DIGITAL TWIN FOR INDOOR AIR QUALITY

BY

HAMIDREZA NOROOZI

THESIS

For the degree of Master of Science in Architecture for Sustainable Design

University of Politecnico di Torino, 2023

Supervisor:

Professor Anna OSELLO

Eng. Matteo DEL GIUDICE

ABSTRACT

By the presence of IoT and developing the systems by using internet the qualification and the accuracy of the life has become more and more important. These feature by using the sensors and the technology of internet could reflect the future of the science.

By merging real-time monitoring and analysis of numerous environmental parameters, digital twin technology has emerged as a potential method for enhancing Indoor Air Quality (IAQ). This Thesis focuses on the usage of digital twins for IAQ, especially on its applications in people counting and Building Information Modeling (BIM).

IAQ is an important factor in building occupant well-being, and digital twin technology offers a comprehensive method to controlling and improving IAQ parameters.

By combining sensor data from numerous sources, such as air quality sensors, occupancy sensors, and BIM models, digital twins enable real-time monitoring of IAQ.

The number of individuals is important for IAQ management since it helps determine ventilation requirements and evaluate probable pollution sources. Occupancy sensors are used by digital twins to precisely detect the amount of people in a building, allowing for dynamic modifications to HVAC systems and ventilation rates dependent on occupancy levels.

BIM integration with digital twin technology improves IAQ management by enabling improved analysis and prediction of IAQ performance by giving a virtual model of the building and its systems. Digital twins provide proactive decision-making by merging BIM data with real-time sensor inputs, allowing building operators to identify and fix IAQ concerns quickly.

To My Mother and Father

List of Figures……V

Acknowledgments…… VIII

List of Acronyms …….... XI

Contents

1.INTRODUCTION..... 1

1.1. Digital Twin Preview For Indoor Air Quality (IAQ)..... 1

1.1.1. Building Information Modelling (Static Data)..... 2

1.1.2. Case Study (FCA)..... 4

1.1.3. Overview of Internet of Things (IoT) Using sensors (Dynamic Data)..... 7

1.1.4.The Strategy of Sustanaible Ventilation in IAQ..... 11

1.1.4.1. The definition of ACH and its formula……12

1.2. State of art in Digital Twin for IAQ..... 14

1.2.1. Reducing the Sick Building Syndrom and Building Related Illnesses..... 15

1.2.2. Reducing the presence of VOCs, CO2, Radon in IAQ……15

2. METHODOLOGY..... 18

2.1. The integration between Static Data (BIM) and Dynamic Data (IoT)..... 20

2.1.1. The simulation of Laser counter (DB)..... 20

2.1.2. BIM Model Set-up..... 24

2.1.3. Using VPL for data entry of BIM..... 29

2.1.4. Creation of filters for to control the occupancy load of each room……45

2.2. Presenting data with Graphical User Interface (GUI)..... 50

3. RESULT AND DISCUSSION..... 58

3.1. Interoperability value for digital twin……58

3.2. Analysis of data output……62

4. CONCLUSION..... 63

4.1. Summary of the Study's Findings..... 63

4.2. Future Developments..... 63

5. REFRENCES..... 65

List of Figures

1.1 Work-sharing for integrated model……2
1.2 BIM system process……3
1.3 FCA case study location……4
1.4 BIM model of case study……...5
1.5 The area of case study to design……6
1.6 Post design of the area first floor……7
1.7 Post design of the area second floor……...7
1.8 The history of IoT ……8
1.9 The edge building sensors……..……..9
1.10 The BIM model of the hospital and the sensors' locations……...……9
1.11 The algorithm of the sensors……10
1.12 The sensors' location on door……..10
1.13 The sensor S1and S2 and T1 models ……..11
1.14 The airflow rate formula ……13
1.15 The minimum standard of Qr-IAQ……..13
1.16 The VOCs definitions……...…...15
1.17 The incoming Radon from soil……16
1.18 The concentration of Radon in Italy in 2017……..…… 17
2.1 The thesis process…….……19
2.2 The excel for laser counter occupancy……..20
2.3 The applying developer tab in excel……..21
2.4 The developer customizing manually……....21
2.5 Active the Macro in excel……22
2.6 Creating two Macros…….……22
2.7 The Macros Codes……23
2.8 Creating shared parameters …….. 24
2.9 Creating parameters group……25
2.10 Creating parameters type……25

