CES500699

Boosting project performance. Engineering Automation Workflow usind Dynamo.

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Learning Objectives

- Design the workflow to automate the creation of Revit and Robot Structural Analysis models using Dynamo
- Learn how to implement automation workflow as part of engineering projects to reduce time-consuming tasks, risk of errors, or inaccuracies
- Learn about maximizing automation workflow to quickly adapt on last-minute changes
- Learn about advantages and disadvantages of developing advanced Dynamo script

Description

Revit software is a powerful tool in the building information modeling (BIM) world that can be linked to Robot Structural Analysis software. Structural analysis requirements and constraints make this link difficult to manage and often result in time-consuming manual adjustments in models. This class will explain how you can use Dynamo for automated creation of intelligent models (including MEP design) and structural analysis models with one engineering data set input based on shaft structure and pumping station project example. The intelligent model output includes all necessary information, schedules with concrete, and mapped required reinforced steel quantities. The second model output uses the same unique geometry while considering all structural load cases and combinations required for detailed design. We'll show you how this engineering workflow allows users-with a previously impossible agility- to react quickly to change, leaving more time to on focus on core engineering rather than model and deliverable generation.

Speakers

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Introduction

Managing and implementing changes is a common challenge for any large-scale project. Designers and engineers must make decisions based on data from all the disciplines involved, which constrained by ever tighter schedules develop their design in parallel. The change management strategy strongly influences budget evaluation and timeliness.

In most cases, the design of stormwater collection wells is standardized to homogenize maintenance operations during the operation phase. This allows the automation of the various tasks necessary for their design.

This article describes the detailed and optimized design process of these wells, using digital twins. This process leverages the use of Revit, Robot Structural Analysis, Dynamo and the APIs (Application Programming Interface) of these tools via the Python programming language.

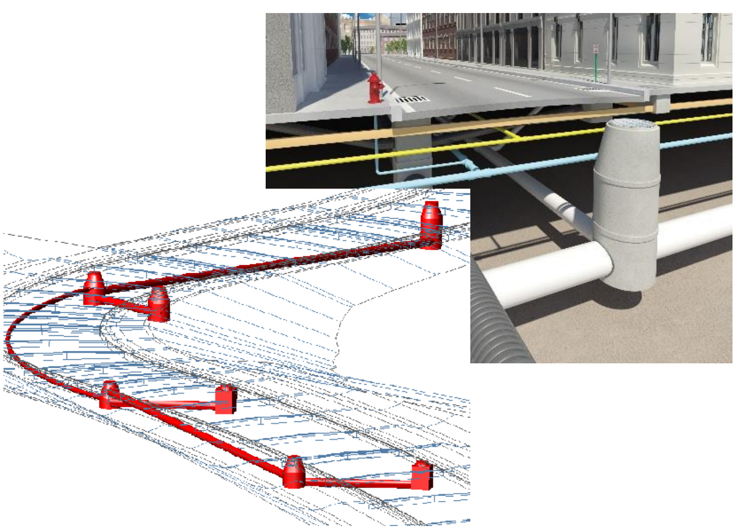
This process allows the creation of:

- a physical model in Revit that includes, in addition to geometry, metadata and reinforcement quantities,
- a calculation model in Robot Structural Analysis including support conditions, load cases, or combinations.

From these 2 models the set plans (plan view, sections, and 3D view) and the calculation note are generated automatically.

In addition, it is easy to carry out, easily and quickly, once again all these tasks with different input data depending on the changes to be taken into account.

The risk of error or inconsistencies that can occur when these tasks are performed manually are then drastically reduced.



Challenge

During each major project, we face serious challenges in the design process involving the management and implementation of significant changes. The mentioned changes may be dictated by many factors, not only structural ones, leading to the requirement to consider many issues in parallel (Table 1). The change management approach influences how you price, design, and manage project delivery within budget. In most cases, shaft configurations are standardized to ensure consistent operation and maintenance procedures, allowing for the development of task sequences that minimize the level of effort required for each modification.

Table 1. Change factors faced during the project

Subject	Change factors
Client	Influence on general arrangement, alignment, shaft location and incoming connections
Land Development Planning	Influence on the location of the structure, alignment and incoming connections
Environmental	Influence on the location of the structure, alignment and incoming connections
Hydraulics	Influence on the flow requirements (sizing), tunnel sizing, number of incoming connection connections and drop structures
CFD Modeling Analysis	Influence on the flow requirements (sizing) and general arrangement of drop structures
Geotechnics	Influence on restraints, loading and structural design
Construction	Influence on general arrangement
Utilities	Influence on the location of the structure, alignment and incoming connections
Operation and Maintenance	Influence on the general arrangement, access and safety requirements and methods of maintenance

This involves solving multidisciplinary problems in parallel. The change management strategy strongly influences the budget, the design process, and the timely management of deliverables.

