# Real-time data and BIM: automated protocol for management and visualisation of data in real time

A case study in the "Teaching House" of the KTH campus.

## GIUSEPPE DIGREGORIO

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# Abstract

Nowadays BIM and real-time data are becoming a central topic for the AECO (Architecture, Engineering, Construction and Operations) industry, they represent new powerful tools for the design and management of facilities.

Building monitoring and real-time data can represent a solution to many important challenges like energy efficiency, indoor climate quality and cost management. Although it is clear the importance of data for a correct use of BIM technology and its potentiality, in literature, are not so common examples of complete workflows for a complete management of data from the input phase to the output one.

The scope of the study is to design a protocol for entering, managing and exporting real-time data using Revit and Dynamo where the customers have a central role during the input phase and a dedicated mode for data display including a desktop version and an augmented reality one for a more immersive experience.

In order to show the real potentiality of the project, the protocol has been utilised for the calculation of thermal comfort parameters of the "Teaching House" situated in KTH campus. All data entered from the students into a form online, via QR-code, have been inserted into Dynamo in order to calculate the desired parameters values which are successively stored into a database for further analysis, everything automatically.

**Keywords:  BIM, real-time data , visual programming, augmented reality, Dynamo, Python, Revit, data management, data visualization, thermal comfort**

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# 1 INTRODUCTION

In the last years computer science and data are becoming more and more important in Architecture, Engineering, Construction and Operations (AECO) industry, they represent new tools at the service of engineers in order to manage a great variety of problems linked with buildings and facilities.

In this scenario there is a new actor that is attracting the interest of AEC firms as well as governments of every country, BIM (Building Information Modelling) and although "his" role is central nowadays it presents different definitions.

BIM is a method based on the use of a parametric model which contains all the information regarding the design, the construction and the operation of a building or facility.

According to Autodesk BIM is a process that involves creating and using an intelligent 3D model to inform and communicate project decisions. Design, visualisation, simulation and collaboration enabled by BIM solutions provide greater clarity for all stakeholders across the project lifecycle. BIM makes it easier to achieve project and business goals[1].

BIM is used to facilitate a more integrated design and construction process that leads to reductions in cost and project duration (Eastman et al, 2008) and is now beginning to have a major impact and more visibility.

According to Barnes there is a convention to categorise BIM under various 'levels', described as follows.

- **Level 0.** This level relates to unmanaged CAD in 2D.
- **Level 1.** This level represents the first step towards genuine BIM and the use of 3D data to present design.
- **Level 2.** This level is a managed 3D format held in separate BIM discipline software tools with data attached. This level of BIM may introduce the first step to utilising other digital add-ons, such as 4D for construction time and sequencing data and/or 5D for cost information.
- **Level 3.** This level of BIM is capable of utilising 4D construction time and sequencing, 5D cost information, 6D project life-cycle information, together with other dimensions for other management information or functions.

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[1] Designing and building better with BIM: https://www.autodesk.com/solutions/bim

The use of this approach does not only determine a reduction of time and money for the design and the management of buildings but it is also fundamental for cutting the carbon footprint of buildings and facilities.

This topic is very important for the European Union, according to the European Directive 2010/31/EU on the energy performance of building which promotes the improvement of the energy performance of buildings within the Union and requires all new buildings to be nearly zero-energy by the end of 2020[2].

"Technology has played a large part in the rise of data availability and use, including increased computer power, enabling the ability to crunch large quantities of data and provide higher-resolution communications, access to the cloud, and less expensive storage options." (Deutsch, 2015).

As a result of the development of internet and cloud databases as well as the decreasing cost of sensors nowadays it is possible to have access to a large quantity of available data in a very simple way.

Thanks to real time data and to a correct way to visualize them inside the model is possible immediately to develop successful management strategies.

In order to manage in a correct way the building in terms of consumption and comfort along all its life-cycle it is fundamental to not use BIM only as a "static" information source.

Actually it is possible to use, in different ways, real time data from sensors or from database in order to make BIM "dynamic".

A "dynamic" BIM represents a very powerful tool for the management of the facility, able to give real time feedback and advice.

An example of a "dynamic" BIM framework that is enriched with real time information is given by Chen at all (2014), performing an experiment involving a bridge deck and 6 rows of temperature sensors.

The research describe a prototype for embedding real time information to a BIM using Revit's .NET API (Application Programming Interface)

Wehbe and Shahrour have been studying the applications of BIM and smart monitoring inthe indoor comfort field. The methodology followed connect together sensors, Arduino, Dynamo and Revit in order to have the possibility to control in real time the comfort parameters and compare the values with the standards.

A very interesting application has been shown by Kensek (2014) the feasibility of connecting environmental sensors such as light or humidity receptors to a building information model.The base case has been created in Rhino and using Grasshopper and Firefly, has been developed a

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[2] EUCommission:https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings

digital model linked with lightning-levels detected by a photoresistor on an Arduino board. All the process has been replicated using Revit and Dynamo.

In this case study has been shown that not only is possible to send data from sensors in order to change the 3D model but also parameter's changes of the 3D model could affect the real building thanks to actuators that can be used to control mechanisms or systems.

The remarkable possibility, highlighted by this case study, to develop intelligent buildings which are aware of the environmental input and able to respond to them such as smart facades buildings.

In light of what said above is possible to assure that BIM is changing the AECO industry, showing a wide range of important application that can improve the way we design buildings in order to decrease cost, consumption and construction time.

The study is focused mainly on real time data and how they can be used for improving the inhabitants' everyday life. Although the real time data can be used in several cases the attention has been focused on indoor thermal comfort in order to give a practical example of how they can be used as support tools.The data provided by users are collected and elaborated in order to have analysis parameters able to help the final user during his decision process. The project is focused on final users, this means that all the process needs to be understandable also for people without engineering skills and knowledge, especially the input and the output part.

In the effort to give people a central role, it was decided to  provide the possibility to insert data in the model  Nonetheless a simple and intuitive visualization of the output is fundamental for giving people the possibility of interacting with the model and let it help them during the decision process. For this reason, in addition to a storage protocol for the output values, it was decided to use a cubic virtual element, called Totem, whose properties are the thermal comfort parameters and whose colour, green or red, is related to an acceptable or not value of PPD according to European standards. The colour code visualization allows the final user to see immediately if the standard is satisfied or not in order to help him or her during the decision process. The visualization of the building's model and the Totem takes place through Unity Reflect Viewer, via two different versions, on desktop or on iOS using the app for mobile device which allow also to visualize the model in Augmented Reality (AR), in this way people don't need to buy the Revit license and all the process is completely free for them.

## 1.1 Background

Emerging computational technologies are redefining the AEC industry and providing new powerful tools for the design and management of facilities.

Building monitoring and real-time data can represent a solution to many important challenges like energy efficiency, indoor climate quality and cost management, for instance.

The buildings' energy efficiency is one of the most relevant and strategic issues that has been debated in Europe during the last years. According to Eurostat the final energy consumption for households, considering the 28 EU states, from 1990 to 2017 increased from 26,5% to 27,2%[3] , this data demonstrates that housing has a great impact on the environment and the scientific community has the moral responsibility and the tools to solve the problem.

Improving the buildings' energy performance is an aspect of fundamental importance, not only for the achievement of the objectives set for 2020 by the EU, but also for the achievement of the longer-term objectives of our climate strategy in the context of the roadmap to a low carbon economy by 2050. The EU has promoted programs, projects and directives, such as 2002/91/EC and 2010/31/EU on the energy performance of buildings, 2006/32/EC on energy services and 2012/27/EU on energy efficiency, in order to increase the efficiency of new and existing buildings.

BIM has a great role in this quest, the renovation of the all design process is seen by the EU as a fundamental part to achieve the final result. As demonstrated by Guo at Wei (2016), BIM technology was proven capable of developing a highly accurate simulation platform for the energy consumption of buildings in order to find the design alternative that can determine the maximum reduction of expenses.

Nonetheless Indoor Environmental Quality (IEQ) is fundamental for health and according to the World Health Organization it is associated with DNA strand breaks, eye irritation, asthma, sick-building syndrome among others.

BIM and real time data can have a central role in the fight against all this problem that affects our buildings and lead a design revolution that can change the way we think about the design and management process.

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[3] Europe 2020 indicators – climate change and energy :
https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Europe_2020_indicators_climate_change_and_energy

## 1.2 **Aim and Scope**

"It's not only about the technology and tools: people make a difference" (Deutsch, 2015).

Conceptually the aim of this project is to introduce people without engineering skills to BIM and help them understand all the benefits linked with the use of this methodology, the achievement of the objectives has not been a simple quest because of the complexity of the topics covered and the various fields considered.

People need to be aware of this design revolution, not only engineers and computer scientists but also the ones without knowledge in this field in order to help them understand the potentialities of this technology.

The most critical parts are the input and the output ones, these sections have been designed for the final users and need to be simple and clear in order to involve people in using this technology and decrease the possibility of human mistakes.

In order to make people part of the protocol they have the responsibility to put data inside the model by filling an online form, the data are processed and used to calculate thermal comfort parameters which can be visualised inside a 3D or an AR (augmented reality) model of the analysed building.

A central part of the project is to allow people to view the results, this means that it is necessary to show them in a simple and direct way, using a code colour as well as numbers for an in-depth analysis.

The scope of the study is to create a protocol to allow users to:

- insert real-time data inside the model using only a QR-code and an online form;

- elaborate data and calculate engineering parameters of interest that can help buildings' designers and tenants during the decision making process;

- visualise data and parameters in a simple way for to simplify the understanding of non-experts;

- collect data and parameters for possible following studies and for the validation of models.

A protocol elaborated in this way represents a complete workflow for the management and implementation of real-data and BIM that covers all stages of the process from the input data to the export and visualization of the output.

## 1.3 **Outline**

The first chapter is a general introduction to the degree project and its purposes, moreover across the various sections, attempts have been made to explain how important are the topics covered, to shed light on the European and Italian regulations and to define the case study. Section 1.4 is fundamental to better understand the current legislation concerning BIM and to show all the AECO industry workers that this is a "revolution" that cannot be postponed.

The aim of the second chapter is to give the reader analytical tools and knowledge in order to  completely understand how the software used works and interact with each other and comprehend the results achieved. Without an overview of the tools used would be hard for the reader to understand how the final result has been achieved.

The first section of the third chapter deals with the input data inserted into the model and explains the whole protocol including the idea behind the form, how the data is sent from the form to Dynamo and how it is managed and stored into the Revit model.

The second part of the chapter displays a practical example of how this protocol can be used in order to face a wide range of problems in buildings and facilities such as thermal indoor comfort. After providing the theoretical background concerning the topic, the limits of the analysis have been displayed and how PMV and PPD have been calculated.

The fourth chapter shows the results achieved and is divided in three paragraphs, the first one deals with the setting of the parameters' values in Revit after the performed calculations, the second one show how the final user can visualize the data in Revit but also with Unity Reflect and the third one explain how is possible export data to Excel for possible future analysis.

The fifth chapter analyses the results achieved in the previous chapter, checking if they are in line with the original purpose, the limits of the research and its implications in order to understand the real value of the research. The purpose of the final part of the chapter offers and analyses possible applications for the protocol in addition to the example considered for the project.

# 1.4 **BIM Regulation**

Taking into account the enormous benefit that the adoption of BIM brings in terms of reduced cost, time and efficiency, it is just a matter of time when BIM techniques will completely replace the traditional methods of construction.

BIM implementation in Europe is making good progress in the last years thanks to the interest shown by academics, companies and governmental institutions.

"There are several targets, mandates and national strategies here to influence professionals so that they shift towards digitalization in the industry and have a common language of BIM. Europe understands that collaboration across borders and standardizing common practices is the key to success and the government is playing a good role in it[4]".



*Figure 1: Overview of Global BIM adoption (McAuley et all 2017)*

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[4] BIM adoption around the world:
https://www.geospatialworld.net/article/bim-adoption-around-the-world-how-good-are-we/

In 2016 an important first step for BIM in European standardization was done in this process towards the adoption of BIM with the adoption of three European Standards.

This was a result of the work by the European Committee (CEN/TC 442) who were set up in 2015 to develop a structured set of BIM standards. CEN/TC 442 have developed three international standards[5]:

- EN ISO 16739:2016 - Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries.
- EN ISO 29481-2:2016 - Building information models - Information delivery manual - Part 2: Interaction framework.
- EN ISO 12006-3:2016 - Building construction - Organization of information about construction works - Part 3: Framework for object-oriented information.

The Scandinavian countries are one of the earliest adopters of BIM technologies with public standards and requirements already in place.

Sweden is only behind the US in the publication of academic papers focusing on BIM and now, the government is also taking initiatives to facilitate nation-wide implementation and public organizations, like the Swedish Transport Administration, have mandated the use of BIM from 2015.

In Italy the rules and the deadlines for the integration of BIM in public procurement are provided by the DM560/2017.

The DM 560/2017 is articulated in nine articles dealing with all the aspects linked with the adoption of BIM from purpose to interoperability and monitoring commission.

The decree provides deadlines for the gradual introduction of the obligation to adopt BIM in public procurement.

The art.6 of the decree defines the time limits of the obligation of BIM in contracts:

- from **1 January 2019** for complex works relating to works for a tender amount equal to or greater than 100 million euros;
- from **1 January 2020** for complex works relating to works for a tender amount equal to or greater than 50 million euros;
- from **1 January 2021** for complex works relating to works for a tender amount equal to or greater than 15 million euro;
- from **1 January 2022** for works with a tender amount equal to or greater than the threshold referred to in Article 35 of the Public Contracts Code;
- from **1 January 2023** for complex works relating to works for a tender amount equal to or greater than 1 million euro;
- from **January 2025** all public works will have to be contracted in BIM mode.

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[5] BICP Global BIM Study - Lessons for Ireland's BIM Programme

The aim of all these efforts is to not fall behind in this race to the future and drive all the AEC industry's actors along this way of important changes.

## 1.5 **Study Case**

The case study is the 'Undervisningshuset' (The Teaching House) situated at Brinellvägen 28a in KTH campus and  inaugurated on Monday 16 October 2017 as part of the celebration of 100t anniversary of the campus.

Undervisningshuset is an example of adaptable building characterized by different types of spaces in order to satisfy all the needs of the students, from classroom for lessons to group rooms and individual study places.

According to ABE school "the idea behind this house is unique. The idea of sustainability and the willingness to be able to use the building in a concrete manner have permeated the project[6]".



*Figure 2: Undervisningshuset, KTH Royal Institute of Technology, Stockholm (Christensen & Co Arkitekter, 2018)*

[6] Teaching House:
https://intra.kth.se/abe/utbildning-pa-grundn/filmen-om-undervisningshuset-1.846376

Undervisningshuset has been designed as a place able to satisfy all students' needs, where they can spend all the day attending lessons and studying.

The control of the indoor comfort parameters is fundamental if we want to create a welcoming place for the students in order to not to affect their productivity and health.

# 2 Tools employed

*This chapter shows and analyses the tools used for the development of the project necessary for a complete comprehension of the entire protocol, the study made necessitated a wide range of knowledge and skills from different fields of study as architecture, engineering and computer science.*

*Nowadays it is not possible anymore to ignore the importance and the utility of computer science, and also engineers with a civil and structural background need to know how to code and face this challenge in order to develop independent solutions for their problems.*

*Although combining concepts from this different discipline can be complicated with the "BIM and Data revolution" it will be necessary to keep up with technological development so as to be able to really improve people every-day life.*

## 2.1 Python

According to the developers "Python is an interpreted, object-oriented, high-level programming language with dynamic semantics. Its high-level built in data structures, combined with dynamic typing and dynamic binding, make it very attractive for Rapid Application Development, as well as for use as a scripting or glue language to connect existing components together"[7].

One of its greatest strengths is its large standard library which provides tools suited to many tasks, including modules for creating graphical user interfaces or connecting to relational databases.

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[7] What is Python? Executive Summary: https://www.python.org/doc/essays/blurb/

The module *math* has been fundamental for the calculation of the thermal comfort parameters, this module provides access to numerous mathematical functions necessary for future calculations[8].

In programming, a function is a set of instructions that performs a calculation, to which a name is assigned. To define a function, is necessary to specify its name and write the set of instructions, once the function has been defined it is possible "to call" the function using the assigned name

Nowadays Python is one of the most popular and used programming languages surpassing C, C++, Java and JavaScript although it is slower than the other languages.

With the aim to show how the popularity of Python increased during the last ten years is interesting to see in Stack Overflow trends the count of tags in posts on the platform concerning different programming languages, given the size of the web site the trends represent a good indicator for language popularity.
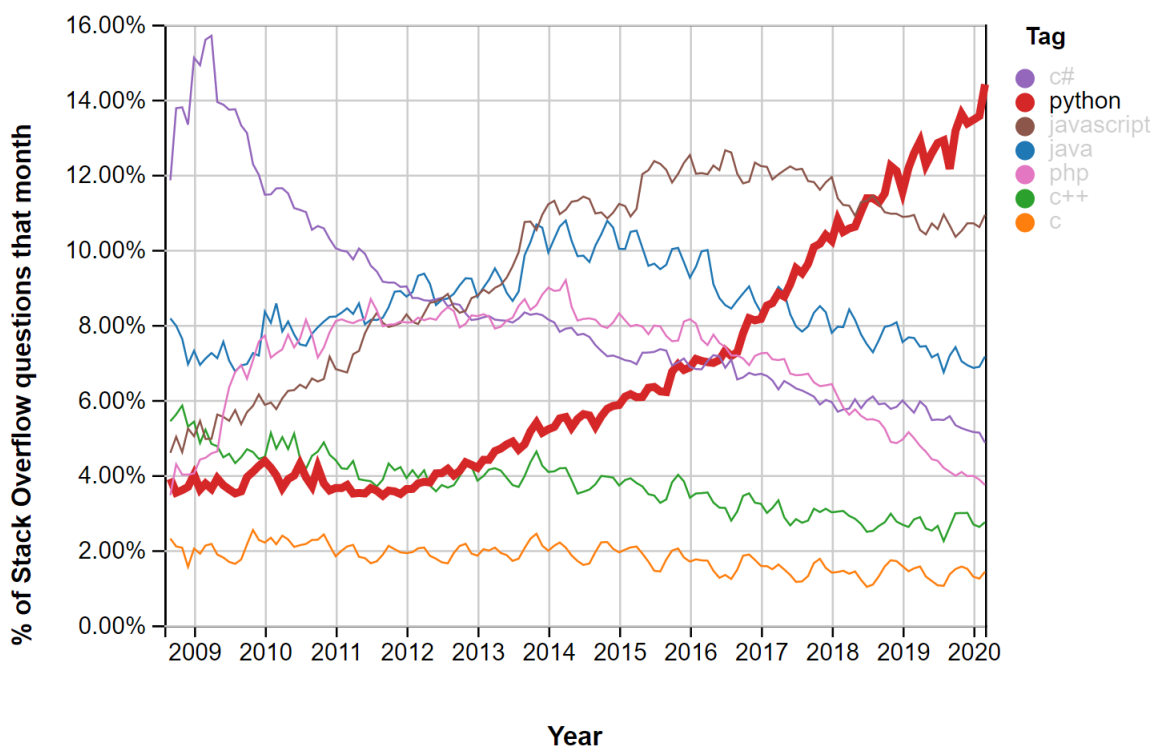


*Figure 1: percentage of tags on various programming languages on StackOverflow*

The main reasons behind Python's success are:

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[8] math — Mathematical functions: https://docs.python.org/3/library/math.html

- **Beginner-friendly**: there's no need to specify the data type, when a variable is declared Python is able to understand if it is an integer, a float value or a Boolean thanks to the context and this for a beginner is a huge help. Moreover the great number of very clear tutorials, books and articles represents a fundamental tool during the first steps with a new language.
- **Versatile**: is possible to find packages for every scope and concerning every field. The Python Package Index (PyPI), the official repository for third party Python software, contains over 200,000 packages for different functionalities such as data analytics, databases, machine learning, scientific computing and automation.
- **Community**: Python has been first released in 1991, this means that it has had plenty of time to grow and develop a supportive and proactive community of users and developers. This means that the majority of the problems encountered have been yet solved or at least dealt with.