2.11 Applying parameters in project parameters……26
2.12 Creating a new project parameters…….26
2.13 Choosing the project parameters type and category…….. 27
2.14 Applying the parameters in room tag…… 28
2.15 Editing the room tag and loading in project……...28
2.16 Using file path for importing the excel file……30
2.17 Importing the excel file……..30
2.18 Using remove list for the list 0…….,……..30
2.19 Creating input laser counter simulation…….31
2.20 Importing the rooms……. 31
2.21 Connecting the rooms to imported excel…….. 31
2.22 Getting the data of LOC……..... 32
2.23 Representing the laser counter in room tag…….……. 32
2.24 Creating the standard occupancy load…….……..…33
2.25 Representing the acceptable occupancy in room tag……..…….….33
2.26 Using python script for conditional situations…….34
2.27 The script of python…….34
2.28 The LCO and AOL comparison…….…..35
2.29 Representing the conditions in comments of rooms……....…...36
2.30 Creating the airflow rate formula in VPL.....36
2.31 Airflow rate conclusion based on LCO and AOL.....37
2.32 Importing the volume room 1.....37
2.33 Final ACH results based on LOC and AOL.....38
2.34 Gathering the ACH of all rooms.....38
2.35 Sorting the data of parameters.....39
2.36 Sorting the data of ACH of rooms.....40
2.37 Using exporting excel node.....41
2.38 Giving the file initial information to excel.....41
2.39 Connecting the all data sorted to the exported excel..... 42
2.40 Exported excel view..... 43

2.41 Whole system of VPL in Dynamo.....44
2.42 The view of Visibility/Graphic.....45
2.43 Creating the filter in VG.....46
2.44 Creating the filter color in VG.....47
2.45 Final result of applying filters in VG view 48
2.46 Final result of applying filters in first floor plan.....49
2.47 Importing the excels in Power BI.....51
2.48 Loading the data of excels in Power BI.....51
2.49 Uploaded sheets in Power BI.....52
2.50 Creating the co-relation between sheets.....52
2.51 Using filters to present the rooms..... 53
2.52 Using filters to present the times..... 54
2.53 Using funnel data analyzer to present the LOC and AOL..... 54
2.54 Using clustered column chart to present the ACH LOC and ACH AOL.....55
2.55 Using single number to present the ACH(AOL)-ACH(LOC)..... 56
2.56 Final sheet 1 design in Power BI..... 57
3.1 First result in on first floor..... 59
3.2 Second result on first floor..... 60
3.3 Third result on second floor..... 61
3.4 Forth result on second floor..... 62
4.1 Further development possibility..... 64

ACKNOWLEDGMENTS

Questo progetto non sarebbe stato possibile senza il supporto di molte persone. La mia relatrice, Anna OSELLO e Matteo DEL GIUDICE hanno apportato numerose revisioni e mi hanno aiutato a chiarire la confusione. Inoltre, voglio ringraziare i miei veri amici Euprepio e Nicola per avermi aiutato in qualsiasi momento. Grazie anche ai dipendenti del reparto DAD e DISEG. Grazie all'Università del Politecnico di Torino per dare la possibilità agli stranieri di studiare e salire di livello. E infine, grazie ai miei genitori e ai miei amici Tara, Omid e Rira che hanno sopportato questo lungo processo con me, offrendo sempre sostegno e amore.

This project would not have been possible without the support of many people. My supervisor, Anna OSELLO and Matteo DEL GIUDICE numerous revisions and helped clarify the confusion. Also, I want to thank my true friend Euprepio e Nicola for helping me at any time. Also, thanks to the DAD and DISEG department employees. Thanks to the University of Politecnico di Torino to give the chance to foreigners for studying and levelling up. And finally, thanks to my parents, and my friends Tara and Omid and Rira who endured this long process with me, always offering support and love.