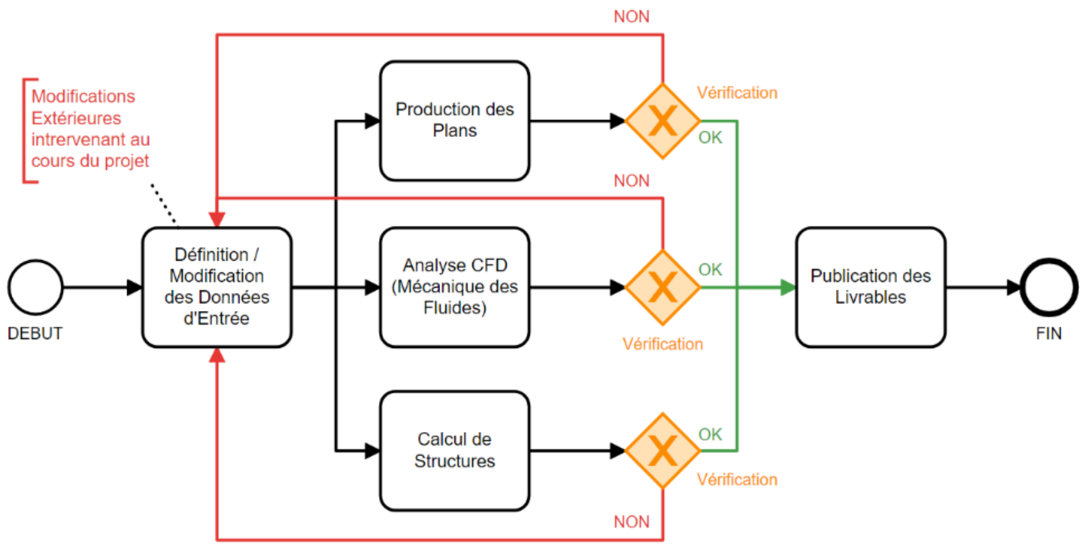


Figure 2. Simplified Design Workflow

The sequence automation required to design stormwater collection wells minimizes the effort required to account for changes during the project.

Implemented Solution Workflow

The solution implemented to minimize the level of effort is mainly based on the automatization of the main tasks conducted to develop project deliverables such as drawings, schedules and quantities, and structural analysis report.

The following main tasks has been automated in separate custom tools all connected to the engineers input data Excel file when relevant:

A1. Creation of the BIM model
A2. Creation of the structural analysis model from the BIM model
A3. Creation of the structural analysis report
A4. Rebar quantity
A5. Creation of the drawings and schedules

They are controlled by an Excel file including all input data needed to manage both the BIM and structural analysis model of all shafts of the project. This allows to manage one single source of truth for input data easily modifiable depending on required changes all along the project lifecycle.

Each task can be performed independently but need to remain in sequence. The engineer retains full control through the management of the excel file and can carry out parametric studies and modification on request with a reduced level of effort. Creating the digital twin from a single source also avoids issues with version control and discrepancies between outputs that are often an issue with transferring data sets between software.