All these factors have been very helpful during the development of the project although the decision of using Python as a programming language came down to the Python node in Dynamo.

Indeed the Python script in the Dynamo's Python node for the calculation of PMV and PPD has not been completely developed by me but derives from a package to calculate several thermal comfort indices (e.g. PMV, PPD, SET, adaptive) and convert physical variables[9] called *pythermalcomfort* developed by Tartarini F., Schiavon S., Hoyt T., and Mackey C. with the MIT license[10].

The script used for the calculation of PMV and PPD is inspired by the function:

```python
def pmv_ppd(tdb, tr, vr, rh, met, clo, wme=0, standard='ISO', units='SI'):
```

belonging to *pythermalcomfort* pack but has been manipulated in order to prevent problems linked with the call of other functions belonging to the package during the processing of the *"pmv_ppd"* function.

In order to fix this problem it has been necessary to remove the possibility of choosing the standard considered between ISO and ASHRAE and the units between the International System of Units and the Imperial Units.

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[9] https://pythermalcomfort.readthedocs.io/en/latest/readme.html

[10] https://pythermalcomfort.readthedocs.io/en/latest/authors.html

## 2.2 **Software Used**

### 2.2.1 **Revit**

According to Autodesk, **Revit** BIM is a software for architectural design, MEP, structural design, detailing, engineering, and construction[11].

More precisely "Revit is a design and documentation platform that supports the design, drawings, and schedules required for building information modelling (BIM). BIM delivers information about project design, scope, quantities, and phases when you need it"[12].

Revit uses 3 types of elements in projects: model elements, datum elements, and view-specific elements. Elements in Revit are also referred to as families and each family contains the geometric definition of the element and the parameters used by the element. Each instance of an element is defined and controlled by the family.

There are two types of properties that control the appearance and behaviour of the elements of the model: type properties and instance properties.

"The same set of type properties is common to all elements in a family, and each property has the same value for all instances of a particular family type"[13].

All the elements of a particular family type are characterized by a shared set of instance properties but the values of these properties are not necessarily the same for each element and changing the value of an instance property affects only the elements selected.

Moreover it is possible to create new instance parameters or type parameters for any family type in order to control and manage all the information in the model.

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[11] Autodesk: https://www.autodesk.com/products/revit/overview

[12] About Revit: https://knowledge.autodesk.com/support/revit-products/getting-started

[13] About Element Properties: https://knowledge.autodesk.com/support/revit-products/getting-started

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The visualization and management of data and properties in Revit can be performed thanks to schedules, it is possible to create and use tabular display of model information extracted from the properties tab or export the data using different types of database such as Excel or Microsoft SQL Server.

Revit supports a multidiscipline design process for collaborative design and can be very helpful not only during the design phase but also during the construction and management process.

The software has features for all disciplines involved in a building project so everyone can use the same software, connecting participants in the building design and construction process. When architects, engineers, and construction professionals work on one unified platform, the risk of data translation errors can be reduced and the design process can be more predictable.

More precisely the design method that enables different team members to work at the same project simultaneously is called "*worksharing*", Revit projects can be subdivided into worksets and every team member works on a local model linked with the central model.
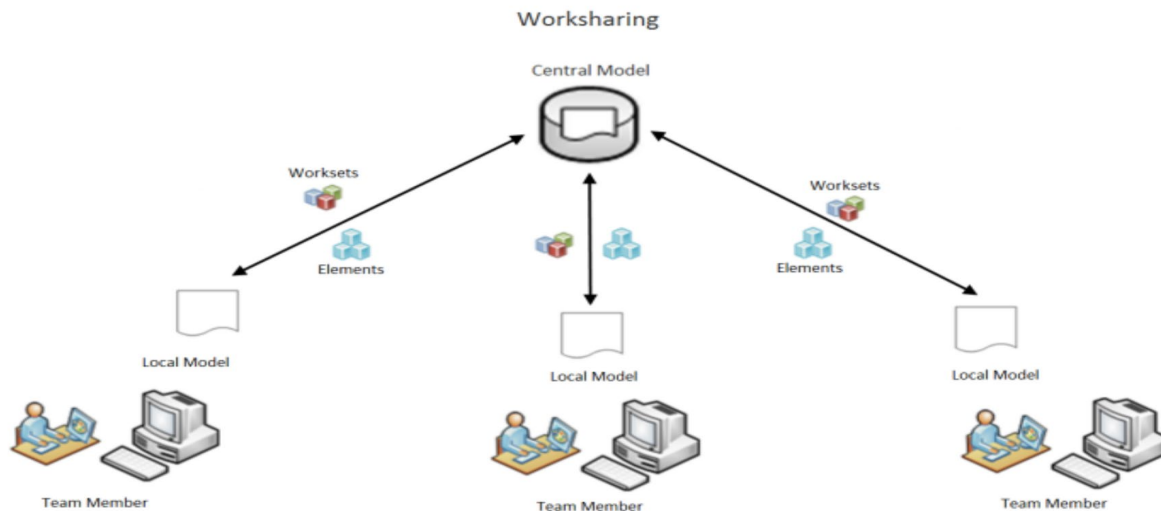


Figure 2: *Worksharing in Revit (Autodesk)*

With the aim to facilitate interoperability between all the actors of the AEC industry has been developed the Industry Foundation Classes (IFC) data model in order to describe architectural, building and construction industry data, which is an international open standard, developed and maintained by buildingSmart international.

"IFC is a standardized open-source file format that is optimized for building information modelling. This means that all the software vendors have equal access to specifications and can create the necessary import and export technology ( Vectorworks Architect,2017)".

Revit provides fully certified IFC import and export based on buildingSMART® IFC data exchange standards.

According to Autodesk for import Revit supports IFC files based on the following buildingSMART International (bSI) data exchange standards: IFC2x3, IFC2x2, IFC2x and IFC4 while for export Revit supports the following standards: IFC4, IFC2x3, and IFC2x2[14].

When a Revit building information model is exported to IFC format the data can be used directly by other members of the team or by specialists in other discipline such as structural and energy engineers in order to use software of their choice that best fit their analysis needs creating at the same time a model that can be shared and effectively used throughout the BIM process.

"In the Revit model, every drawing sheet, 2D and 3D view, and schedule is a presentation of information from the same virtual building model. As you work on the building model, Revit collects information about the building project and coordinates this information across all other representations of the project. The Revit parametric change engine automatically coordinates changes made anywhere in model views, drawing sheets, schedules, sections, and plans"[15].

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[14]AboutRevitandIFC:
https://knowledge.autodesk.com/support/revit-products/learn-explore/caas/CloudHelp/cloudhelp/2021/ENU/Revit-DocumentPresent/files/GUID-6708CFD6-0AD7-461F-ADE8-6527423EC895-htm.html

[15]About Revit:
https://knowledge.autodesk.com/support/revit-products/getting-started/caas/CloudHelp/cloudhelp/2021/ENU/Revit-GetStarted
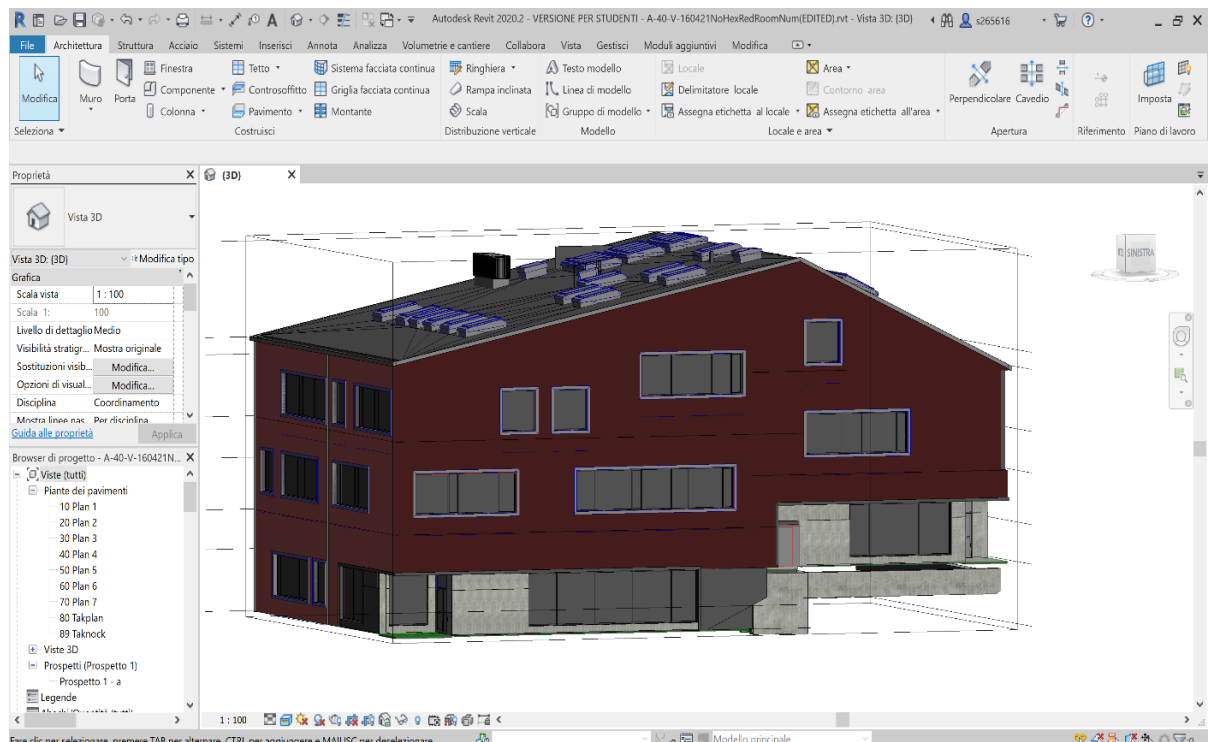
*Figure 3: 3D view of Undervisningshuse's Revit model*

Thanks to the API access is possible to improve the potentiality of Revit using add-ins that can make our design experience more simple and intuitive.

An *application programming interface* (API) is a software to software interface that defines the contract for applications to talk to each other over a network without user interaction.

A very important factor to take into consideration is that the Revit .NET API allows users to program with any .NET compliant language and the software house offers an API designed to allow developers to integrate their applications with Autodesk Revit.

According with Autodesk is possible to use the Revit Platform API for :

- Creating add-ins and macros to automate repetitive tasks in the Autodesk Revit user interface;

- Enforcing project design standards by checking for errors automatically;

- Extracting project data for analysis and to generate reports;

- Importing external data to create new elements or parameter values;

- Integrating other applications, including analysis applications, into Autodesk Revit products;

- Creating Autodesk Revit project documentation automatically;

The possibility to extend Revit functionality with API access and add-ins has been fundamental for the development of the project especially for the management of the information with Dynamo and for the visualization of the data with Unity Reflect.

## 2.2.2 Dynamo

"Dynamo is a visual programming tool that works with Revit. Dynamo extends the power of Revit by providing access to the Revit API (Application Programming Interface) in a more accessible manner"[16].

In visual programming the relationships and instructions of a program are defined through a graphical user interface instead of writing out a repeatable set of instructions with a programming language such as JavaScript, Python, or C.

The main elements of Dynamo's visual programming are the nodes contained into the Dynamo library and the wires.

- **NODES**

   Whit Dynamo is possible to create programs using graphic elements called "nodes" instead of typing codes, every node needs an input and returns an output and can be linked with other nodes thanks to wires in order to perform specific tasks.

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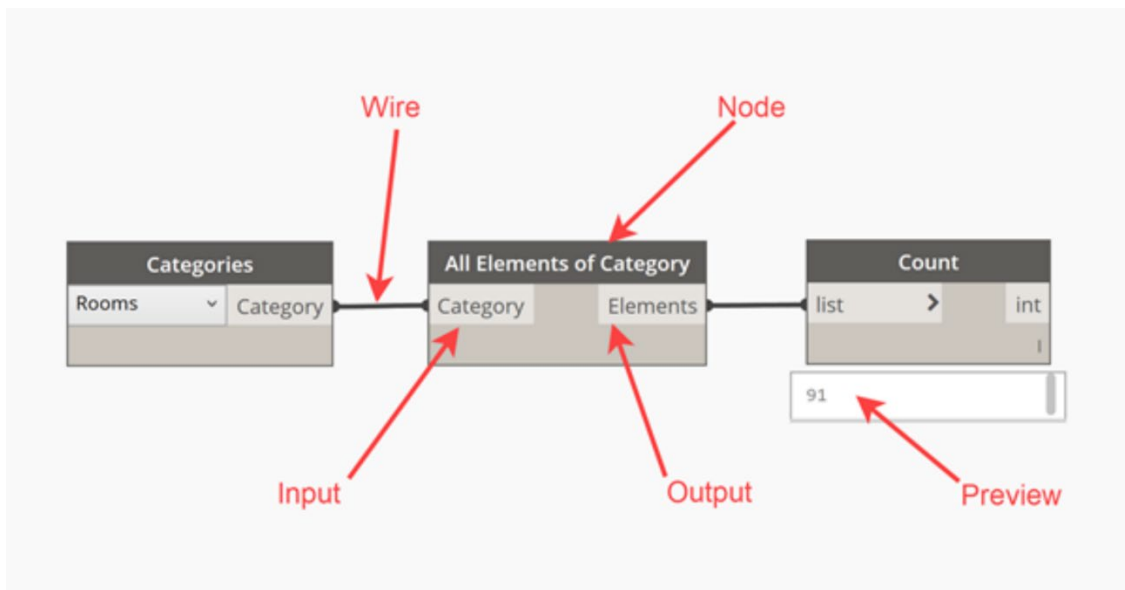[16] https://archsmarter.com/what-is-dynamo-revit/

*Figure 4: Example of Dynamo's connections between node (archsmaster.com)*

Not considering some exceptions the majority of the nodes in Dynamo consists in 5 parts[17]:

1. Name - The Name of the Node with a Category.Name naming convention;
2. Main - The main body of the Node - Right-clicking here presents options at the level of the whole Node;
3. Ports (In and Out) - The receptors for Wires that supply the input data to the Node as well as the results of the Node's action
4. Lacing Icon - Indicates the Lacing option specified for matching list inputs (more on that later);
5. Default Value - Right-click on an input Port - some Nodes have default values that can be used or not used.

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[17] Nodes: https://primer.dynamobim.org/03_Anatomy-of-a-Dynamo-Definition/3-1_dynamo_nodes.html
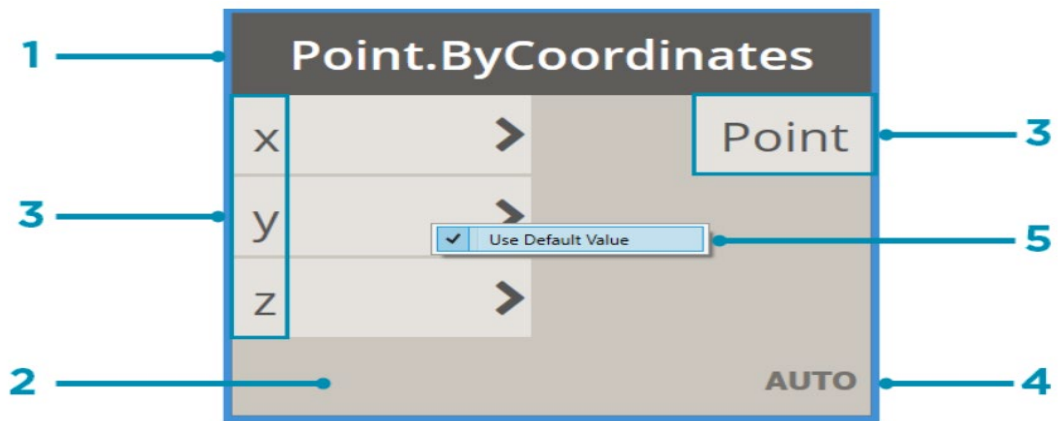
*Figure 5 Example of Dynamo's node (primer.dynamobim.org)*

In Dynamo each node performs a specific task connecting the outputs from one node to inputs on another one using wires creating a chart flow along all the nodes used which represents the steps required to achieve a particular task.
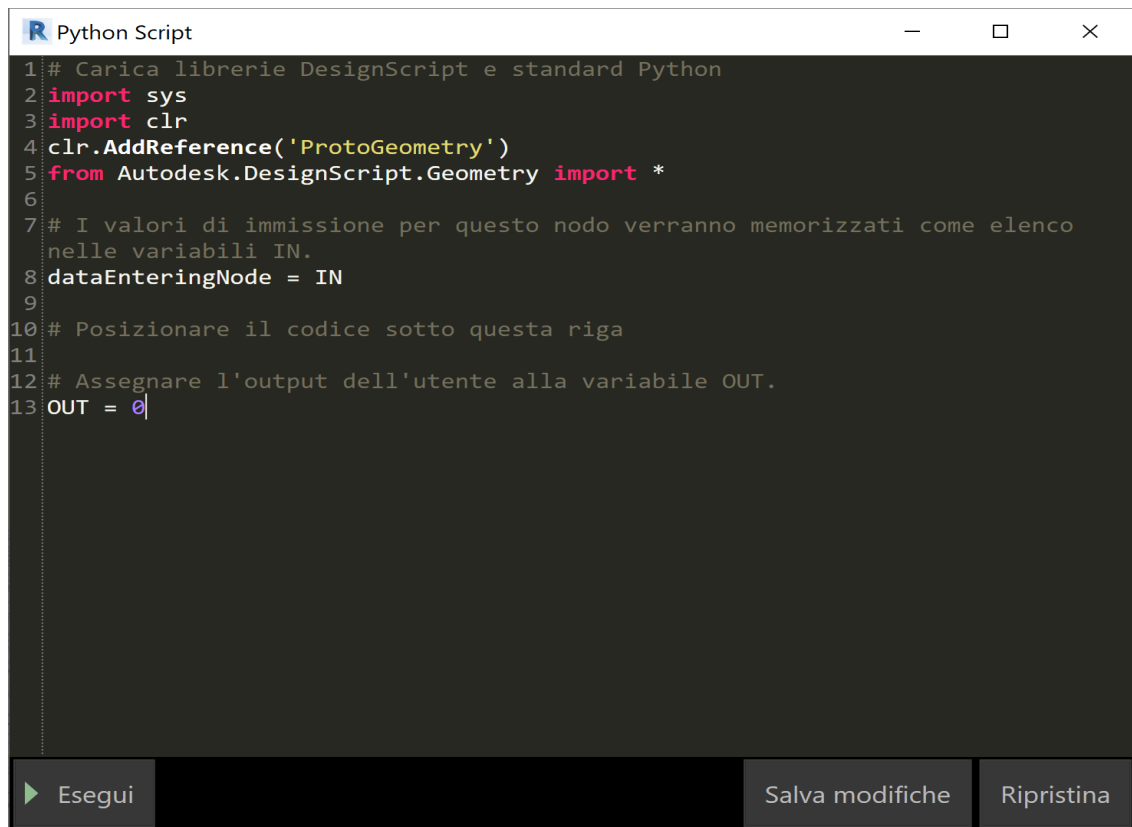
Dynamo users can also create their own nodes in order to make the graph cleaner and more organized that can be reused in other projects and they can share it with the global Dynamo community.