List of Acronyms

ACH

Air Changing per Hour

AOL

Acceptable Occupancy Load

BIM

Building Information Modelling

BRI

Building Related Illnesses

DB

Data Base

GUI

Graphical User Interface

HVAC

Heating Ventilation and Air Conditioning

IAQ

Indoor Air Quality

IoT

Internet of Things

LCO

Laser Counter Occupancy

VPL

Visual Programming Language

VOC

Volatile Organic Compounds

VBS

Visual Basic Script

VG

Visibility/Graphic tab in Revit

MQTT

Message Queue Telemetry Transport

SBS

Sick Building Syndrome

1.INTRODUCTION

Air pollution is the single largest environmental health risk in Europe. Heart disease and stroke are the most common reasons for premature death attributable to air pollution and are responsible for 80% of cases of premature death; lung diseases and lung cancer follow.[1] Air pollution could be separated into two different categories according to the location of a person, one of them is the outdoor air quality, and another is indoor air quality (IAQ). Also, the definition of air pollution could be Any alteration of the chemical, physical, biological characteristics of air, due to changes in the concentration of its normal constituents, and, above all, due to the presence of new compounds, harmful to animals, humans, vegetation, and/or materials.[2]

Attempts have always been made to improve indoor air quality using HVAC systems based on variables that have a direct impact on air quality. These variables have a direct impact on human health. Therefore, monitoring indoor air quality can lead to a reduction in these impacts in each location. Many factors are required for a qualified IAQ, and each of them can play a crucial role.

Although, there are so many factors for reaching the better monitoring the air quality like the sensors for detecting the CO2, NO2, and …, however, just a few research and essays focused on the occupancy load which not only plays a huge role in air quality, but also it was the most important factors during the Covid-19.

In this work, an attempt was made to develop a real-time indoor air quality monitoring system based on the digital twin as dynamic data and the Building Information Modeling System as static data of a building in Torino named FCA, which was a location for manufacturing Fiat and some other car companies in Italy.

1.1. DIGITAL TWIN PREVIEW FOR INDOOR AIR QUALITY

A Digital Twin is an integrated Multiphysics, multiscale simulation of a vehicle or system that mirrors the life of its corresponding flying twin by using the best available physical models, sensor updates, fleet history, and so on." The Digital Twin is ultra-realistic and may take into account one or more critical and interdependent vehicle systems like propulsion/energy storage, avionics, life support, vehicle construction, thermal management/TPS, and so on. Manufacturing flaws that may have an impact on the vehicle may also be specifically evaluated.[3]

In addition to this, among all sources A Digital Twin is a virtual replica of a physical system or asset that is used to simulate and analyze its behavior under different conditions. In the context of indoor air quality, a digital twin can be created to model the behavior of a building's HVAC (heating, ventilation, and air conditioning) system and the flow of air throughout the building.

By creating a digital twin, building operators can monitor and optimize the IAQ parameters in real-time, such as temperature, humidity, occupancy load and air quality, which leads to improve indoor air quality and occupant health and comfort.

1.1.1. BUILDING INFORMATION MODELING

The key element of sharing ideas among the engineers and actors has always given to the representation languages in the construction process. From this point of view, the construction industry has seen many developments during that time.

Nowadays, one of the most important developments for the AECO individuals is to share their works in a digital way. Building Information Modeling, known as BIM, enables the engineers and architects to share their work interoperability.

By the presence of BIM engine 3D modeling the losing data is limited to the minimum. This fact comes from the flexibility and the power of the BIM modeling as a static model but with a lot of parameters.

BIM enables effective collaboration among architects, engineers, contractors, and other project stakeholders. Different teams may use BIM to access a common database, allowing them to collaborate in real time and make educated choices. It means that a team whole can use a single database DB model with the specific collaborations of different scales.[4]

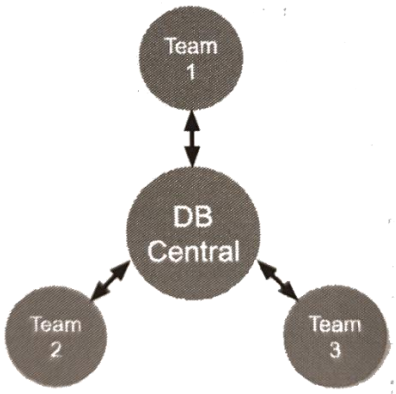


Figure 1.1: work-sharing for integrated model [5]

BIM acts as a central repository for all construction-related data, including designs, materials, specifications, and papers. Construction teams may use BIM to work quicker, more precisely, and make more significant decisions.