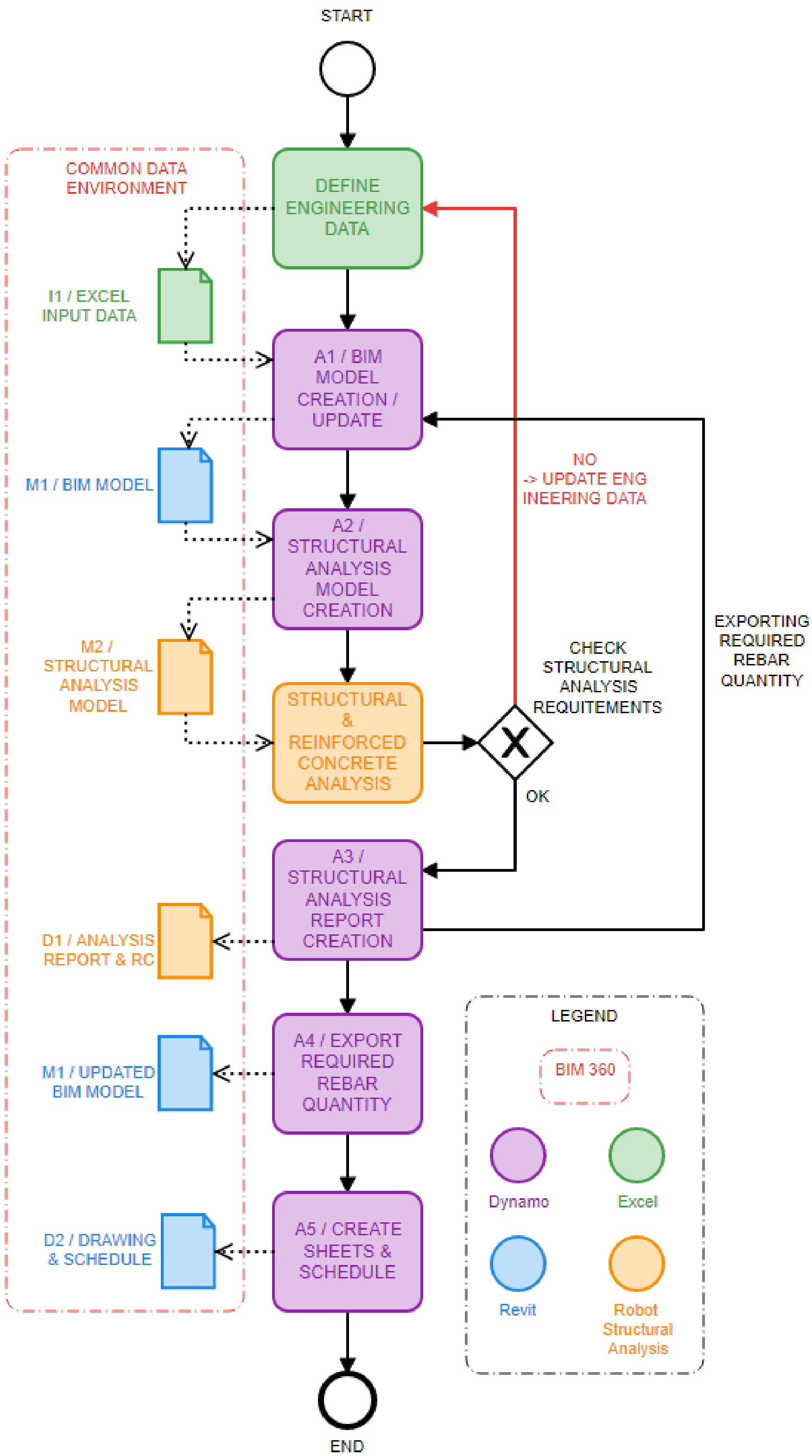


Figure 3. Solution workflow

The workflow is supported by a cloud-based Common Data Environment (CDE) in which input data, models and deliverables are stored. This CDE allows to give access to project materials to any relevant stakeholders for modification or review purpose and contributes to make the workflow even more seamless.

To develop this workflow the following software packages have been used:

Table 2. Software

Workflow Component	Software
Input data	Microsoft Excel
BIM model, drawings and schedules	Autodesk Revit
Structural Analysis Model	Autodesk Robot Structural Analysis
Automation	Dynamo for Revit and Microsoft Excel
Common Data Environment	BIM 360

As shown in the table above the automated tasks are programmed with Dynamo for Revit, Python scripts and Excel macros developed in Visual Basic for Application. Automating the task using a Dynamo Graph offers the flexibility to quickly adapt the script in case of design changes affecting the general arrangement of the shaft and is the primary tool to automate the creation of the BIM model in Revit but also of the structure analysis in Robot Structural Analysis.

Workflow Execution

Main input data

The input data is grouped within the Excel workbook in which the parameters of all project shafts is stored. It includes several worksheets, arranged contextually for each different types of input data such as the description of the overall geometry, the coordinates of the shaft, material properties, loads and load cases, load combinations and most structural design Input parameters for the Robot model executing the concrete design.

2	3	4	5	6	7
Coordinates		Ground	Tunnel	Tunnel	Tunnel
Easting	Northing	Level	Level	Diameter	Angle
[m]	[m]	[m]	[m]	[m]	[degree]
230346.965	393777.828	5.000	-14.000	3.000	90.000
230069.375	394620.987	5.000	-20.000	4.000	180.000
230004.646	396089.304	5.000	-5.000	4.000	209.000
229167.358	397308.873	10.000	-20.000	3.000	193.000

Figure 4. Structure geometry and coordinates in Microsoft Excel

2	3	4	5	6	7
Chamber Diameter [m]	Base Slab Level [m]	Top Slab Level [m]	Chamber Wall Thickness [m]	Concrete Grade [-]	Base Slab Thickness [m]
12.00	-15.500	-9.50	0.500	C50	1.500
15.00	-20.500	-14.50	0.500	C50	1.500
15.00	-5.500	0.50	0.5	C20	1.500
12.000	-25.500	-19.50	0.5	C25	1.500
				C32	
				C40	
				C50	
				C65	

Figure 5. Structure material properties in Microsoft Excel

The structure of the data in the workbook has been defined to simplify the data gathering and checking for the project engineer and includes formulas converting those data to make it readable by the Dynamo graph.