Conceptually a "Dynamo Custom Node" is a container in which it is possible to embed other nodes in order to carry out a wide range of tasks.

Another very interesting node available in Dynamo is the "Python Node" which is a scripting interface within a visual programming environment[18] used, in the project for the calculation and the management of the thermal comfort parameter.

The Python Node can be used for creating a node that faces a specific task when the given node cannot make Dynamo even more versatile and able to handle different types of problems.

---

[18] Python Nodes: https://primer.dynamobim.org/10_Custom-Nodes/10-4_Python.html

```
R Python Script                                          —   □   ×
 1 # Carica librerie DesignScript e standard Python
 2 import sys
 3 import clr
 4 clr.AddReference('ProtoGeometry')
 5 from Autodesk.DesignScript.Geometry import *
 6
 7 # I valori di immissione per questo nodo verranno memorizzati come elenco
   nelle variabili IN.
 8 dataEnteringNode = IN
 9
10 # Posizionare il codice sotto questa riga
11
12 # Assegnare l'output dell'utente alla variabile OUT.
13 OUT = 0

  ▶ Esegui                          Salva modifiche     Ripristina
```

Figure 6: *Python Node'S window*

- **WIRES**

  "Wires connect between Nodes to create relationships and establish the Flow of our Visual Program. We can think of them literally as electrical wires that carry pulses of data from one object to the next"[19].
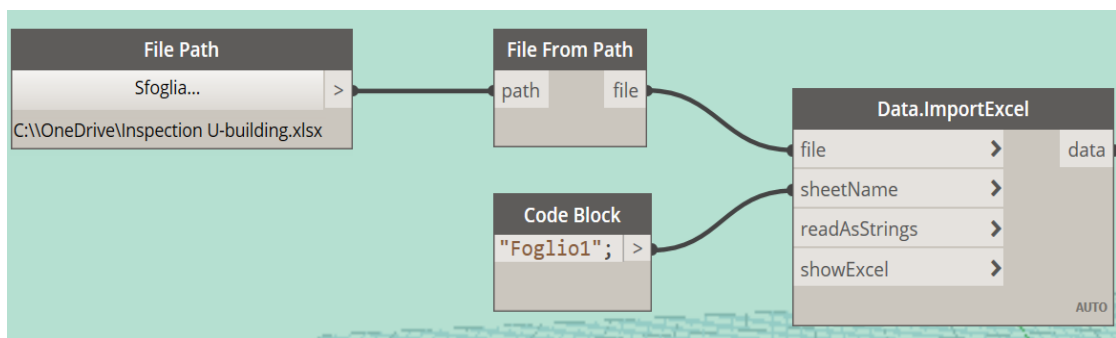


*Figure 7: Example of how wires are used to connect nodes.*

- **LIBRARY**

---

[19] Wires: https://primer.dynamobim.org/03_Anatomy-of-a-Dynamo-Definition/3-2_wiring_programs.html

"The Dynamo Library contains the Nodes we add to the Workspace to define Visual Programs for execution. In the Library, we can search for or browse to Nodes. The Nodes contained here - the basic Nodes installed, Custom Nodes we define, and Nodes from the Package Manager that we add to Dynamo - are organized hierarchically by category"[20].
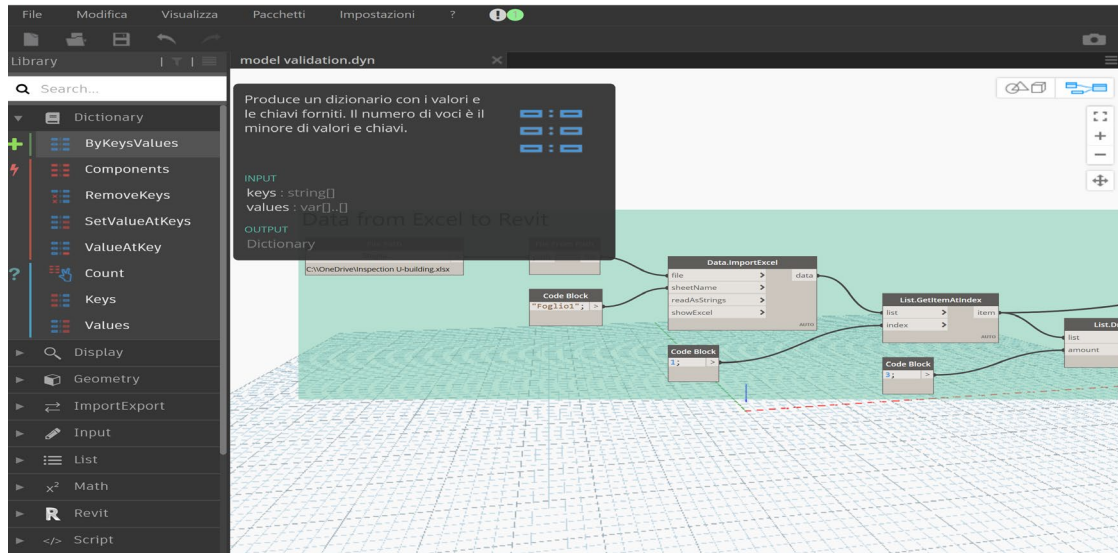


*Figure 8: Library in Dynamo's interface*

The library can be improved using Dynamo Packages from third party developers as Dynamo Sap, a parametric interface for SAP200 or Bumblebee which is an Excel and Dynamo interoperability plugin that vastly improves Dynamo's ability to read and write Excel files.

A Package is a collection of Custom Nodes that can be downloaded from the Dynamo Package Manager, a public online portal where developers can publish their Packages and users can download them according to their needs.

Dynamo is a powerful tool that can help Revit users in an impressive number of situations, from the access to building data to the simulation of building performances.

For the development of this project, Dynamo has been fundamental for its capacity of import, export and manage data.

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[20] DynamoLibrary:https://primer.dynamobim.org/03_Anatomy-of-a-Dynamo-Definition/3-3_dynamo_librar-ies.html

Dynamo allows us to import and export data to different platforms such as Access, Excel, Microsoft SQL Server using standard nodes or packages as Bumblebee and in different formats like XML, Json, HTML, etc [21] .
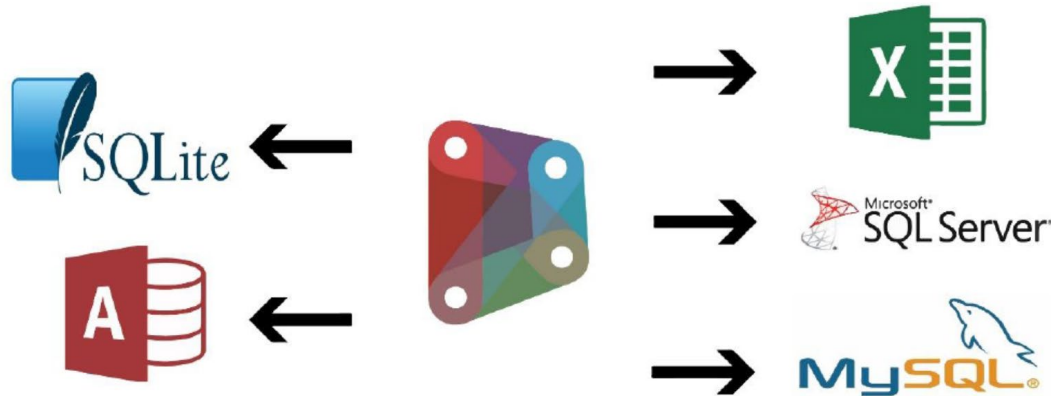


*Figure 9: Example of Database that can be used with Dynamo (Autodesk University)*
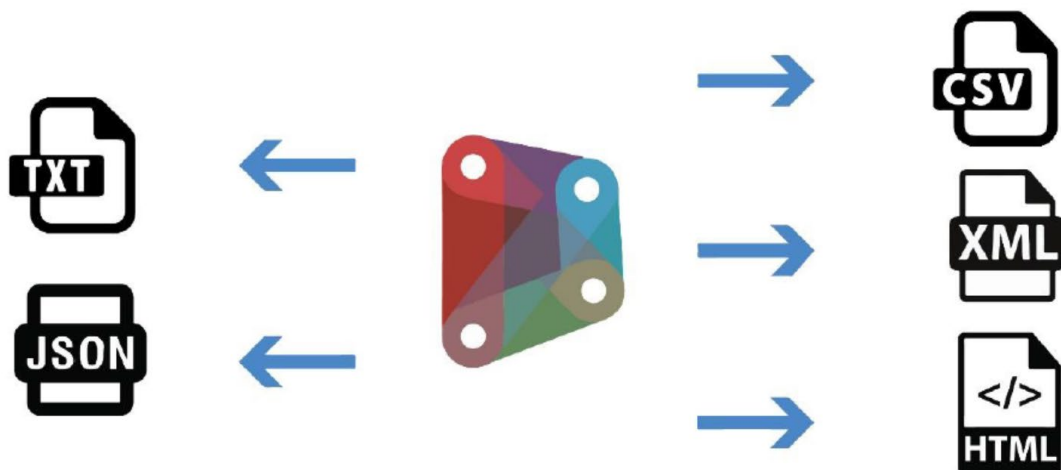


*Figure 10: possible data formats exported with Dynamo*

For the development of the project has been used Excel which is a simple tool that presents all the features needed for the administration of the data involved, moreover the software is well

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[21] Turn Revit Data into Useful Information with Visualization Techniques and Workflows: https://medium.com/autodesk-university/turn-revit-data-into-useful-information-with-visualization-techniques-and-workflows-a644bd2172d3

known to almost everybody, is installed in nearly all the computer and it interfaces very well with Dynamo and Revit.

## 2.2.3 **Unity Reflect**

According to the software house, Unity Reflect is a software to transfer BIM data into real-time experiences on a range of devices and in AR and VR[22].

Thanks to Reflect is possible to develop a real-time 3D model of Revit multiple models, but also of SketchUp or Rhino, keeping all the metadata and maintaining a live link between them, with the possibility to use Unity Pro as editor in order to customize and animate the user experience.

The BIM data is stored on a computer that runs Unity Reflect or on a network server while a cloud-hosted project management server stores project names and permissions in order to determine which access users have access to.

Unity Reflect is very helpful also for work-sharing because different team members, such as architects, structural, mechanical, electrical and plumbing engineers can work simultaneously on the same project and visualize in real-time the changes made by the project members.
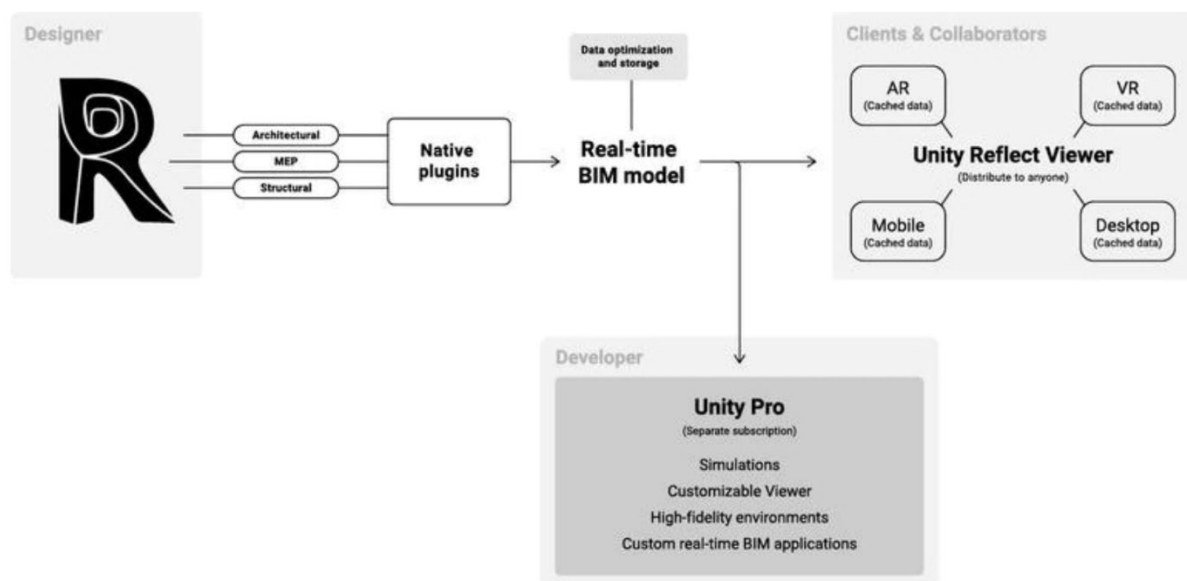


*Figure 11: Unity Reflect workflow*

---

The application provides access to the source code, in this way is possible to customize the GUI (Graphical User Interface) or create a more complex experience linked with the visualization and the simulation of data but this requires Unity Pro as editor.

The strength of Unity Reflect compared to other 3D software as BIMx or is the possibility to see in real time all the changes made and this is fundamental for the purpose of the study.

Once installed the add-in is possible to synchronize the model with Reflect Unity defining the Host Sync Server and the name of the project in order to share it with the chosen team members and the customers.
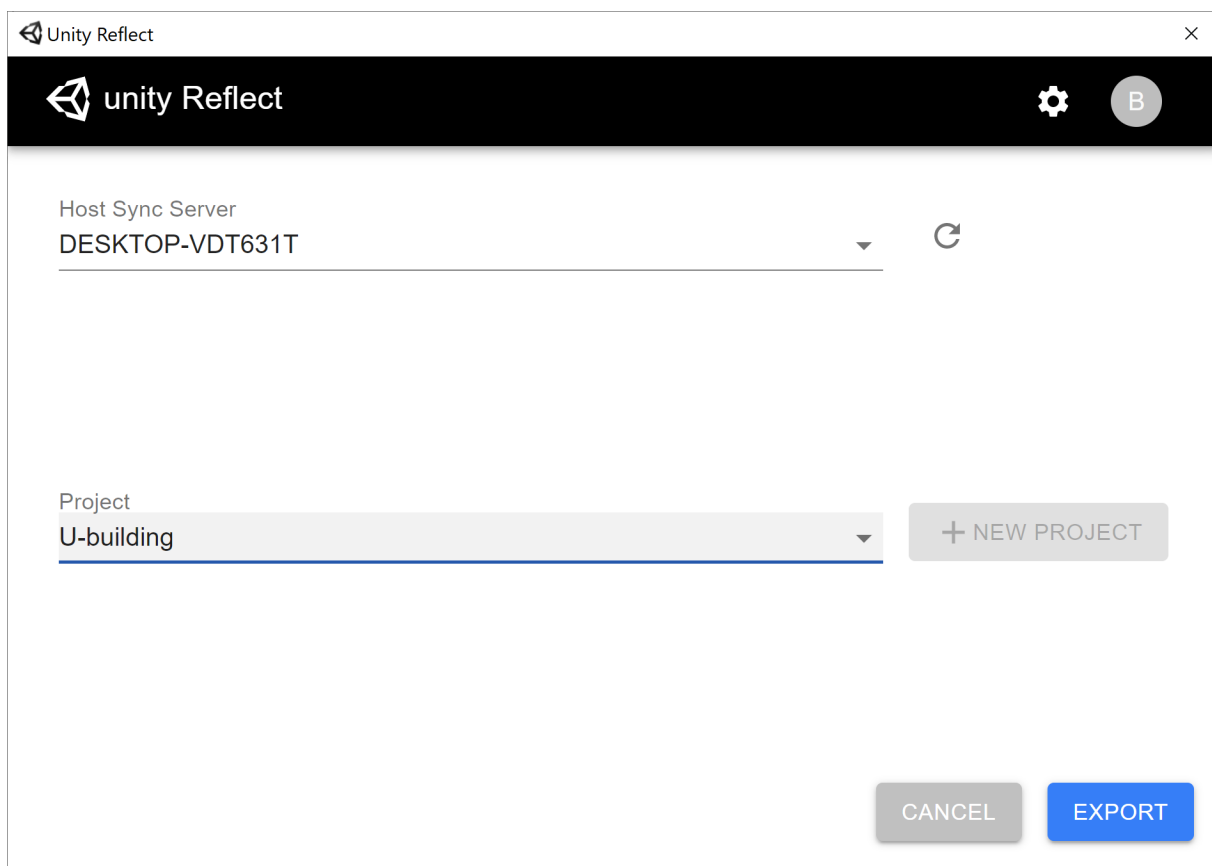


*Figure 12: Unity Reflect synchronization window*

Although every change made in Revit appear in real-time also into the shared 3D model, the software presents some problems with modification made through Dynamo, for this reason is necessary to re-synchronize the model when the colour of the Totem changes but this process takes only few minutes and don't represents a deal breaker.

Clients and collaborators can access the unity Reflect Viewer available on PC, supporting iOS and Android in order to visualise the 3D model with a wide range of devices.

