the solution of the cubic equation described in section 2.4 were applied to determine the required foundation width. This integration between Dynamo and Excel enhances calculation accuracy and reduces the time required for foundation design, making it a practical solution for real-world applications.

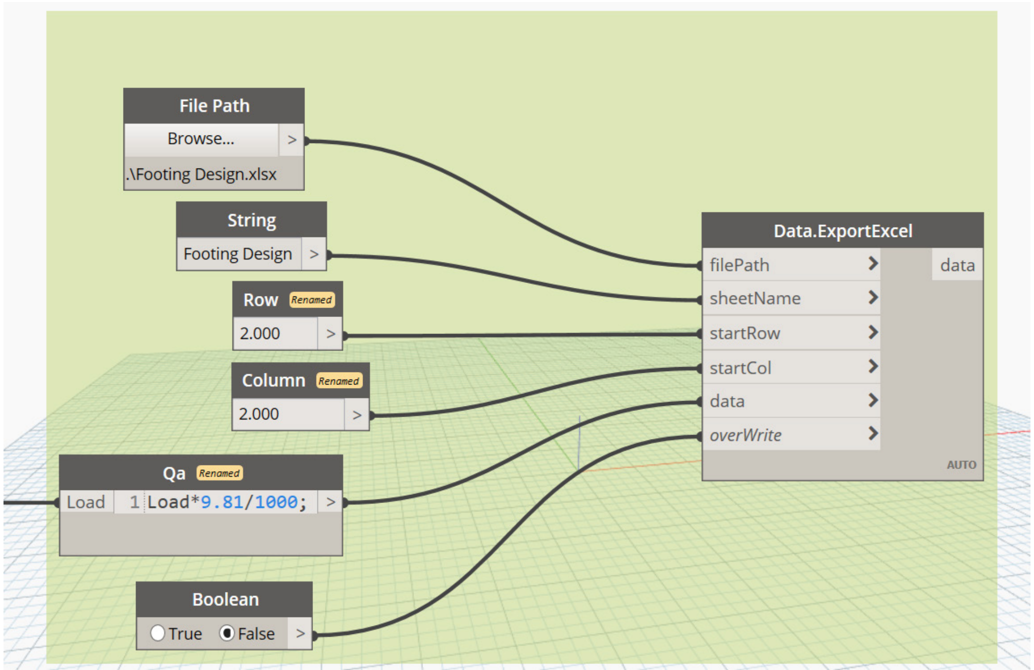

Figure 11. Compute the design load and export to Microsoft Excel.

3. Results and Discussion

This section presents the outcome of the foundation design using the cubic equation solver, comparing results from Dynamo and hand calculations. It also discusses the implications of using BIM tools like Autodesk Revit and Dynamo for design automation.

3.1 Test on Cubic Equation Solver

The case of shallow foundation design (Das, 2010) is presented in Table 3. The soil supporting the foundation has a friction angle (ϕ) of 35°, with no cohesion (c = 0) and a unit weight (γ) of 18.15 kN/m^3. A square foundation at depth D_f = 1 m was subjected to a total design load of 30,000 kg, equivalent to a required allowable load of 294.3 kN. The cubic equation solver was employed using a factor of safety (FS) of 3, as outlined in Eqs. (4)–(10), to determine the foundation width (B). The required foundation width of 0.92 m was calculated, satisfying Terzaghi's bearing capacity equation (Eq. 1). The solution is summarized in Table 3.

Table 3. Calculation of Shallow Foundation Width from Sample Problem (Das, 2010)

Shallow Foundation Design Example		
Required allowable bearing load, Q_a	294.3	kN
Factor of safety, *FS*	3	
Soil unit weight, γ	18.15	kN/m^3
Soil cohesion, *c*	0	kN/m^2
Internal friction angle of soil, ϕ	35	deg
Depth of foundation, D_f	1	m
N_c	57.75	
N_q	41.44	
N_γ	45.41	
a_1 (Eq. 4)	2.28	m
a_2 (Eq. 5)	2.68	m^3
Q (Eq. 6)	0.58	m^2
R (Eq. 7)	0.90	m^3
Discriminant, *D* (Eq. 8)	0.62	m^6
Required foundation width, *B* (Eq. 10)	0.92	m

3.2 The Total Design Load

Weight data of beams, columns, floors, and roof structures were extracted from the Autodesk Revit program and connected to the Dynamo program. The unit weight of concrete was set at 2,400 kg/m^3 according to ASTM standards, including longitudinal steel reinforcement and structural steel (Sornkate, 2017). All structural weights and design live loads for floor and roof structures were included in the total design load for the foundation (Ministerial Regulation No.6, 1984). A comparison of total dead load and design load between the results from Dynamo and hand calculations is shown in Table 4.