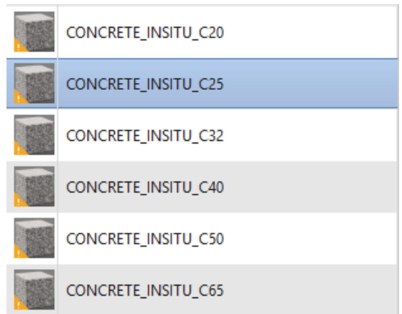


Figure 6. Structure material properties in Revit

Creation of the BIM model

From the input data structured in the Excel file the BIM model is generated automatically in Revit.

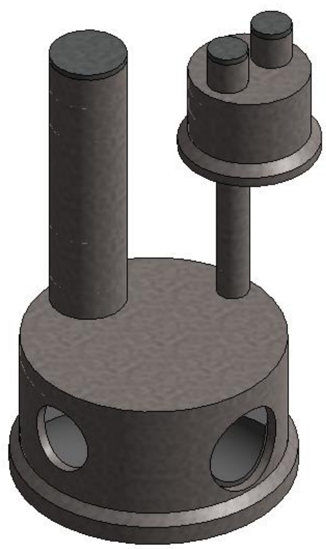


Figure 7. BIM model in Revit

Each component of the shaft is named and identified with a unique marker. In addition, to the geometry and properties of the shaft components, the custom graph (ie. Script in Dynamo) automatically defines the analytical model of the shaft supporting the creation of the structural analysis model in the next step of the workflow.

Even if the analytical model is managed by default in Revit the graph allows to adjust it as required by the structural analysis principles and define exactly the elevations, location, slabs or walls, and the exact dimension of the opening. The graph also defines the boundary conditions of the shaft considering different ground layers and their respective stiffness.

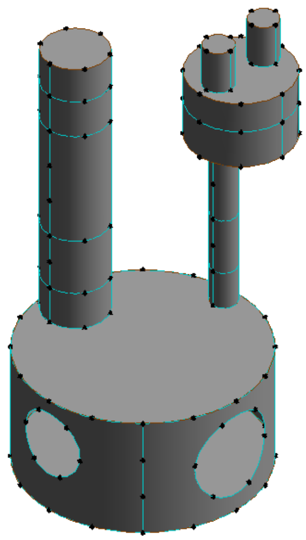


Figure 8. Analytical model in Revit

CFD Modeling

A further advantage of the BIM model is the possibility of easy and quick export to *.sat format. The file is saved in this way on the CDE platform that simplifies the build of the computational fluid dynamics (CFD) analysis ensuring data consistency and reduced level of effort. Based on the specified flows, the CFD model establishes the hydraulic boundaries, verifies the overall dimensions and provides feedback for adjustment based on hydraulics of the shaft configuration. The implementation of these CFD outputs back I nto the source data is simplified through adjustments of the inputs parameters and reruns of the script.

The hydraulic engineer can simply communicate any comments for change on the same platform through comments directly in the BIM model that gets assigned directly as a task to the civil engineer in charge. The use of these commenting functions ensure clear assignments of tasks, real time availability of comments, visual context for ease of understanding and a close out register that can be used to track status of change management.

Creation of the structural analysis model

The second step of the workflow aims to create the structural analysis model of the shaft leveraging the main input data and the BIM model created as part of the previous steps.