After the project has been opened into the "Project window", the "Project View mode" appears like below:



*Figure 13: Unity Reflect 3D model of the Undervisningshuset*

Is possible to move inside the environment and explore the building using the mouse to rotate the camera and pressing and holding the W,A,S and D keys to move the camera into the environment.

According to *learn.unity.com* the bottom UI consists of five buttons: [23]

- The **Folder** button will pull up the Projects window again;
- The **Phone** button will pull up three other buttons;
    - **On-Screen**: This allows you to view the model on your devices screen. This is the default option.
    - **Tabletop AR**: Allows you to view the model in augmented reality.
    - **Headset VR**: Allows you to view the model with a HTC Vive.
    - The **Phone** button will pull up three other buttons
- The **Refresh/Sync** will refresh and sync up the model to the one in Revit and view the updates simultaneously;
- The **Three Bars** UI button will pull up category tabs to the right of the screen that you can then click in order to toggle specific items on or off, depending on whether you want them shown in the viewport.

---

[23] Using the Reflect Viewer on Desktop: https://learn.unity.com/tutorial/using-the-reflect-viewer?courseId

Multiple stakeholders, from project leaders to consultants and clients, can access Viewers simultaneously on the device of their choice, making it easy to collaborate and drive consensus. The Viewers also include built-in BIM filtering to isolate various components of the project, from mechanical and plumbing to doors and windows[24].



*Figure 14: Three Bars button and the menu on the side (learn.unity.com)*

- The **Settings** button allows you to choose between model quality and responsiveness. A better-looking model means you'll need to sacrifice frame rate.

[24] Unity Reflect is here: https://blogs.unity3d.com/2019/11/19/unity-reflect-arrives-in-december

# 3 Input: Real-Time Data

*In this chapter have been analysed the role of real-time data and how they can be used for fixing real facilities' problems.*

*The chapter is mainly divided in two parts, the first one shows how is possible to insert real-time data inside the BIM model, starting from the selection of the form and dealing with all the path's steps involved to import the information in Dynamo and consequently in Revit.*

*The second part shows a practical example of how the processing of real-time data can be used in order to analyse the* Undervisningshuset's *thermal comfort. Starting from a theoretical over-view of the topic, it has been shown how thermal comfort parameters are calculated in Dynamo and the limits of the performed calculation.*

## 3.1 Input: Real-Time Data

Data and information are among the most important elements in BIM, they represent tools to help the AECO industry to boost productivity, increase accuracy, improve decision-making based on solid and recent information during the decision process and the management of the facility.

The possibility to deliver immediately the information collected can improve considerably the background of information available decreasing time and cost for the construction of the build-ings as well along all its life cycle.

"Most of the BIM processes and workflows are clear and established for the geometric and visualization tools of the technology, but not for data management"(Noves, 2017).

Although it is clear that data are fundamentals for the "BIM system" and they represent a tool that can really improve the way we design and manage facilities, is not so obvious which is the best way to collect, process and visualize the information.

"Learning technology and tools is important but one message stands out, it is not enough any-more to learn existing tools, design and construction professionals need to feel comfortable either shaping existing tools to fit their needs, or otherwise creating their own tools" (Deutsch, 2015).

One of the most important targets of the project has been to develop a protocol for entering data user-friendly, efficient and suitable to face different problems. The idea is to provide a tool with a structure that can easily be changed and adapted from other designers in order to fulfil their needs.

## 3.1.1   Selection of the Form

In computer science, the word "form" usually indicates the user interface part of a web request that allows the user to insert and send data to a web server / application server.

It is possible to develop a form in different ways, using the HTML <form> element or using a wide range of on-line applications.

HTML (Hyper Text Markup Language) is the standard markup language for creating Web pages, it describes the structure of a Web page and consists of a series of elements.
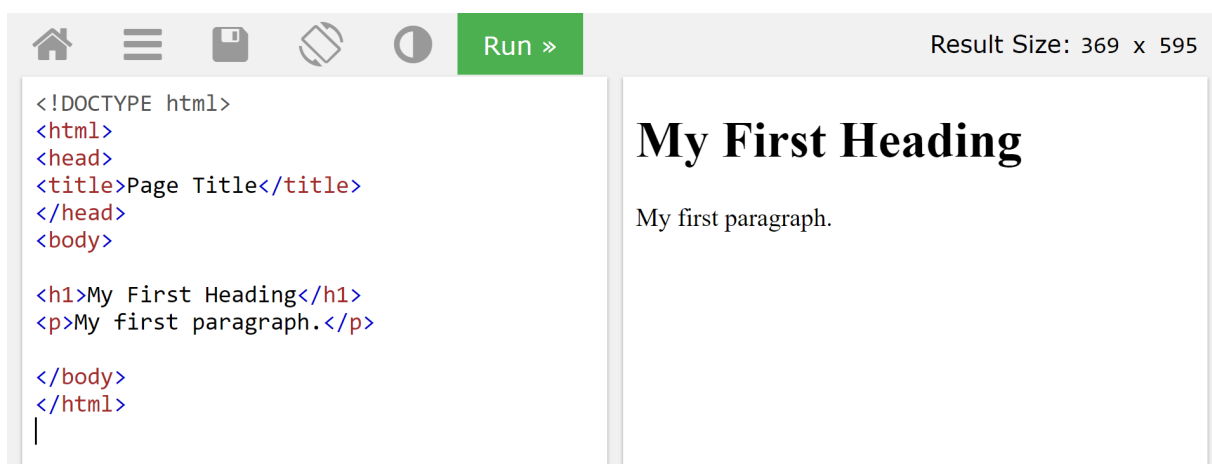


*Figure 17: Example of a simple HTML Document*

Currently it is possible to avoid learning how to use HTML tanks to different on-line services, because of the wide range of possibilities it has been necessary to analyse the several possibilities in order to find the most suitable tool.

The way form builders work is relatively straightforward, with drag & drop operation it is possible to create labels and questions for the information needed and respondents use the fields established to provide the information.

The choice of the most useful Online Form Builder Apps has been based on the need to have a form that:

• is designed to work on any website or does not need it;

• is simple and fast to use;

• is flexible and able to meet all types of user demands;

• does not need fee-based services.

The following online Form Builder Apps have been considered:

**Google Forms:**

Google Forms is a survey administration app that is included in the Google Drive office suit along with Google Docs, Google Sheets and Google Slides.

It is an excellent resource for many reasons, it is entirely free, it only needs a Google account for working and includes all the basic form fields such as short and long answer text boxes, checkboxes, multiple choice selection, dropdown menus and file uploads.

The information collected is automatically connected to a spreadsheet which is a computer application for organization, analysis and storage of data in tabular form.

Thanks to Zapier every time there is a new spreadsheet row in Google Sheets the application automatically updates a row in Microsoft Excel then it updates data in Dynamo.

A great advantage of Google Forms is that it is not needed to embed the form to a website in order to create the QR code because it is possible to use directly the URL of the Google form.



*Figure 18: Form developed using Google form*

**Microsoft Forms:**

Microsoft Forms is a web-based application within an Office 365 suite that allows users to build quick intake forms and surveys.

It is very similar to Google Form, it is simple and it collects responses in real time but in this case the data can be saved directly into an Excel file, this means that we don't need to send data from a spreadsheet to an Excel sheet using applications such as Zapier.

If the form has been created in Forms on the Web it is necessary to download every time an offline Excel workbook, this implies that in Dynamo would be necessary to change every time the file path within the Dynamo node Excel.ReadFromFile.

Microsoft Forms is completely free, includes the basic form fields but it doesn't allow uploading files and doesn't present all the functions developed in Google Form.

 When the form is built it is possible to send the direct link to respond or to grab the embedded code to add the form to a website.

# INSPECTION OF THE U-BUILDING

1. Name of the inspector *

Inserisci la risposta

2. Date of the inspection

Immetti la data nel formato dd/MM/yyyy

*Figure 19: Form developed using Microsoft Form*

**JotForm:**

JotForm's software creates forms with a drag and drop creation tool and an option to encrypt user data.

Is a very powerful and feature-rich platform that presents a wide range of functionality such as example text, character limits, hover text and input table.

It doesn't require any knowledge of HTML, CSS, JavaScript, etc.

All its options are available for every form, regardless the type of account (Starter, Bronze, Silver, Gold) which regulates the number of forms and the number of submissions.
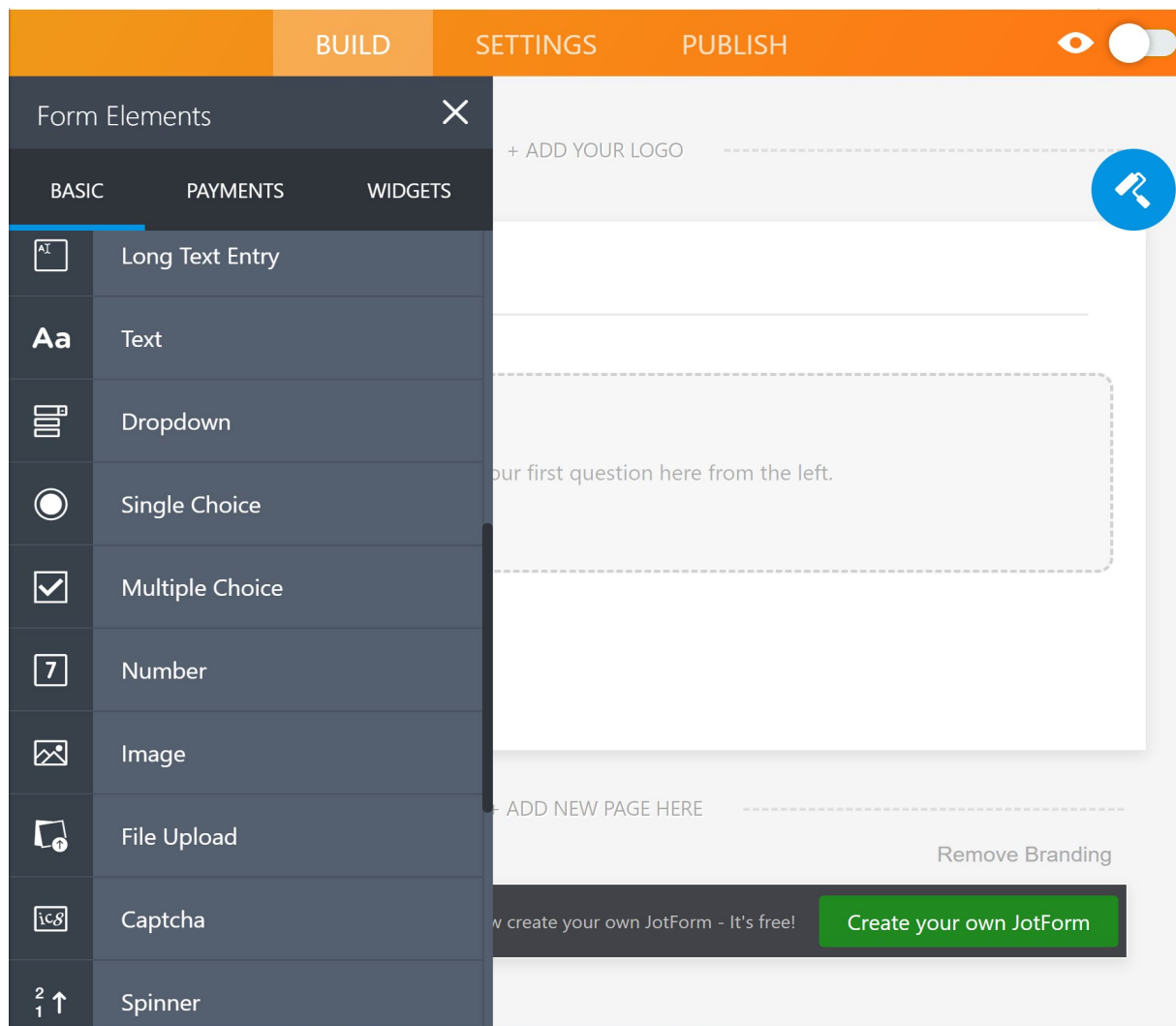
*Figure 20: Build interface and features of JotForm*

**Form.io:**

According to the developers Form.io is an enterprise class combined form and API data management platform for developers who are building their own complex form-based business process applications.

Is not as simple to use as the other applications but it presents many interesting functionalities and actions, everything from sending emails, authentication, and even saving submissions in the database are configured through independent actions associated with the form.

An interesting aspect is that every project within Form.io can provide custom Roles which users can be assigned when they authenticate into the platform.

*Figure 21: Build interface and features using Form.io.*

Analysing the different Online Form Builder Apps it is clear that Form.io and JotForm are the high performing ones, they presents the greater number of features, the possibility to authenticate the access and in the case of Form.io the possibility to create APIs with a essentially JSON schema editor.

They are simple to use after a few hours of training but they require ,in order to use all the features, a subscription to a fee-based service.

In order to bring people closer to BIM is important to avoid as much as possible paid services, Form.io and JotForm are very powerful tools but they don't fit with the aim of this project.

In addition the form has to be simple and this means that it is not necessary to use many functionalities or actions.

The applications better suited to our needs are Google Forms and Microsoft Forms, simple to use, completely free, mastered by a great number of people and perfectly able to satisfy our requirements.

Both of them do not necessarily need a website for developing the QR-code.

Microsoft Forms has the advantage to collect data directly inside an Excel file but as mentioned above it is necessary to download every time an offline Excel workbook, this means that in Dynamo it would be necessary to change every time the file path.

This problem can be fixed by creating the form in Excel Online, the Excel workbook is automatically stored in OneDrive for Business and contains a live data connection to the form. Any new response data inside the form will be reflected in the Excel workbook.

For creating the form in Excel Online is necessary to sign in to Office 365 which is a suite for creating, modifying and sharing documents and is for free only for students.

In order to not have to subscribe to Office 365 another solution can be to create the form in Forms on the Web and a folder in which to save every time the offline Excel workbooks.

Is it possible to write a script in Python in order to pick inside the folder the latest file:

```
import glob
import os

list_of_files = glob.glob('/path/to/folder/*.xlsx')   #path to any .xlsx file in the designated folder

lates_file = max(list_of_files, key = os.path.getctime)

return latest_file
```

*Figure 22:Python script for picking the last Excel file insied the folder.*

Thanks to this script it is not necessary to change the path into the Excel.ReadFromFile node every time a new Excel workbook is downloaded into the folder.

An important aspect to consider is that every time the form is filled the position of the data of interest in the Excel sheet change and this can complicate the organization of the nodes and relations in Dynamo.

This problem can be avoided using Google Forms, as mentioned above the data are automatically connected to a spreadsheet but Dynamo can only read Excel file, this problem can be fixed using Zapier, which is a software as a service (SaaS) also known as Web-based software.

In light of this the best solution is to use Google Form, simple, flexible, and powerful combined with Google Sheets, Zapier and Excel.

## 3.1.2   Path from Google Form To Dynamo

The protocol that enables people to insert real-time data inside the BIM model involves different steps characterized by the use of a wide range of tools, the diagram below show briefly all the passages needed.

*Figure 23: overview of the data path*

# QR CODE

The first step of the protocol is represented by a QR code (Quick Response code) which is a machine-readable optical label that presents data that points to a website or application.

To create a QR code is extremely simple and online there are plenty of sites where it is possible to create them for free.

QR codes can be natively scanned without downloading external apps on various mobile device operating systems such as iPhones with iOS11 or other Android devices.

The camera app is able to scan the QR code and redirect the users to the form online, making it very simple for them to open the form and insert the data.



Figure 24: QR code linked with the form

## GOOGLE FORM AND GOOGLE SHEET

Once the Google form is opened thanks to the QR code the user can fill the form with the requested information:

- Name of the user;
- Date of the inspection;
- Temperature of the room (°C);

- Relative Humidity of the room (%);
- Mean Vote (MV);

In order to decrease the possibility of human errors it is not possible to send the form if all the fields are not filled and if the values of temperature, relative humidity and mean vote are not numbers.

All the results are saved in Google Drive and automatically organized in charts and diagrams easy to visualize for the administrator.
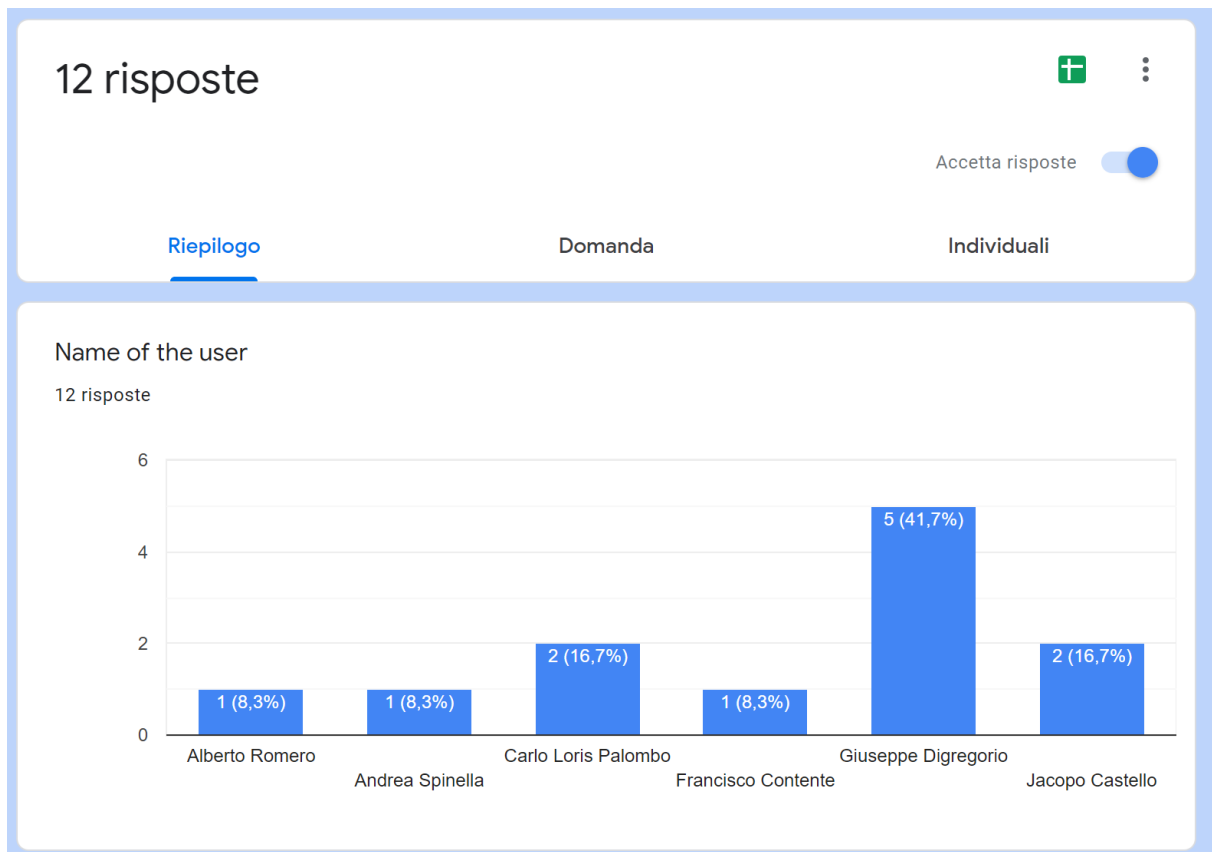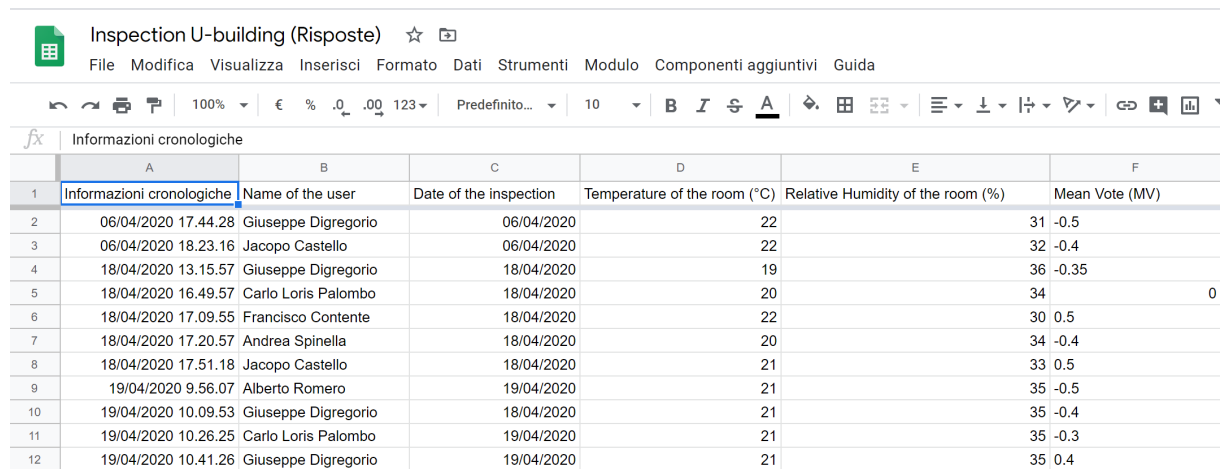


*Figure 15: Replies' section of the form.*

Moreover the results are saved in Google Sheets which is an online spreadsheet app that allow users to create and format spreadsheets[25] offered by Goolge within its Google Drive service.