Table 4. Comparative Summary of Weight Deductions from Dynamo and Hand Calculations

Total Design Load			
Type of Load	Autodesk Revit + Dynamo	Hand Calculation	Unit
Total Weight of Concrete Column	1953.86	1953.86	kg
Total Weight of Concrete Floor	4195.2	3840	kg
Total Weight of Concrete Beams	2553.6	3456	kg
Total Weight of Reinforced Steel	460.37	402.11	kg
Total Weight of Steel Roof	670.65	701.34	kg
Total Weight of Building (*DL*)	9833.68	10353.31	kg
Total Design Live Load (*LL*)	3869.09	3510.00	kg
Total Design Load, (*DL* + *LL*)	13702.77	13863.31	kg
Total Design Load per Footing	33.61	34.00	kN

3.3 Foundation Size Calculation

The total design load per foundation (Q_a) was multiplied by the factor of safety to establish a secure foundation size. The required foundation width (B) was calculated using Microsoft Excel with Eqs. (4)–(10), as shown in Table 5.

Table 5. Shallow Foundation Design

Shallow Foundation Design		
Required allowable bearing load, Q_a	33.61	kN
Factor of safety, *FS*	3	
Soil unit weight, γ	17.66	kN/m^3
Soil cohesion, c	49.05	kN/m^2
Internal friction angle of soil, ϕ	23	deg
Depth of foundation, Df	2	m
N_c	21.75	
N_q	10.23	
$N\gamma$	6	
a_1 (Eq. 4)	41.25	m
a_2 (Eq. 5)	2.38	m^3
Q (Eq. 6)	189.03	m^2
R (Eq. 7)	2597.85	m^3
Discriminant, D (Eq. 8)	6181.61	m^6
Required foundation width, B (Eq. 10)	0.24	m

The required foundation width of 0.24 meters satisfies Terzaghi's bearing capacity equation, Eq. (1).

3.4 Future Research

This study demonstrates the benefits of using Dynamo to automate foundation design, but future research could explore its application under more varied conditions. Testing the methodology on soil types with higher variability or using more complex building models could provide additional validation. Additionally, incorporating other factors such as lateral loads or seismic activity could enhance the robustness of the current model for broader applications in construction projects.

4. Conclusion

In conclusion, this research investigates the intricate interplay of diverse variables that influence foundation dimensions. Simultaneously, it aimed to devise a comprehensive suite of computational protocols that seamlessly connect Autodesk Revit Dynamo with Microsoft Excel, enhancing the process of building foundation design. The key findings of this study can be succinctly summarized as follows.

Firstly, the program interface developed to bridge Autodesk Revit and Dynamo effectively determined the weight distribution across various building elements. Notably, the total design load derived from the combined efforts of Autodesk Revit and Dynamo slightly deviated from the value obtained through manual calculations.

Subsequently, Microsoft Excel played a crucial role by ingesting the data regarding the total design load. It facilitated the precise computation of foundation dimensions. In parallel, applying Terzaghi's ultimate bearing capacity theory enabled the calculation of the maximum soil bearing capacity, a pivotal factor in foundation design. Utilizing closed-form formulas within Microsoft Excel proved to be an effective strategy for solving complex equations, yielding accurate results.

Accuracy is particularly important in determining the required foundation width, a pivotal outcome obtained through Microsoft Excel calculations. It underscores the reliability and efficacy of the computational framework developed in this study.

This research sheds light on the intricate dynamics of foundation dimension influences and contributes a practical and efficient computational approach to streamline the foundation design process. Integrating Autodesk Revit Dynamo and Microsoft Excel and incorporating established theories collectively results in a robust methodology with promising applications in construction and structural engineering.

Acknowledgments

The author (Apinut Nuntiya) wishes to thank the Faculty of Engineering, Chiang Mai University, for their help and support under the Research Assistance Scholarships.

Funding

This research was supported by CMU Junior Research Fellowship Program.

Conflicts of interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, P.S., D.R., C.B.; data curation, P.V. and P.P.; software, S.M.; validation, P.N. and R.S.; writing–original draft, P.S., A.N. and K.J.; writing–review & editing, C.B. and D.R.

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