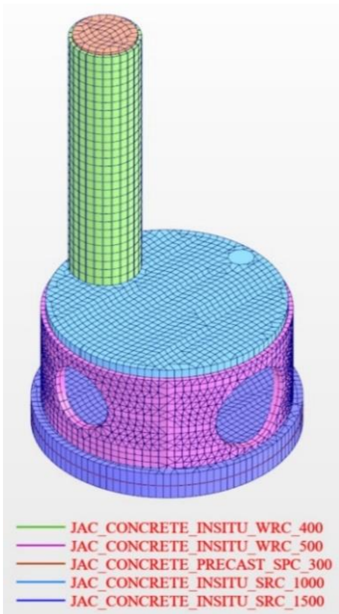


Figure 9. Structural model in Robot Structural Analysis

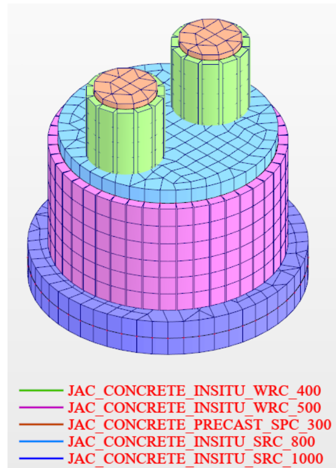


Figure 10. Structural model in Robot Structural Analysis

The main part of the structural analysis model is created from the BIM model, this guarantees data consistency between the two models, creating a digital twin between the geometric and structural model. But even if the analytical model created during the previous steps has been adjusted it is neither perfect nor complete. During the transition of the model between Revit and Robot Structural Analysis the Revit analytical model is adjusted as needed and structural properties are added based on the main input data from the Excel workbook such as linear releases between floors and walls, loads, load cases, combinations, meshing parameters and reinforced concrete parameters.

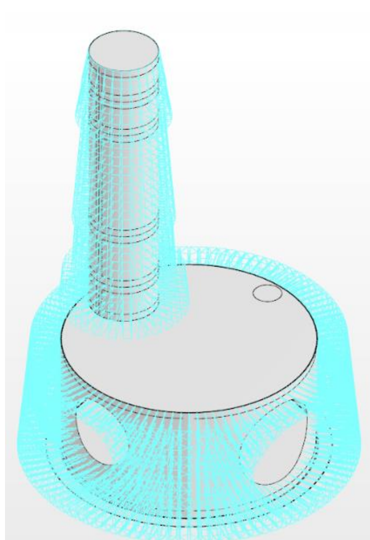


Figure 11. Ground pressure load in Robot Structural Analysis

0	1	2	3	4
No.	Label	Nature	Name	Description
1	DL1	dead	DL1	Dead Load
2	DL2	dead	DL2	Ground I
3	DL3	dead	DL3	Ground Water I
4	DL4	dead	DL4	Buoyancy I
5	DL5	dead	DL5	Ground II
6	DL6	dead	DL6	Ground III
7	DL7	dead	DL7	Ground Water III
8	DL8	dead	DL8	Buoyancy III
9	DL9	dead	DL9	Ground IV
10	LL1	live	LL1	Live Loads I
11	LL2	live	LL2	Live Loads II
12	LL3	live	LL3	Live Loads III
13	TEMP1	temperature	TEMP1	Maximum Gradient
14	TEMP2	temperature	TEMP2	Minimum Gradient
15	TEMP3	temperature	TEMP3	Heating Temperature
16	TEMP4	temperature	TEMP4	Cooling Temperature
17	SHR1	temperature	SHR1	Shrinkage
18	SEIS1	seismic	SEIS1	Hashash Load I
19	SEIS2	seismic	SEIS2	Water Load I
20	SEIS3	seismic	SEIS3	Shaft Mass I
21	SEIS4	seismic	SEIS4	Hashash Load II
22	SEIS5	seismic	SEIS5	Water Load II
23	SEIS6	seismic	SEIS6	Shaft Mass II
24	SEIS7	seismic	SEIS7	Hashash Load III
25	SEIS8	seismic	SEIS8	Water Load III
26	SEIS9	seismic	SEIS9	Shaft Mass III
27	SEIS10	seismic	SEIS10	Hashash Load IV
28	SEIS11	seismic	SEIS11	Water Load IV
29	SEIS12	seismic	SEIS12	Shaft Mass IV
30	ACC1	accidental	ACC1	Accidental Load

Figure 12. Load cases defined in Excel

At the end of this step a full structural analysis model is available in Robot Structural Analysis. The analysis can be performed as well as the reinforced concrete design to determine the required rebar.

Seismic load application

Consideration of seismic loads in underground structures is one of the more complex issues, there are several structural design approaches. Not all are supported by all structural softwares. Due to the type and dimensions of structure, it was decided to apply the approach developed by Y. Hashash, consisting in estimating the displacement of the soil onto the structure on the basis of:

- ratio of peak ground velocity to peak ground acceleration,
- distance from source to site,
- ratio of ground motion at structure depth to motion at ground surface,
- shear wave velocity, the influence of groundwater on the structure and
- the acceleration of the structure are also taken into account.

This structural design approach is not an available function in Robot for structural analysis. The structure of the workflow allowed us to develop an automated input function into Robot, that enabled the execution with these theoretical considerations.

This was achieved via conversion of the ground displacement calculated in Excel to an equivalent load. The entire process of the application of the seismic load has been automated, the soil displacement calculated using the formulas in Excel, converted to the equivalent load using a prepared script, and then applied to the finite element nodes as a nodal force - assigned to the appropriate load case.