---

[25]How to use Google Sheets: https://support.google.com/docs/answer

Every time the users fill the form, data is collected inside the designated Google Sheets spreadsheet called "Inspection U-building" which can be accessed from Google Drive.



*Figure 16: Data collected in Google Sheet*

## ZAPIER

Zapier is an online automation tool that connects different apps to perform repetitive actions without coding or relying on developers to build the integration[26].

The automated workflow between the chosen apps is called "Zap", once it is set up the tool is able to check the app and starts the workflow when there is a pre-set particular event called "Trigger".

When the "Trigger" is activated, Zapier automatically performs a chosen "Action" which is an event that completes the Zap.

For our purpose has been necessary to select the apps we want to connect, Google Sheet with Microsoft Excel:

---

[26] What is Zapier: https://zapier.com/learn/getting-started-guide/what-is-zapier/
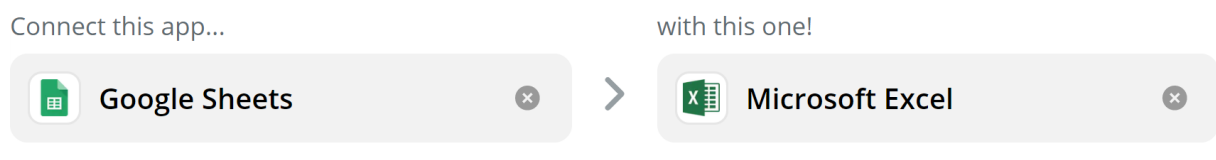
*Figure 17: Zapier's connection between two apps*

And choose what the "Zap" has to do:
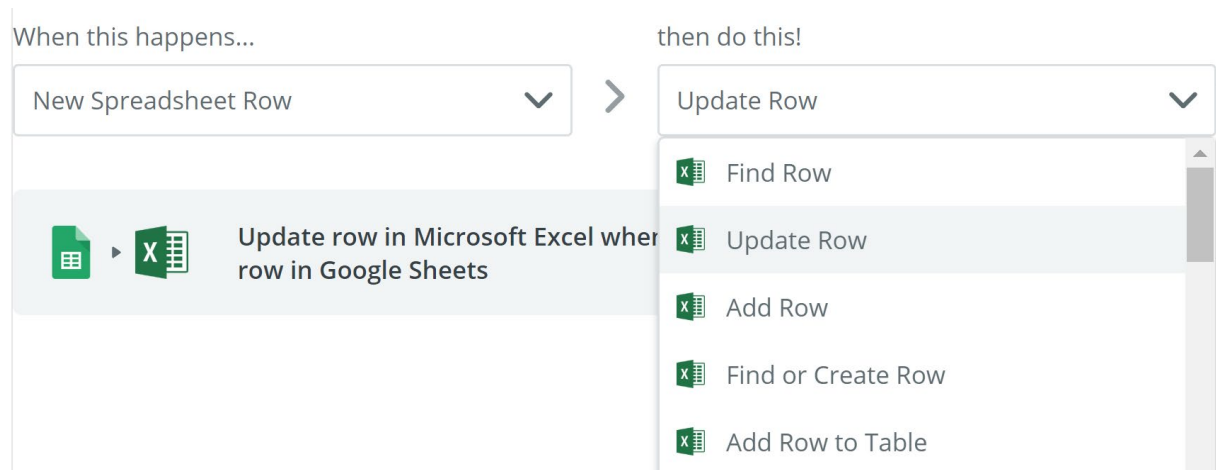


*Figure 18: Trigger and Action chosen*

Instead of adding a row into the Excel Sheet it is better to update it in order to have the data of interest every time in the same position and simplify the work in Dynamo and at the same time collect all the data in Google Sheets.

In this way in the Excel spreadsheet will be only a single row with the last data inserted into the form while in Google Sheets all the data will be collected.

## FROM EXCEL TO DYNAMO

The Excel spreadsheet is saved in OneDrive is a file hosting service and synchronization service operated by Microsoft which presents a client application that allows users to synchronize their entire OneDrive storage with their computers for offline access.



*Figure 19: Excel input data spreadsheet*

Once the data are in Excel is possible to export them to Dynamo thanks to the node "ImportExcel", according to Dynamo Dictionary[27]:

- Description:
  The "ImportExcel" node read data from a Microsoft Excel spreadsheet and they are returned in a series of lists by row
  Rows and columns are zero-indexed, for example, the value in cell A1 will appear in the data list at [0,0].

- Inputs:
  file: var
  sheetName: string
  readAsStrings: bool
  showExcel: bool

- Outputs:
  Type: data

---

[27] ReadFromFile: https://dictionary.dynamobim.com/#/Office/Excel/Action/ReadFromFile
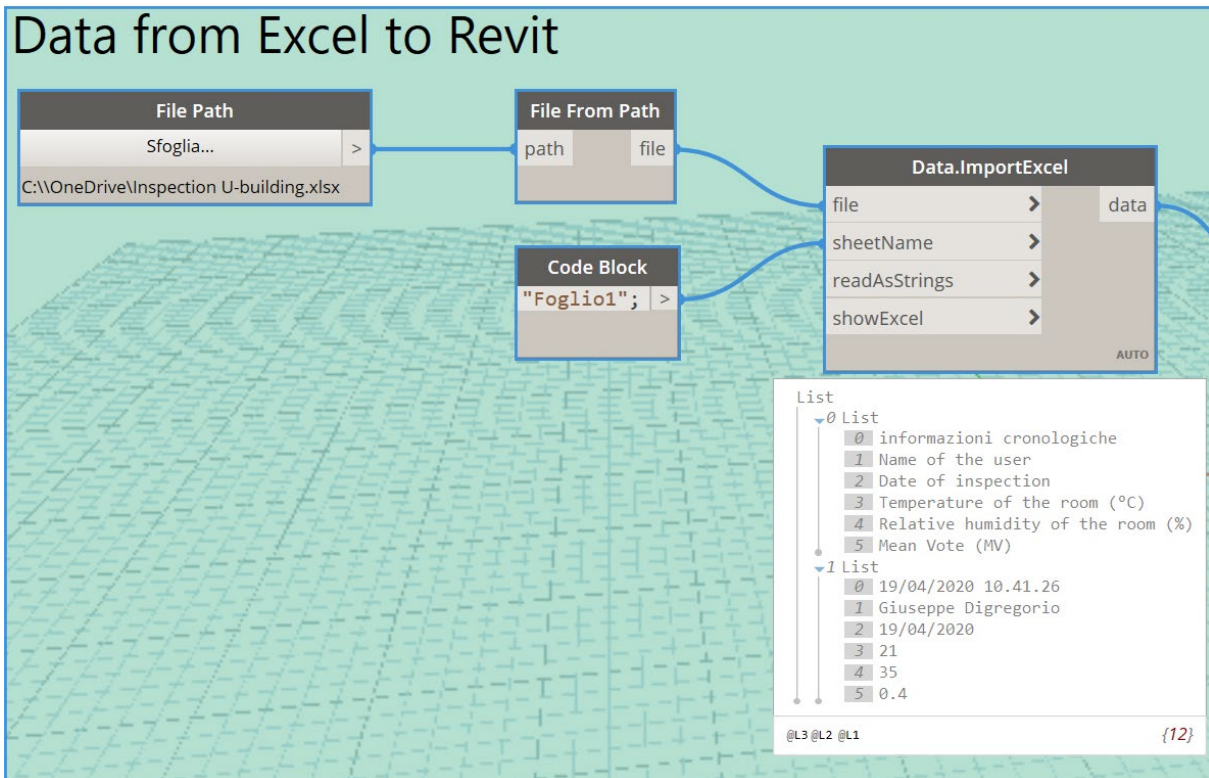
*Figure 20: Data path from Excel to Revit*

The degree project has been a File Path node and File From Path node to create a file object that points to a text file.

### 3.1.3 Data Management in Revit

Once developed the protocol for the input data is necessary to figure out how to manage and store them inside the model.

Has been decided to create a new type of family called "Totem", every element belonging to the family is cubed shaped and characterised by a set of parameters that are the ones of interest for the project.
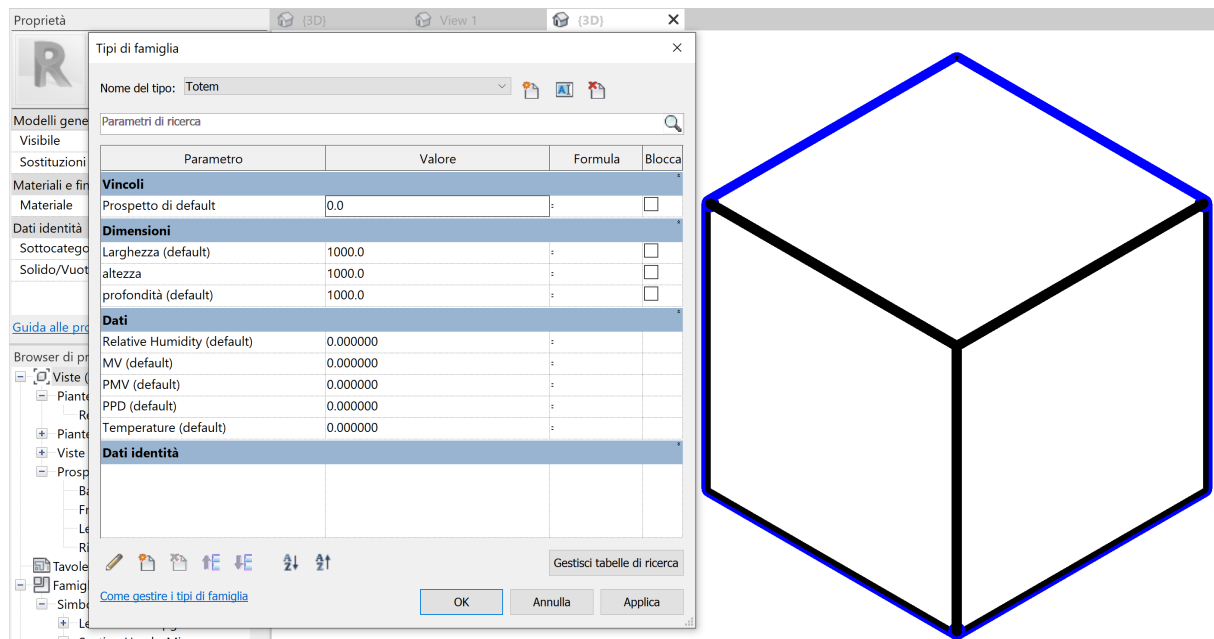
*Figure 21: Totem family*

In light of what said above it is possible to assert that, once loaded into the model, the Totem represents a database inside the Revit model referred to a room, flat, plane or building depending on the requirements and thanks to Dynamo is possible to set the values of the parameters.

For the purpose of the project a Totem has been placed in room U31 in order to collect the data regarding only that room.
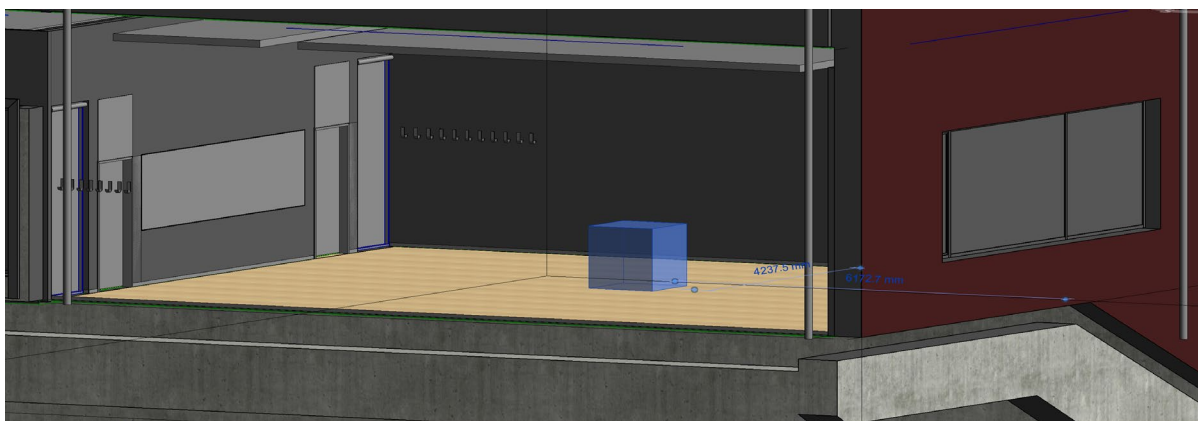


*Figure 22:Totem into the Revit model*

## 3.2 Data Processing: case of indoor thermal comfort

In order to show the potentiality of data in BIM and how they can improve daily life of people is interesting to consider the environmental well-being of the individual which represents user satisfaction with regard to the indoor environment in which it is located.

The level of satisfaction is determined by physiological and psychological conditions which are a function of the values assumed by a set of physical quantities related to the environment.

It is also conditioned by external environmental factors (climate, site), internal environmental factors (type of building and management), and individual subjective factors.

The feeling of well-being is different from person to person and depends on age, sex, physical and mental state, metabolism, time of the day, uses and habits.

One of the major concerns we face today in homes, schools, and workplaces is poor indoor environmental quality (IEQ), which can lead to poor health, learning difficulties, and productivity problems (Kubba, 2012).

According to major international Standards (ASHRAE 55-2010, EN 15251:2007, ISO 7730:2005), building IEQ is determined by:

- Thermal Comfort;
- Visual Comfort;
- Acoustic Comfort;
- Indoor Air Quality.

In order to determine the different types of comfort is necessary to determine a wide range of parameters according to Standards.

| Thermal Comfort | Visual Comfort | Acoustic Comfort | Indoor Air Quality |
|---|---|---|---|
| • Air Temperature<br>• Mean Radiant Temperature<br>• Relative Humidity<br>• Air Velocity<br>• Metabolic Rate<br>• Clothing<br>• Local Thermal Discomfort<br>• Predicted Mean Vote (PMV)<br>• Predicted Percentage of Dissatisfied (PPD) | • Light Intensity<br>• Glare Index<br>• Color Rendering Index | • Sound Intesity | • Ventilation Rate<br>• Carbon Dioxide concentration levels<br>• Pollutants concentration levels |

*Figure 23:Indoor Environmental Quality parameters according to Standards EN 15251:2007 and ISO 7730:2005*

## 3.2.1   Termal comfort parameters

Thermal Comfort is a psychophysical condition of the user which is in an environment where you can cancel the sensations of heat or cold perceived without massive interventions of the body thermoregulation system.

According to Godbole, the European Union heating and cooling in buildings accounts for half of energy consumption (Heating and Cooling-European Commission, 2016). In 2017, about 39% of total U.S. energy consumption was from the residential and commercial sectors (U.S. Energy Information Administration, 2018).

Moreover the theme is very important because according to Martin et al., approximately the 75% of the complaints in facilities are thermal comfort related, this data highlights even more the importance of the chosen topic.

It is generally accepted that there are six factors that determine thermal comfort conditions, four environmental factors together with two additional personal factors (Chow, 2017) :

- Air Temperature (tDB) : temperature of the air measured with a thermometer in the shade;

- Mean Radiant Temperature (tMR) : area-averaged surface temperature of the surroundings, it affects the radiation that is received from surrounding surfaces;

- Relative Humidity (RH) : is the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at a given temperature;

- Air Velocity (vr) : relative air velocity towards the subject, it affects the potential for the heat loss via air convection;

   Clothing level (clo) : the insulating characteristics of clothing inhibit heat loss from the human body;

*Table 1: Examples of Clo-value*

| Clo-value (clo) | Example |
| --- | --- |
| 0 | Naked, swimwear |
| 0.5 | Light trousers + shirt or light dress + blouse |
| 1.0 | Business suit or dress + jumper |
| 2.0 | Heavy suit, overcoat, gloves, and hat |

Activity: muscular activity directly impacts the metabolic rate and thus heat production, 1 met is the basic metabolic flux, whatever activity leads to higher values that the organism must dispose of to ensure homeothermia.