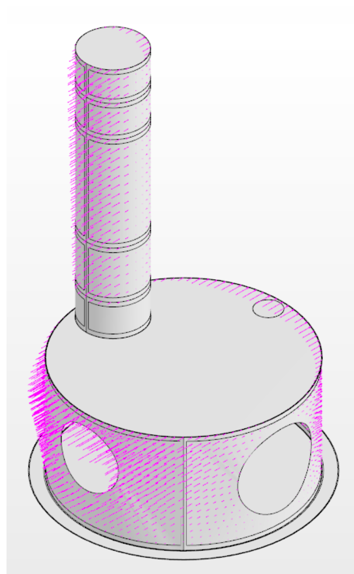


Figure 13. Seismic nodal forces in Robot Structural Analysis

The applied script introduces the flexibility to changes and improves the speed of re-applying the load that disappears after manual editing the dimensions of the finite element mesh if needed.

Calculation

The next workflow step is to obtain the structural analysis results by manually running the analytical calculations.

The calculation of the required reinforcement is carried out via the use of the proposed reinforcement in the excel input sheet and use within Robot to a predefined standard such as Eurocode.

All parameters and data necessary for the calculation are pre-defined in Excel, such as: cement class, structure class, creep coefficient, environmental classification, allowed crack limits, allowed deflection, concrete cover and rebar diameters.

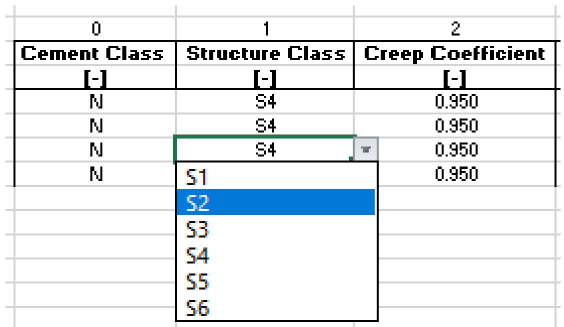


Figure 14. Reinforcement parameters defined in Excel

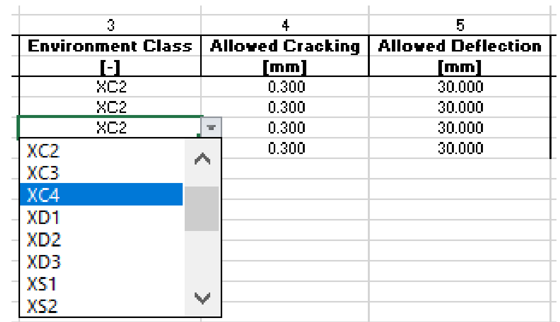


Figure 15. Reinforcement parameters defined in Excel

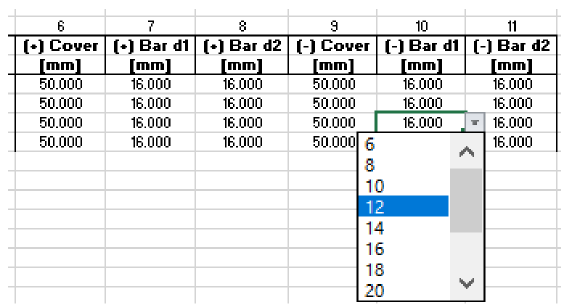


Figure 16. Reinforcement parameters defined in Excel

This approach provides an easy, fast, and transparent way to define data, which saves time and reduces the risk of errors that can occur when defining this data in a structural analysis program. Quality Control on the structural analysis is further improved through the structured way input data is presented. The use of the digital twin also ensures that Model geometries can be checked via a check of the project drawings as the deliverables are all dynamically linked.

Post processing

The essential part of the design process is the final deliverables in the form of Models, Drawings, Schedules, and Structural analysis reports. Unfortunately, the level of effort required to produce structured and concise deliverables is often underestimated. Hence a particular focus was given to develop automation scripts for these final reports and drawings.

Rebar quantity

After calculating the required amount of reinforcement, the data with these results for individual structural elements are automatically exported to the BIM model, which is the core with all information about the designed structure. Based on this model, drawings and schedules are generated, defining elements such as volume of concrete, the average amount of required reinforcement (top and bottom in each direction) and the mass of required reinforcement. An important item is the ratio of reinforcement to concrete, which allows the designer to easily and quickly assess the structure and decide on its possible optimization or adjustments to improve capacities. The data in the BIM model can be used to produce Bill of Quantities and other BIM workflows such as scheduling, sequencing etc.

Creation of the drawings and schedule

Plans, Elevations, Sections, 3D Views and Schedules are automatically placed in the appropriate position and scale on the drawings. The outstanding element is the annotation of the drawings. Dates, revisions, and data of persons responsible for the project, such as: designer, reviewer, are controlled by data defined in the Excel. This solution allows us to easily edit these issues, avoiding mistakes in case of many changes.