*Table 2:Activities and metabolic rate*

| Activity | W/m² | Met |
|---|---|---|
| Reclining | 46 | 0.8 |
| Seated relaxed | 58 | 1.0 |
| Standing relaxed | 70 | 1.2 |
| Domestic work | 170 | 2.9 |
| Walking on level, 5 km/h | 200 | 3.4 |
| Running, 15 km/h | 550 | 9.5 |

Thanks to this parameter it is possible to calculate the predicted mean vote (PMV) index which describes the indoor thermal environment in both the phases of design and auditing (Fanger, 1970).

PMV index represents the mean vote that people would assign to a given environment using a seven-point thermal sensation scale.

There are several scales used for occupants to report their perceived thermal comfort, and the two most used ones are the seven-point scales of Bedford (1936) and ASHRAE (2013), as shown in Table 3.

*Table 3:Scales for subjective warmth*

| Index value | ASHRAE | Bedford |
|---|---|---|
| | How do you feel just now? | |
| + 3 | Hot | Much too warm |
| + 2 | Warm | Too warm |
| + 1 | Slightly warm | Comfortably warm |
| 0 | Neutral | Comfortable |
| − 1 | Slightly cool | Comfortably cool |
| − 2 | Cool | Too cool |
| − 3 | Cold | Much too cool |

The scale above allows people to assign a vote to any environmental condition.

It is now a question of determining which vote is considered enough, to this end one last quantity is introduced, the Predicted Percentage of Dissatisfied (PPD).

An individual who gives an environmental rating greater or equal to +2 or less or equal to -2, corresponding respectively to the sensations of heat and of cold, is conventionally defined as dissatisfied.

The response is statistical, so even in conditions of neutrality there is on average a certain percentage of dissatisfied or towards the heat (2,5%) or towards the cold (2,5%).

This means that in the best conditions 5% of the individual is unsatisfied.

The relationship between PPD and PMV is:

$$PPD = 100 - 95^{-0.03353PMV - 0.2179PMV^2} \quad (1)$$

Graphically:
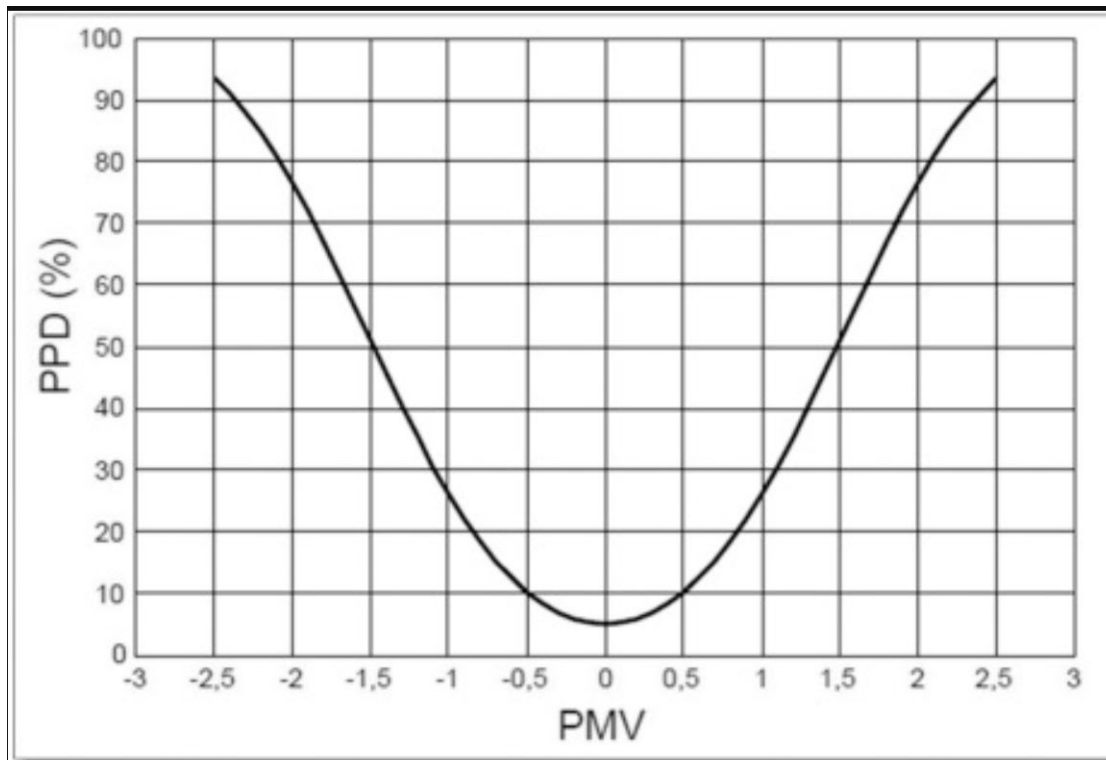


Regulations establish limits of acceptability on the basis of these trends, for example Fanger indicates a max PPD of 7.5% which suggests a PMV between +/- 0.35, ISO 7730 prescribes a PMV between +/- 0.5 which means a max PPD of 10% and ASHRAE 55 accepts 20% for the PPD which means a PMV between +/- 0.85.

## 3.2.2 Calculation of PMV and PPD thanks to Python Script

Once the limits and the purpose of the analysis are understood, it is possible to investigate how PMV and PPD are calculated and how the items of interest are isolated from the list of the "Import.Excel".
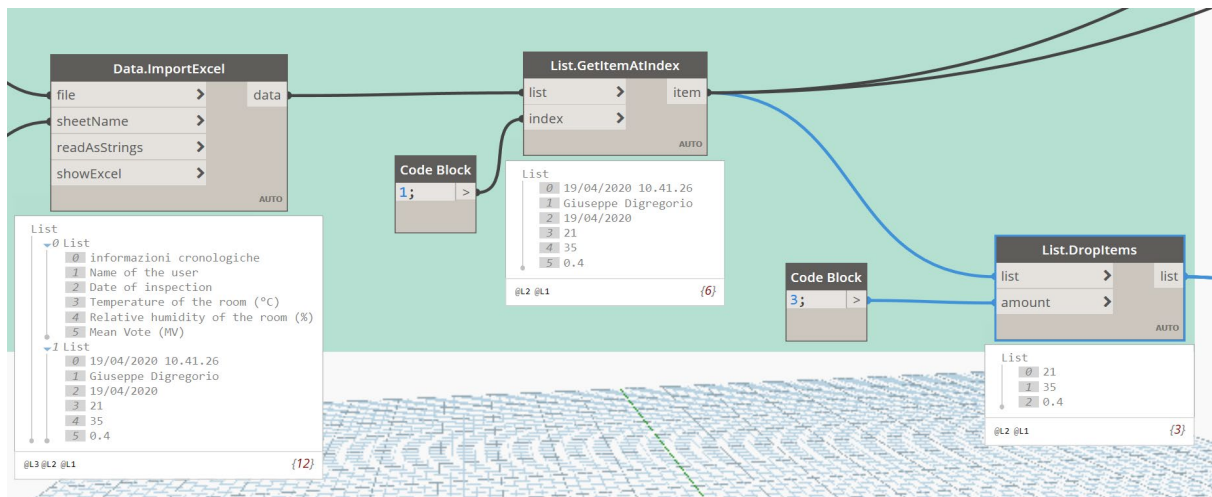


*Figure 24: isolation of the items of interest for PMV and PPD's calculation*

Almost everything that is done with Dynamo involves lists which are the way how data organise data also known as elements or items.From Excel has been imported a list which presents two items which in turn are two lists, the first one consists in the name of the parameters, the second one consists in the relative values.

With the node "GetItemAtIndex" is possible to pick the second item which is the list of values and thanks to the node "DropItems" is possible to select the last three values related to temperature of the room, relative humidity and MV.

Temperature of the room and relative humidity are two of the six input parameters that the script needs for the calculation of PMV and PPD as shown in the figure below:



*Figure 25: First part of the Python Script for the calculation of PMV and PPD*

After importing the .NET Common Language Runtime (CLR) using *import clr* and the math module using *import math* the arguments of the function pmv_ppd have been declared as inputs of the Python Script Node and its output is the function itself which returns a list of two values, PMV and PPD

In Dynamo the input values are linked with the Python Script Node as shown in the figure below:
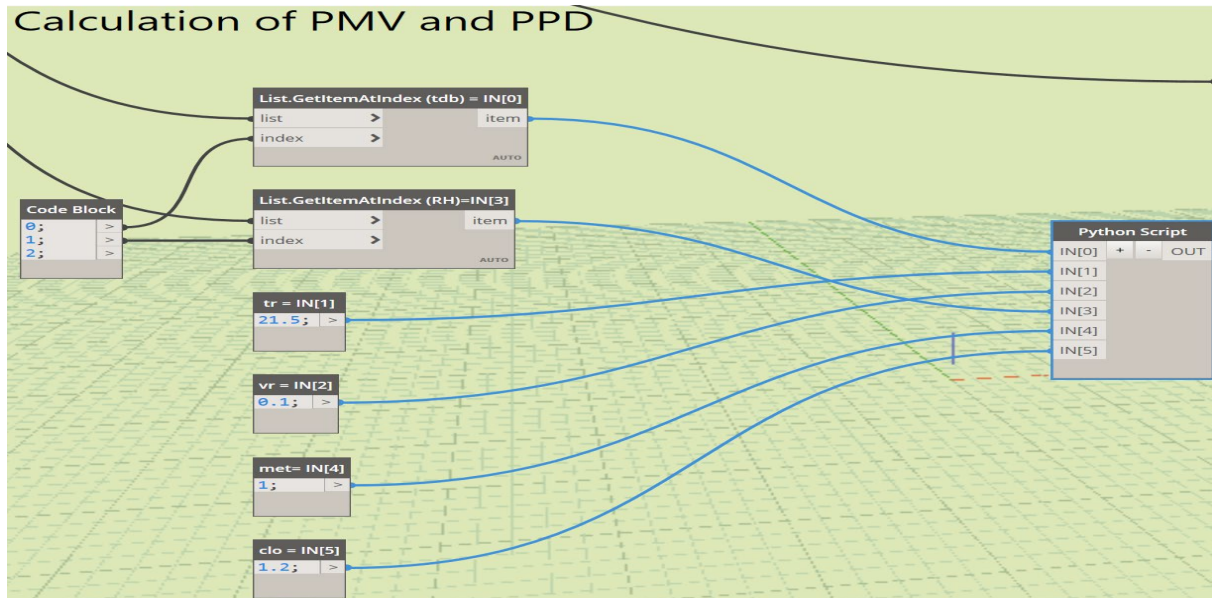


*Figure 26: Workflow for the calculation of PMV*

## 3.2.3  Limits of the analysis and values chosen

The calculation of PMV and PPD thanks to the Python node in Dynamo is an example of how real-time data can be used to deal with real problems, with that in mind is simple to understand why has been performed as a simplified calculation.

After a deep analysis of the task, performed taking into account the purpose of the example, the parameters chosen to be inserted by the users tanks to the form have been air temperature and relative humidity of the room while the other ones can be inserted by the designer as number values without importing data inside the model or additional calculation.

For air velocity and mean radiant temperature it is necessary to use very specific instruments, in addition to being very difficult to measure without a proper background knowledge in this field. Leaving that responsibility to the customer seemed unrealistic to us especially because air temperature and the relative humidity are enough for involving users into the BIM process and show how to manage real time data.

The choice of the value has been performed taking into account the results obtained from God-bole and reported on his thesis about the relationship between mean radiant temperature and PMV. The case study of the project was the "Undervisningshuset" and the report presented measurements related to the room U31.

Mean radiant temperature can be measured by calculation methods or in a more precise way by specific instruments. Godbole in his study has used, to measure mean radiant temperature, the Black Globe Thermometer which consists of a black globe in the centre and a temperature sensor.

The measurement set was as follows:
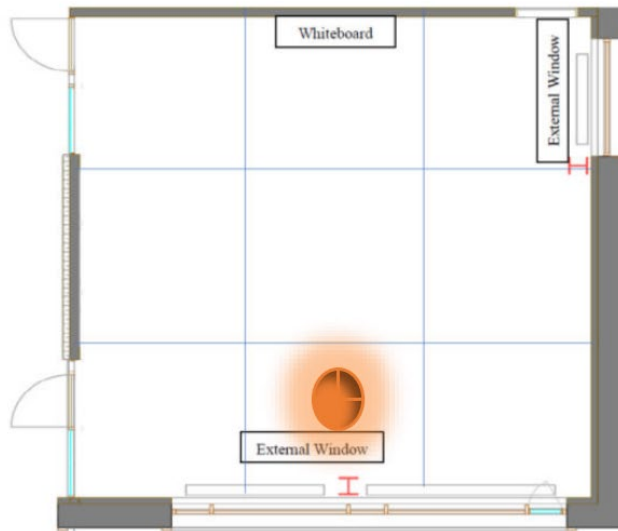


*Figure 27: Black Globe Thermometer's position for the room U31*

The measurements related to the room U31 have been performed during the second part of the study with two visits in order to not disturb the lessons.

The values of the MRT calculated have been inserted into the table below in the following manner (minimum value, maximum value, range, mean value, variance.

*Table 4: values of MRT calculated by Godbole*

| Date | Time | Outside Weather | Room | AT | MRT | OPT | PMV | AT-PMV Spearmans correlation | MRT-PMV Spearmans correlation |
|---|---|---|---|---|---|---|---|---|---|
| | | | U21 | 20.72<br>21.61<br>0.89<br>21.26<br>±0.22 | 20.55<br>22.41<br>1.86<br>21.73<br>±0.43 | 20.73<br>22.16<br>1.43<br>21.78<br>±0.42 | -0.480 | 0.677 | 0.743 |
| 2 May | 15-17 | +10.5 mostly cloudy | U31 | 21.33<br>22.06<br>0.73<br>21.81<br>±0.21 | 21.34<br>22.72<br>1.37<br>22.18<br>±0.30 | 21.43<br>22.72<br>0.96<br>22.12<br>±0.27 | -0.408 | 0.528 | 0.235 |
| | | | **U41** | 21.39<br>22.61<br>**1.22**<br>22.15<br>±0.31 | 21.39<br>23.03<br>*1.64*<br>22.48<br>±0.35 | 21.53<br>23.03<br>1.23<br>22.43<br>±0.29 | -0.326 | **0.422** | **0.304** |

Minimum value
Maximum value
Range
Mean value
Variance

In light of data collected and considering the different periods of the year when the calculations have been performed the MRT's value chosen for the calculation is 21,5 °C.

For further analysis it is possible to change the "Number" node with a node for the numerical calculation of the MRT starting from the temperature of the surfaces of the room or importing directly the sensors' measurements. The same procedure can be performed for the air velocity but considering all the measurement performed has been considered as a realistic value 0,1 m/s.

The values for the clothing level and the activity, considering the aim of the facility and the category of people who use the facility, are quite homogeneous and simple to predict. According to *Table 1* and *Table 2* is possible to set up the following values:

- clo=1,2  typical value assigned to winter clothing;
- met=1 value typically assigned to sedentary activities

# 4 Results

*In this chapter have been displayed the results achieved during the project which refers to application fields very different from each other, proving the wide interdisciplinarity of the work.*

*The first section deals with the setting of the parameters' values in Revit using Dynamo's nodes in order to update in real-time the values every time they change.*

*The second section explains how the results can be visualized in Revit or using Unity Reflect Viewer on desktop or thanks to a iOS based device with the possibility to access AR experience.*

*The third paragraph is focused on how the final data can be exported into a database and stored for a wide range of purposes.*

## 4.1 Setting of the parameters' values

A protocol has been developed in Dynamo in order to upload the parameters' values inside the  Revit model of the building every time new data is inserted through the online form.

The core of the process is the node "SetParameterByName" which enables the user to modify Revit element's parameters given its name and the corresponding value[28].

In order to better understand the procedure it is useful to analyse the inputs of the node.

**Inputs:**

- Element: the element chosen belongs to the Totem family, it has been placed into the room U31 in order to host all the data referred to that room and, as previously shown in paragraph 3.1.3, it presents yet all the parameters of interest with a default value;

- parameterName: all the parameters' names are selected from the element thanks to "Get Family Parameter" node and sorted in a list of five items using the "ListCreate" node;

- value: all the values as the parameters are sorted in a list of five items, the first tree derive directly from the online form (temperature of the room, relative humidity, MV), the last two (PMV and PPD)  derive from the Python node as explained in paragraph 3.2.3.

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[28] Dynamo Dictionary:
https://dictionary.dynamobim.com/#/Revit/Elements/Element/Action/SetParameterBy Name

The organisation of values and names in two lists has enabled to use only one "SetParameterByName" node making the workflow easier to read and faster to run.

**Output:** selected element with updated parameters.

The setting of the parameter have been performed using Dynamo as shown below:
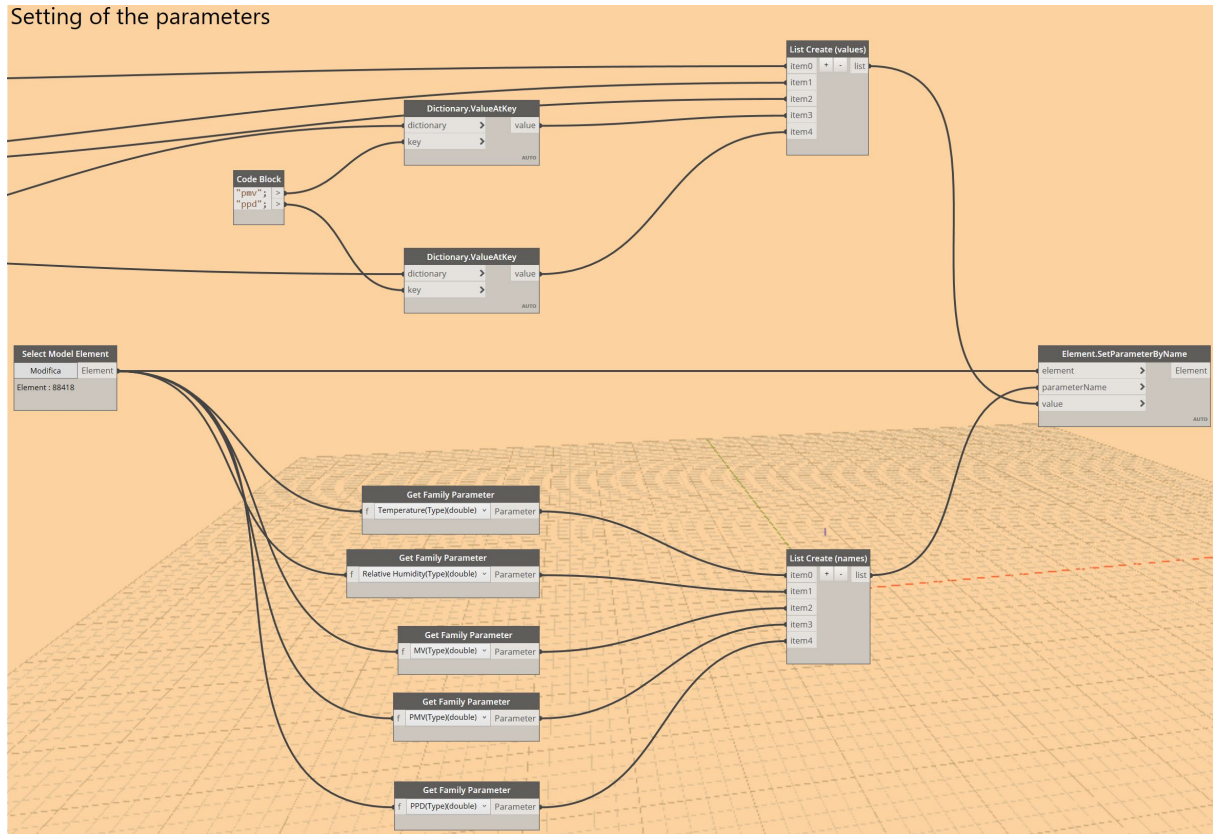


*Figure 28:setting of the parameters with Dynamo*

All the parameters' values are linked with the online form, this means that whenever users insert a new information in real-time, data are updated automatically into the model without any further action.



**BEFORE** **AFTER**

| Dati | | Dati | |
|---|---|---|---|
| Relative Humidity (default) | 0.000000 | Relative Humidity | 35.000000 |
| MV (default) | 0.000000 | MV | 0.400000 |
| PMV (default) | 0.000000 | PMV | -0.330000 |
| PPD (default) | 0.000000 | PPD | 7.300000 |
| Temperature (default) | 0.000000 | Temperature | 21.000000 |

*Figure 29: updating of the parameters' value in Revit*

## 4.2 Visualization of data in real time with Revit and Unity Reflect

Although all the parameters' values inserted into the online form are stored and available for further analyses one important task for the project has been the development of a simple way to visualise the data in order to let customers understand immediately how is the thermal comfort inside the room.

For the visualization of data has been chosen to use a colour code of two colours, green and red, according to the values inserted into the model form the customer.

After considering to change the colour of the floor or the walls it has been decided to intervene in the colour of the Totem which represents a perfect tool for our purpose and does not affect at all the aspect of the room keeping the realism of the environment.

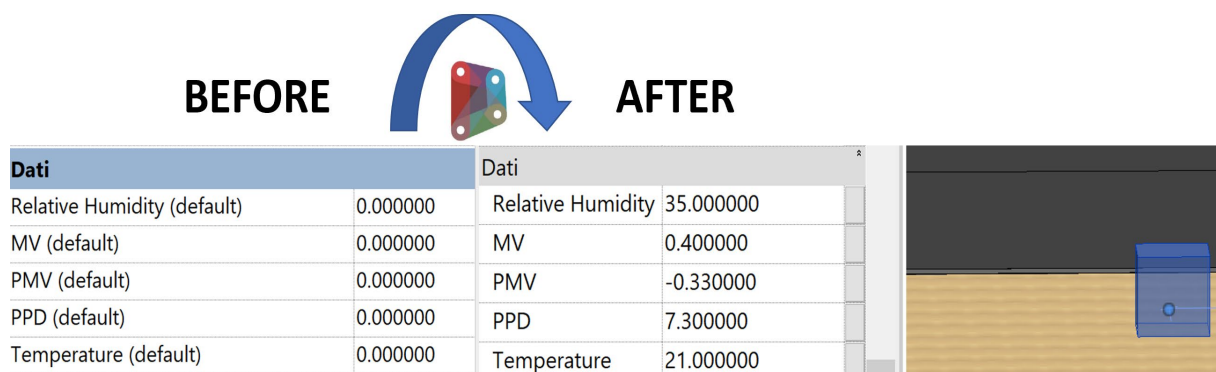In order to better understand how the procedure has been performed can be helpful show and explain how the problem has been handled in Dynamo:
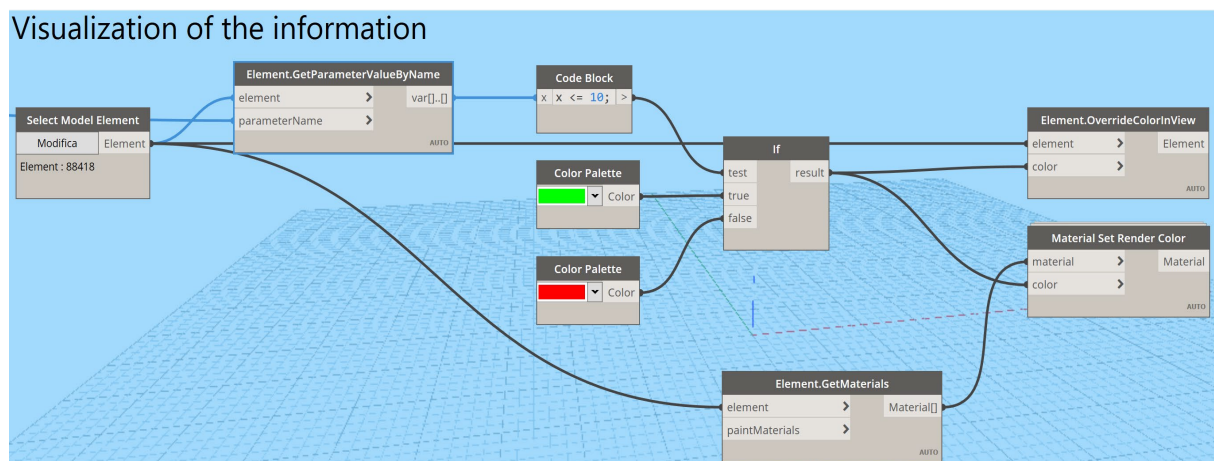


*Figure 30: visualization of the information's workflow*

For the visualization it has been necessary to choose one single parameter among those considered able to describe the thermal comfort of the room, to link the chosen one with the colour code and set a threshold value for the change of colour.

The ISO 7730, the European Standard for the analytical determination and interpretation of thermal comfort, prescribes a PMV between +/- 0.5 which means a max PPD of 10%.

PMV and PPD depend on each other and are both parameter able to describe properly the thermal comfort of the room, for our project the parameter PPD have been chosen as control parameter.

PPD's value can be selected using the node "GetParameterValueByName" which returns the value of an element's parameter given the parameter name as a string and it is used for the operation of a conditional control node "If".

The "If" node is characterised by three inputs and one output:

**Inputs:**

- test: Boolean value;
- true: any data type;
- false: any data type.

**Output:** if the test value is 'true', the node will return the item from the 'true' input (green colour), if test is 'false', the node will return the item from the 'false' input (red colour).

In our case the test is a simple inequality, $x < 10$, in order to establish if the calculated PPD's value is lower than 10% as prescribed by ISO 7730 and the true and false value are two colours, green and red.

In this way, every time data are inserted in real-time into the model, a new value of PPD is calculated and compared with the limit imposed by these regulations, returning a different colour according to the conditional control node.

The colour of the Totem has been changed using two different nodes, "OverrideColorInView" which change the element's colour in the active view regardless of the current model display style[29] and "Material set render color" a custom node belonging to Genius Loci pack which can set the rendering colour in the Appearance Asset of the given material with the provided colour.
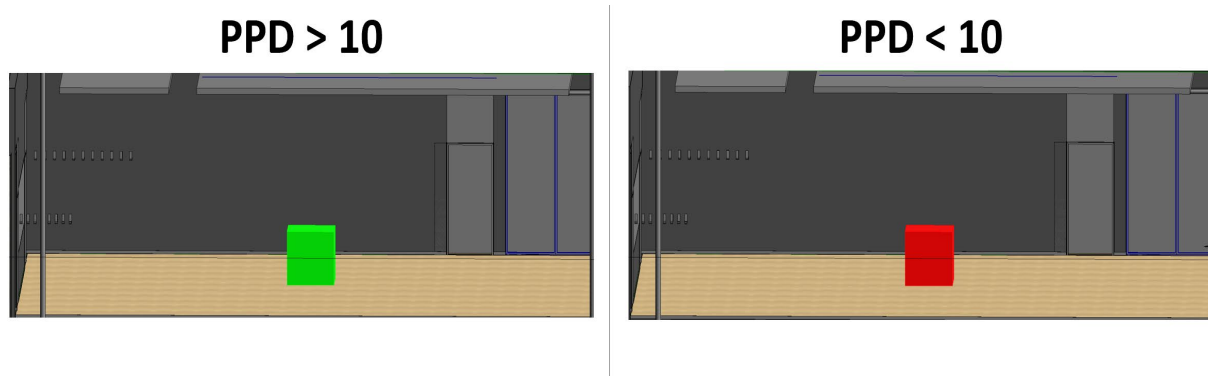


*Figure 31: Visualization of the information in Revit*

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[29]Dynamo Dictionary: https://dictionary.dynamobim.com/#/Revit/Elements/Element/Action/OverrideColor-InView

Although the data are easily readable in Revit, it has been necessary to find a way to share the results with the customers which usually do not have the expensive license to download the software, for this reason has decided to use Unity Reflect.

The main aim has been to create for the users a compelling visual experience accompanied with the possibility to see in real time the thermal comfort's change visualized thanks to the colour of the Totem, Unity Reflect is one of the very few software available on market able to do it.

For the customers have been developed two different possibilities for the visualization of the 3D model using Reflect Viewer on desktop and on iOS. For both the scenarios is necessary to synchronize the project in Revit with Unity and share the project with the Unity account after the log in.

Using the iOS version is possible to activate the Augmented Reality experience allowing the designer to project the 3D model into the real word using the device's camera[30].

**Reflect Viewer on Desktop**

After opening the project in Reflect Viewer on Desktop the environment is as shown below:



*Figure 32: 3D model of the Student Building (outside view)*

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[30] Using the Reflect Viewer on iOS: https://learn.unity.com/tutorial/using-the-reflect-viewer-on-ios

The environment is completely explorable simply using keyboard and mouse and the customer can virtually enter inside the building and explore the interior in a very simple way.

The level of accuracy of the model is very satisfying considering that can be improved and personalized further with Unity Pro to suit your needs.
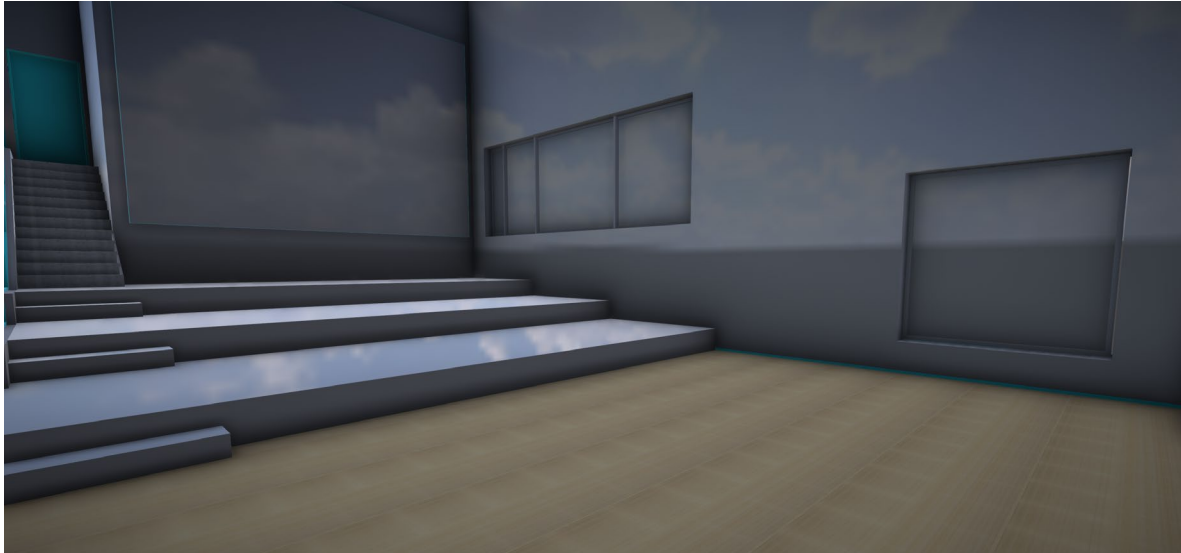


*Figure 33: 3D model of the Student Building (inside view)*

With Unity Reflect is possible also to manage the visibility of the elements inside the model, selecting the Category option, for instance, will display all the categories of components in the Scene.

Selecting the Eye icon is possible to turn off the chosen category while selecting a category is possible to highlight all the elements belonging to that category inside the view.
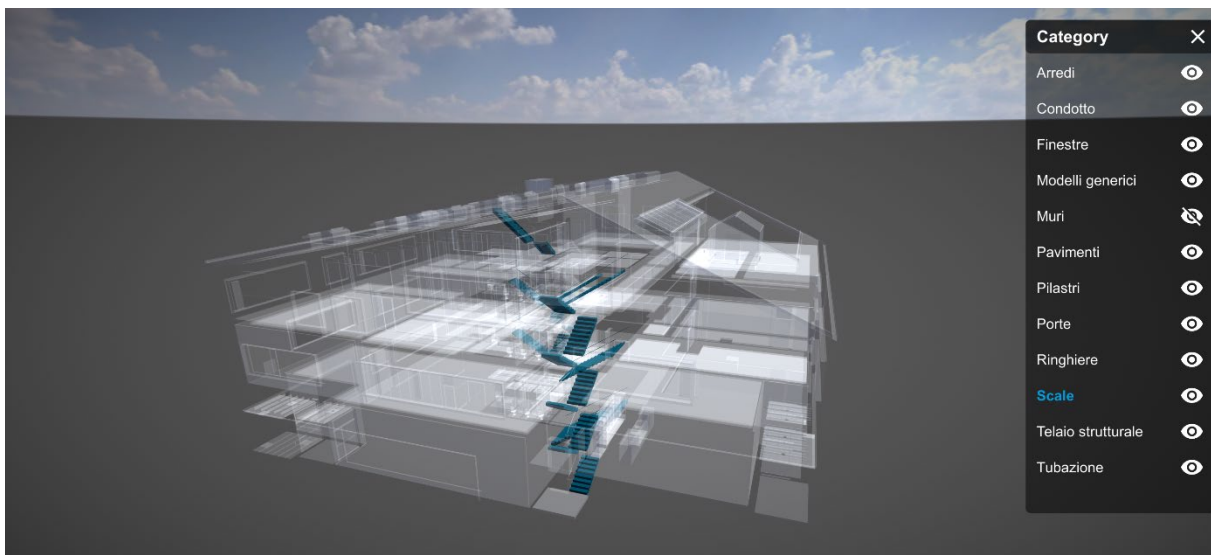


*Figure 34: 3D model of the Student Building (visualisation of the categories)*

Moreover it is possible to visualise correctly the colour of the Totem according with the PPD's value, in this way the customer can simply explore the model, enter inside the room of interest and check in few seconds if the thermal comfort of the room fulfils the requirement of ISO 7730 about PPD.
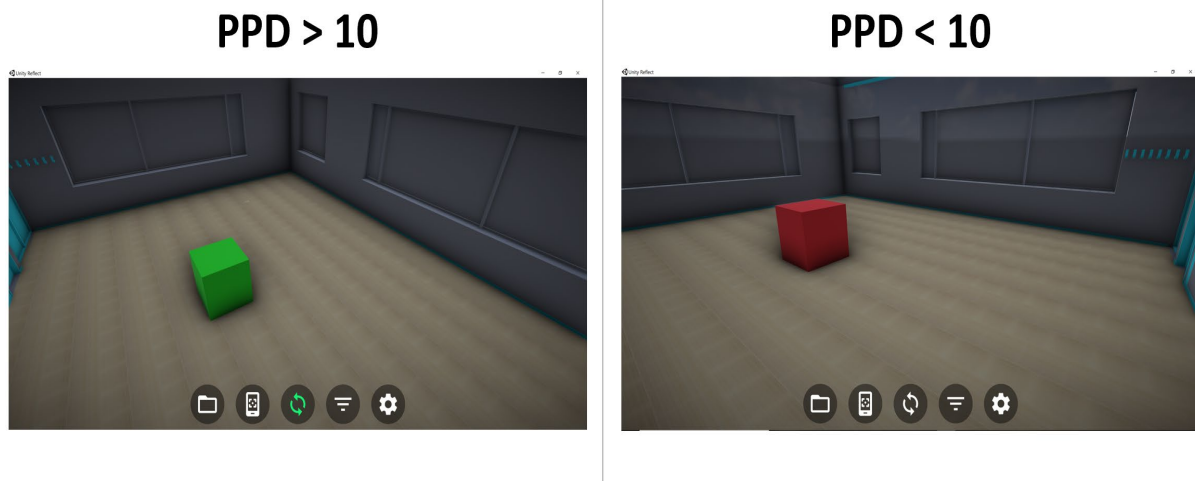


*Figure 35: 3D model of the Student Building (visualisation of the Totem)*

**Reflect Viewer on iOS**

To utilize Reflect Viewer is needed:

- an iOS-based device connected to the same network as the Reflect server;
- to install the iOS Reflect Viewer application available in the iTunes app store;
- to select the sign in option to access the chosen Unity account;

selecting the Mobile Button is possible to choose two different views:

- **On Screen** which is similar to the version on Desktop both for the view that for the features, the only difference is that the environment can be explored using the touch screen.
- **Tabletop AR** which allows the user to walk around a small-scale model of the building in Augmented Reality.

The Augmented Reality option allows the customer to project the 3D model into the real world using the device's camera and provide him a very immersive experience in which he is literally able to move into the environment with the phone.

All the functionalities available in the Reflect viewer are still available in the AR scene as the Layers button for the management of the visibility of elements in the scene[31].