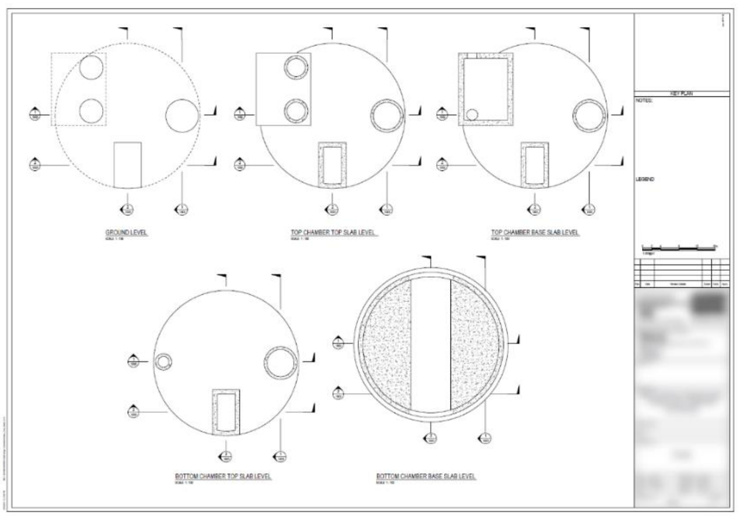


Figure 17. Revit Sheet with Plan View at different levels

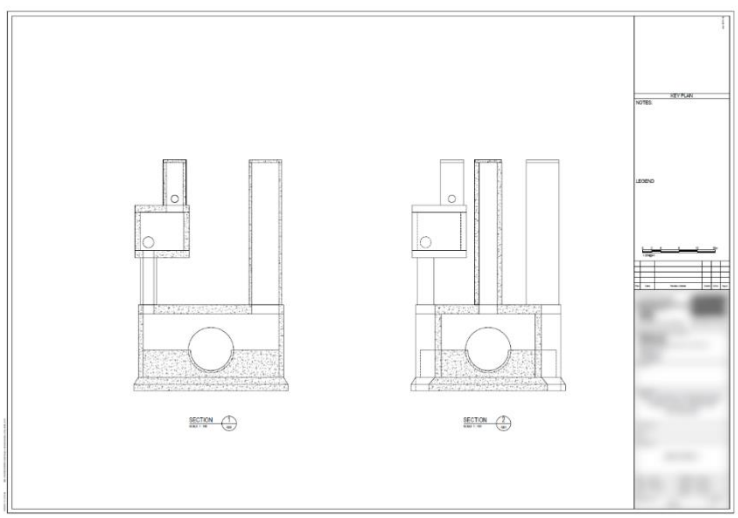


Figure 18. Revit Sheet with Sections

Creation of the structural analysis report

Required components of the structural analysis report are grouped using a Dynamo graph including the list of load cases, views of the different structural components with meshing, internal force colour map or required reinforcement heat maps.

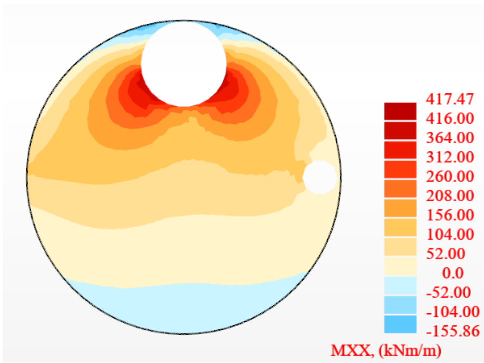


Figure 19. Mxx [kNm] results in Robot Structural Analysis

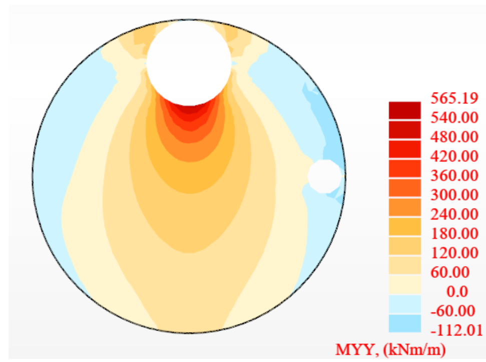


Figure 20. Myy [kNm] results in Robot Structural Analysis

MXX (kNm/m)	NXX (kN/m)	QXX (kN/m)
1176.64>>	-640.07	-8.23
-827.15<<	-758.07	695.34
-315.11	**-38.35>>**	-673.06
-276.93	**-988.14<<**	35.42
-818.75	-751.98	**720.09>>**
-552.46	-199.96	**-924.02<<**
MYY (kNm/m)	**QYY (kN/m)**	**tYY (kPa)**
1145.77>>	1.45	1.45
-903.48<<	-39.58	-39.58
-825.47	**943.73>>**	943.73
-861.09	**-756.70<<**	-756.70
-825.47	943.73	**943.73>>**
-861.09	-756.70	**-756.70<<**