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[31] Using the Reflect Viewer on iOS:
https://learn.unity.com/tutorial/using-the-reflect-viewer-on-ios?courseId=5dd58fc1edbc2a001f5b0b32&pro-jectId=5e71452cedbc2a11679e29f3#

After selecting the Tabletop AR option is necessary to detect a flat surface with the phone camera.
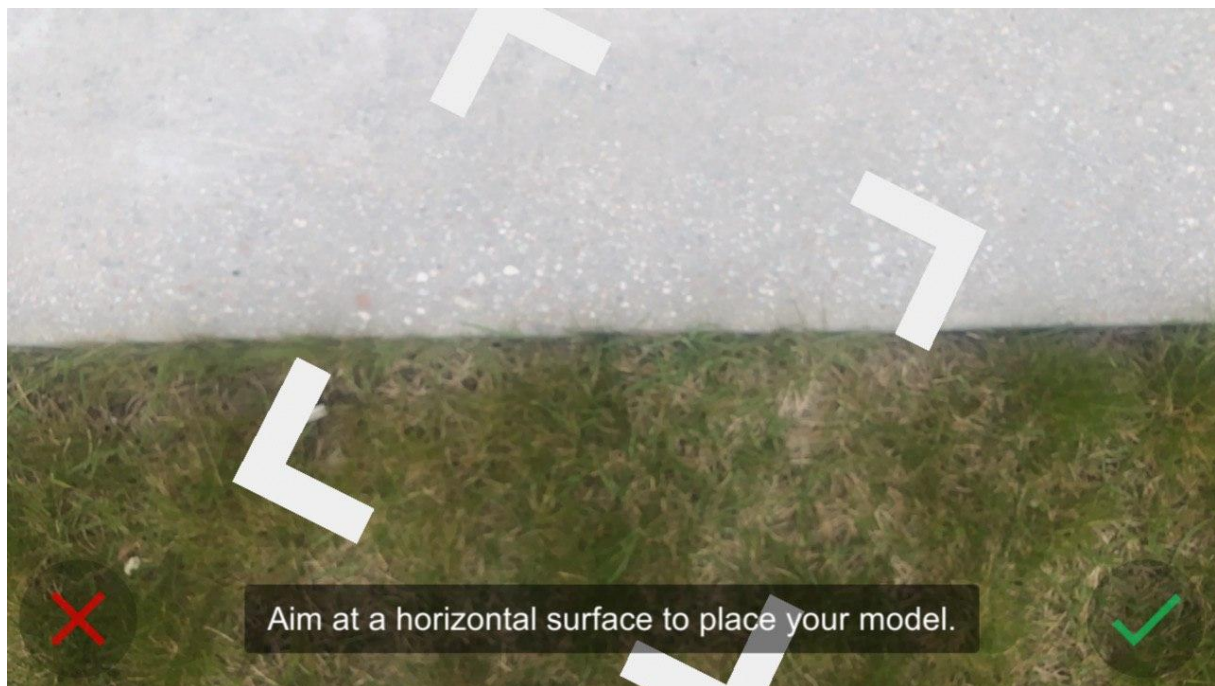


*Figure 36: Plane detected*

Once the green checkmark has been selected the augmented reality model will be placed in the scene, ready for being explored.



*Figure 37: Augmented Reality view*

Augmented reality provides an interactive and immersive experience in which real-world environments and computer-generated objects are enhanced.

While exploring the AR model of the "Undervisningshuset", moving the phone camera is possible to access the building and control the thermal comfort of the room.
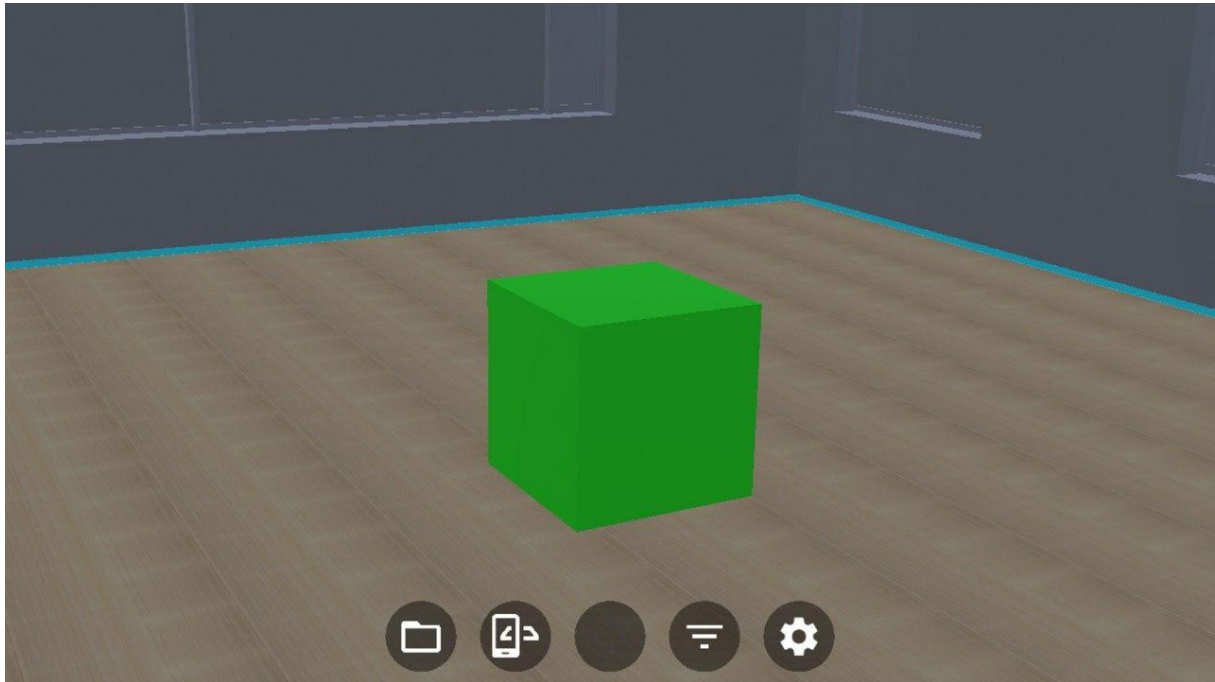


*Figure 38: AR model of the Student Building (visualisation of the Totem)*

## 4.3 Data export for following analysis

The final part of the workflow is focused on how to export the elaborated data from Revit to any database chosen, in the case of the developed project, an Excel spreadsheet.

It is fundamental to store data at the end of the process keeping track of the output values after all the calculations because they can be used for different purposes as:

- the monitoring of possible errors;
- development and verifications of models;
- more complex analysis of any kind.

In order to show how to export data and how they can be used, has been developed a protocol in Dynamo that allows to export the values of PMV and MV for each user in order to compare them and try to understand how the predicted mean value calculated the Python script differs to the one directly inserted by the user. In this way is possible to use data to validate or correct the model with the aim to have a better correspondence between real values and predicted ones.

The Excel spreadsheet where data are exported is organised in four columns containing the following information:

- Date of data entry;
- Name of the user who inserted the information;
- Value of the calculated PMV;
- Value of the MV inserted by the user.

| | date | user | PMV | MV |
|---|---|---|---|---|
| 1 | date | user | PMV | MV |
| 2 | 06/04/2020 17.44.28 | Giuseppe Digregorio | -0,23 | -0,5 |
| 3 | 06/04/2020 18.23.16 | Jacopo Castello | -0,23 | -0,4 |
| 4 | 18/04/2020 13.15.57 | Giuseppe Digregorio | -0,58 | -0,35 |
| 5 | 18/04/2020 16.49.57 | Carlo Loris Palombo | -0,46 | 0 |
| 6 | 18/04/2020 17.09.55 | Francisco Contente | -0,24 | 0,5 |
| 7 | 18/04/2020 17.20.57 | Andrea Spinella | -0,46 | -0,4 |
| 8 | 18/04/2020 17.51.18 | Jacopo Castello | -0,35 | 0,5 |
| 9 | 19/04/2020 9.56.07 | Alberto Romero | -0,33 | -0,5 |
| 10 | 19/04/2020 10.09.53 | Giuseppe Digregorio | -0,33 | -0,4 |
| 11 | 19/04/2020 10.26.25 | Carlo Loris Palombo | -0,33 | -0,3 |
| 12 | 19/04/2020 10.41.26 | Giuseppe Digregorio | -0,33 | 0,4 |

*Figure 39: Exported data from Revit to Excel*

Thanks to Dynamo it is possible to export data from Revit with the "ExportExcel" node which writes data to a Microsoft Excel spreadsheet. Data are written row by row with sub lists to be written in successive rows.

Inputs:

- filePath: string
- sheetName: string
- startRow: int
- startCol: int
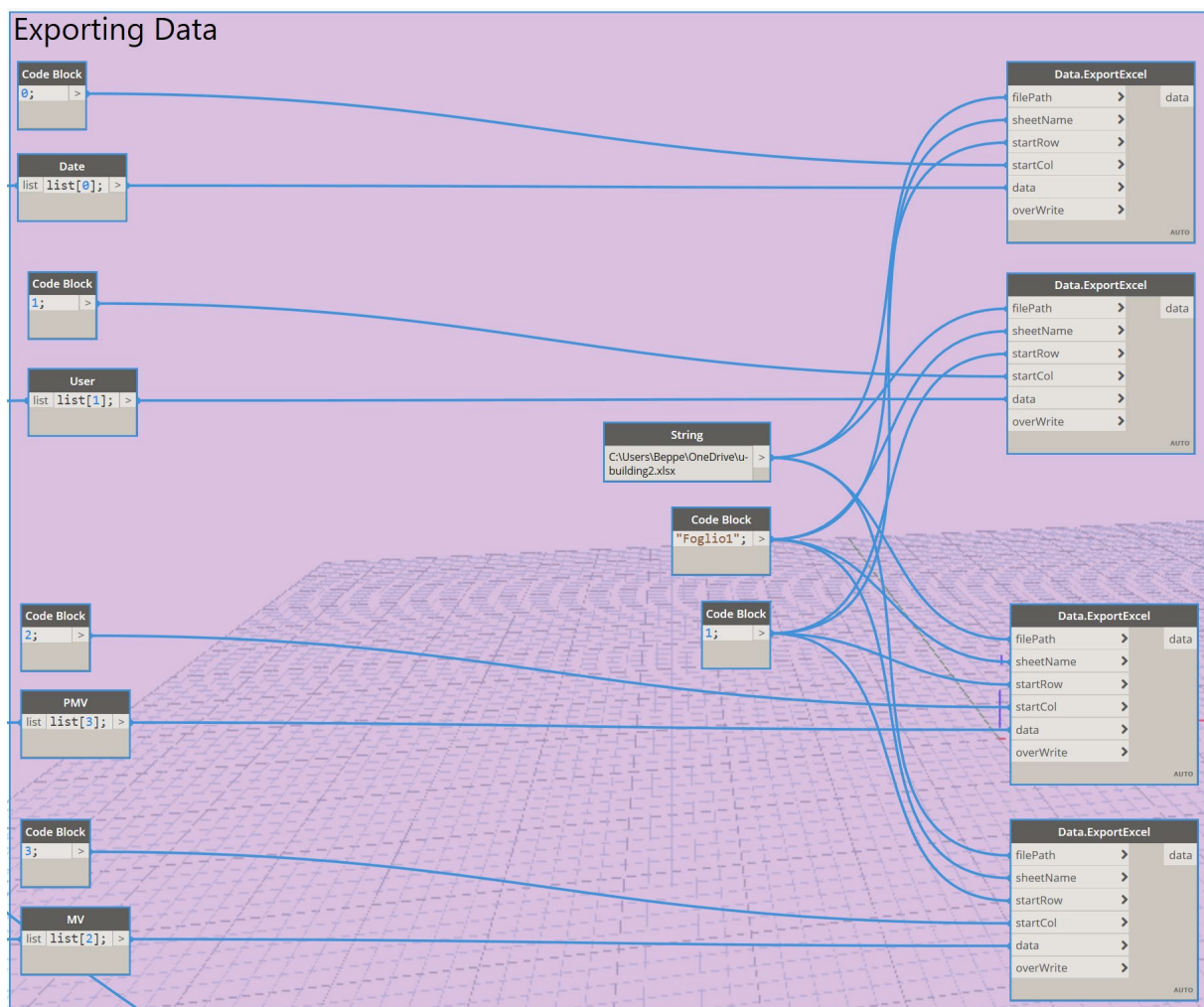- data: var
- overWrite: bool



*Figure 40: Workflow to export Data from Revit to Excel*

# 5 Discussion and Conclusion

*In this chapter have been discussed the relevance and importance of the results achieved with the developed project.*

*The aim of the first section is to summarize the key findings, interpret the results, their implications but also the limitation of the research while the one of the second paragraph is to clarify the contributions of the research why the protocol developed is important and innovative.*

*The third section shows other possibilities of use for the protocol in addition to the one considered into the project degree in order to display how useful can be the integration of real-time data and BIM.*

## 5.1 Discussion

The results indicate that the aims of the project have been achieved, the customer has an active role in the process in order to be part of the "BIM process" and the data visualization is very effective.

Thanks to the QR-code the users can share information in a very simple way and Dynamo allows to insert them into the model in real-time and to export the elaborated information demonstrating that it is a tool suitable for our purpose.

The visualization via colour code is very simple and understandable, moreover the possibility to let the customer use the Unity Reflect Viewer in two different ways represents an important achievement making possible for every customer to explore the model, visualize the information available especially with the AR version available on iOS device.

The results show that with the designed protocol it is possible to manage and collect a great quantity of real-time data and let them interact with the BIM model of the building with the purpose to improve the everyday-life of the customers and help the designers in the decision-making process.

Due to the fact that real-time 3D software for BIM are very new on the market, Unity Reflect, for example, has been released in late 2019, they do not present yet all their potential. Because of this the visualization of the Totem's colour is not completely in real-time but it is necessary to resynchronize the model in Revit.

The resynchronization of the model can be performed with the simple click of a button in Revit and by reopening the model in Unity Reflect, it is very simple and does not affect the results obtained. After various attempts it is possible to assert that probably the problem is linked with the interoperability between Dynamo and Unity Reflect but in the coming years it will be almost certainly fixed.

Although in literature is possible to find examples regarding BIM and real-time data, the totality of them do not take into account the human factor, they do not consider people as a part of the process and although sensors nowadays are very reliable, for the development of this technology is necessary to involve them and to let them understand the enormous advantages of the BIM revolution.

Compared with other research, in this project has been given very importance to the visualization of the results in order to create an immersive experience for the user, further studies should take into account to improve this experience bringing BIM data into virtual reality (VR), which can be very simple with Unity Reflect VR Viewer.

## 5.2 Conclusion

We have seen that Real-time data and BIM are becoming two of the major characters among the AECO industry and represent powerful tools for improving deeply the way facilities are designed and managed. This "revolution", driven also by various governments, requires new levels of knowledge focused especially in computer science, more precisely in database management and coding in different programme languages. These types of skills don't usually belong to the background of a civil engineer but are necessary if we want to really improve the way buildings are administered.

Although Revit and Dynamo represent powerful tools for the management of data, in literature it is difficult to find a protocol that explains and shows a complete workflow to import, manage and export data in real-time. The protocol developed in this project deals with all the steps of the data process in a clear way with a special focus to the visualization of data not always accessible for everyone because usually requires paid software which cannot be afforded by everybody. In this project thanks to Unity Reflect the customer is able to explore the model and visualize the information just downloading an app on the phone.

During the development of the project a great importance has been given to final users with the certainty that if customers were placed in a position to understand the unlimited potentiality of this technology the AECO industry would benefit enormously from it. The human element has influenced every decision performed in order to find every time the most simple solution for the customer among the ones available, this choice has made the development of the workflow more difficult but it has been necessary to meet the objectives set out during the concept phase.

The study case chosen is a clear example of how real-time data can be imported and used for very important problems that affect facilities, a deep knowledge of the phenomenon achieved collecting and storing information represent the first step for the resolution of this kind of difficulties.

The management and the processing of data in real-time represents a powerful tool for the decision process, one of the greatest strengths of the developed protocol is its great versatility, the study case chosen deals with thermal comfort but it can have infinite different applications possible keeping the workflow structure intact.

## 5.3 Possible future applications

The protocol has been developed in order to provide a versatile tool, suitable for a wide range of cases. Although the project has been considered thermal comfort indoor, the same workflow can be used for the management and visualization of a great number of phenomena.

The implementation of the developed protocol with actuators and sensors would represent an important breakthrough in a wide number of applications fields. The possibility to link together BIM, real-time data, actuators and visualization tools can really help engineers to design smart buildings and infrastructure able to manage and monitor themselves.

The applications below represent perfect examples of how useful a data management protocol can be, especially if implemented with actuators and sensors. Although real-time data management can be very effective for decreasing costs and time of realization and management they can be used to deal with issues related with safety of people and infrastructure monitoring.

### 5.3.1 Bridge Monitoring

Nowadays bridge monitoring is an important topic, with the available technology and knowledge the collapse or the lack of control of some bridges is not acceptable anymore and is AECO industry's duty to face this important problem.

The possibility to place and set-up a certain number of sensors that in real-time are able to send the data collected to the database and from that one to the chosen BIM software could be very helpful in different applications.

With the data collected by the placed accelerometers it could be possible to validate the designed FEM model of the bridge monitored with the calculation of real acceleration, eigenfrequencies and displacement and with software like Dynamo would be possible to insert this information into the BIM model for further analysis.

Moreover a protocol able to analyse automatically the accelerations detected, calculate the deflections along the bridge and warn the monitoring centre or directly close the bridge in case of extremely worrying deflections could represent an important step forward for bridge monitoring in terms of safety but also in terms of maintenance management.

Another interesting possible application is the development of a protocol for the inspection of the infrastructures, tools like QR codes allow the inspectors to insert in a simple way data and comments about the state of the structure and collect it into the BIM model in order to control in a smart and efficient way the management and the maintenance of the facilities.

In light of what said above it is clear that the management of real-time data can be a game changer for the management of infrastructures as bridges resulting in a decrease of management and maintenance costs and increasing security for the structure and safety for users and workers.

### 5.3.2 Management of indoors during epidemics

The situation going on all over the word concerning the virus COVID-19 is showing us the importance of the air quality in indoor environments of facilities and buildings.

Due to the lack of proper digital tools that automate air quality management, the AECO industry should consider the possibility of developing such systems to fulfil this absence. In this optic, an optimal solution could be the usage of probes and sensors that provide real-time data to a BIM software, which would process them and elaborate further actions.

For example, it could be possible to collect real-time data from indoor sensors in order to analyse the indoor air quality or the presence of possible indicators of viruses presence. This data can be used to automatically control the air conditioning system in order to take the proper measurements on the room at risk avoiding the inefficiency otherwise generated by a centralized system which could not do this.

Could be possible also to set-up other ways to sanitize the room as UV lamps, activated thanks to specific sensors. Real-time data can be inserted in BIM software to reach a spatial management of the indoor environment linking the data with the room correspondent giving to the manager of the facility real-time feedback useful for the decision making process.

Moreover data can be successfully exported to the BIM environment for further analysis and research about the spreading of the virus in inside environments and the efficiency of the methods implemented for the sanitation of the air.

Based on what stated above it appears clear that a protocol for the management and collection of real-time data in a BIM environment can handle a wide range of problems affecting facilities and infrastructures. This kind of application can sensibly improve the awareness and simplify operations during buildings-related works, both for on-place and remote actions, creating a more direct link between workers and engineers.

# References

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