Figure 21. Forces envelope table in Robot Structural Analysis

Common Data Environment

As already mentioned, all input data, models, Dynamo graph, and outputs are stored in a cloud-based Common Data Environment, in this case, Autodesk BIM 360, set up for the project helping to provide the same and latest up to date project data to all stakeholders, managing version control and change. This is considered essential when a significant amount of changes happen during the project as it can be used as a single source of truth for everyone reducing the risk of errors. Furthermore, the development of a focused workflow ensures full control at any stage of the project.

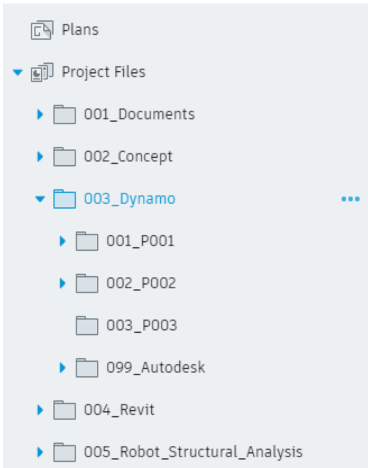


Figure 22. Project management on BIM360

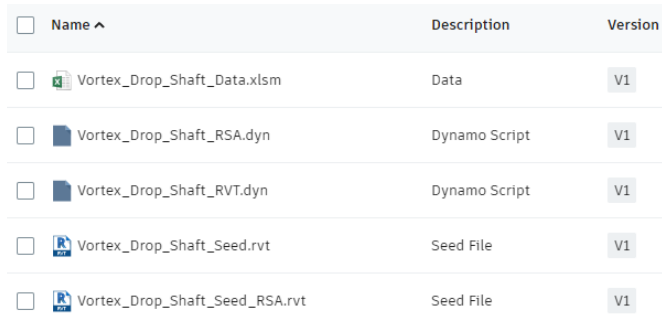


Figure 23. Project files on BIM360

Benefits

Automation of the design process in the presented workflow ensures that engineers can focus on the optimization of structure through the ease of editing and rerunning of scripts. As a result, the engineer is released from carrying out mundane tasks to track changes, edit base information, reproduce existing deliverables with minor changes and edits, and focus his attention on details and improvements.

Although the development of such workflows requires considerable time, focus and effort, the resulting the use of the workflows still reduces the overall level of effort required for project execution. The benefits are significant for major projects with many similar structures and less so if only a small number of structures are analysed.

Another important advantage is the higher quality of the engineering output and deliverables, the ability to eliminate errors, discrepancies and inaccuracies that may occur during manual modelling, leading to improved quality . The information is created in a format that allows for conversions for other deliverables that are not addressed in this workflow. Industry focus such as the IFC initiative from buildingSmart ensures that further potential can be unleashed via format compatibility in the future.

Conclusion

As mentioned above, the proposed solution has many advantages, but it should be assessed when its use is profitable. Based on the collected data on the valuation of the time of manual execution of complete construction models and the estimated time devoted to automatic modeling, taking into account the time for development or adaptation of the script for the current project, we achieve total tool efficiency with at least 4 structures (as shown in the figure below). However, the determining factor remains the number of changes made during the design process.

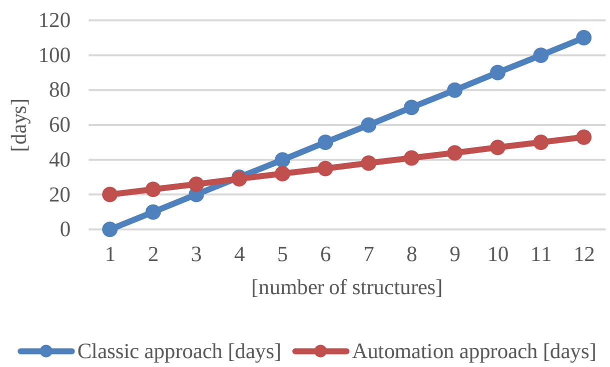


Figure 24. Implemented solution workflow efficiency

Furthermore, the workflow and programming development has allowed the engineers to understand efficient working methods application in even a manual approach. It highlighted that tools available on the market allow for efficiencies, notwithstanding whether they are used in a manual or automated approach, but that there is work to be done from the Engineer perspective to achieve complete Design, Engineering and Analysis as an Integrated solution.