By simulating energy analysis and displaying material utilization, BIM aids in the promotion of green building practices and sustainability. Architects and designers may determine the most

efficient strategy to decrease energy use, carbon footprint, and environmental impact by modeling several scenarios of building design.

Overall, there are so many benefits in using BIM modeling and giving a specialized parameter of a specific project. We can say that BIM could increase the accuracy, flexibility, cost efficiency, and sustainability of a project.

Figure 1.2: BIM system process [6]

1.1.2. CASE STUDY

In the 1960s and 1970s, several Italian automotive manufacturers (that later merged into the FCA Group) launched programmers to protect and promote their historical heritage, which led to the opening of the Centro Storico Fiat (Fiat Historical Center) in Turin in 1963.[7] It is in Mirafiori area of Torino.

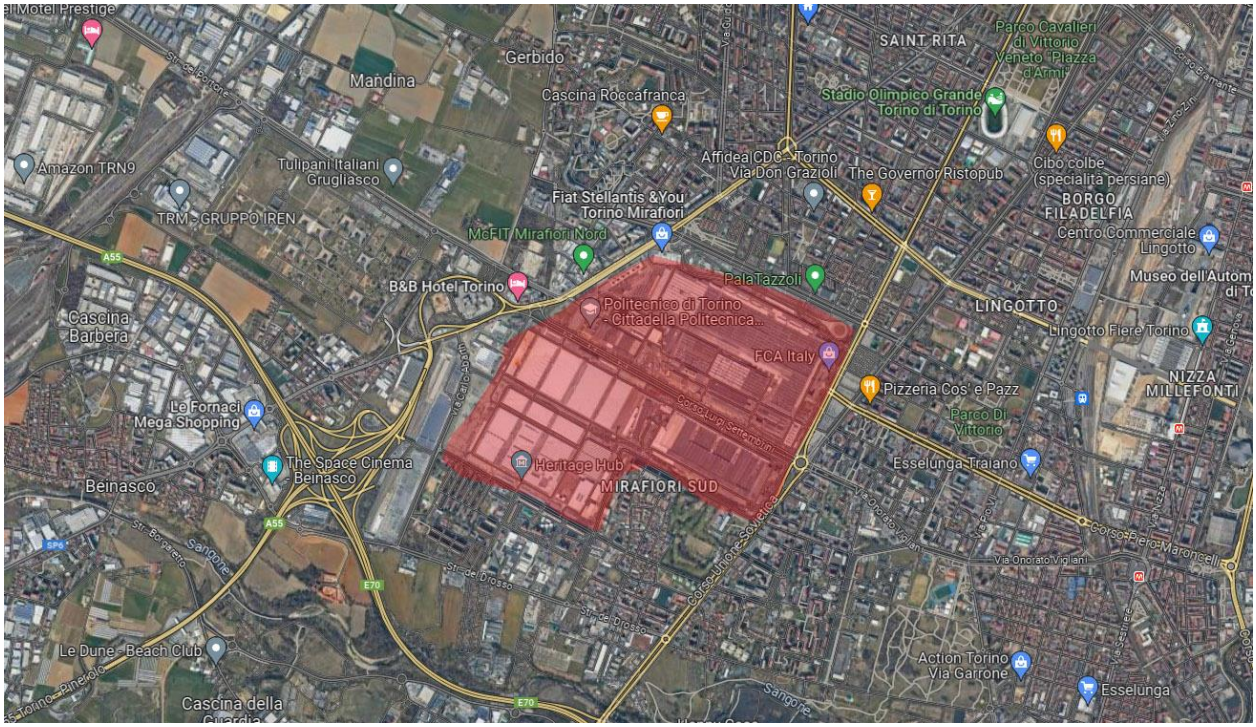


Figure 1.3: FCA case study location

These days, according to the policy of municipality the FCA has been moved to another place and the building of FCA is abandoned. This part of the building is constructed by the steel structure. The area of FCA is around 2.000.000 m_2 in which it was divided into the manufacturing, testing system, offices, and montaging system.

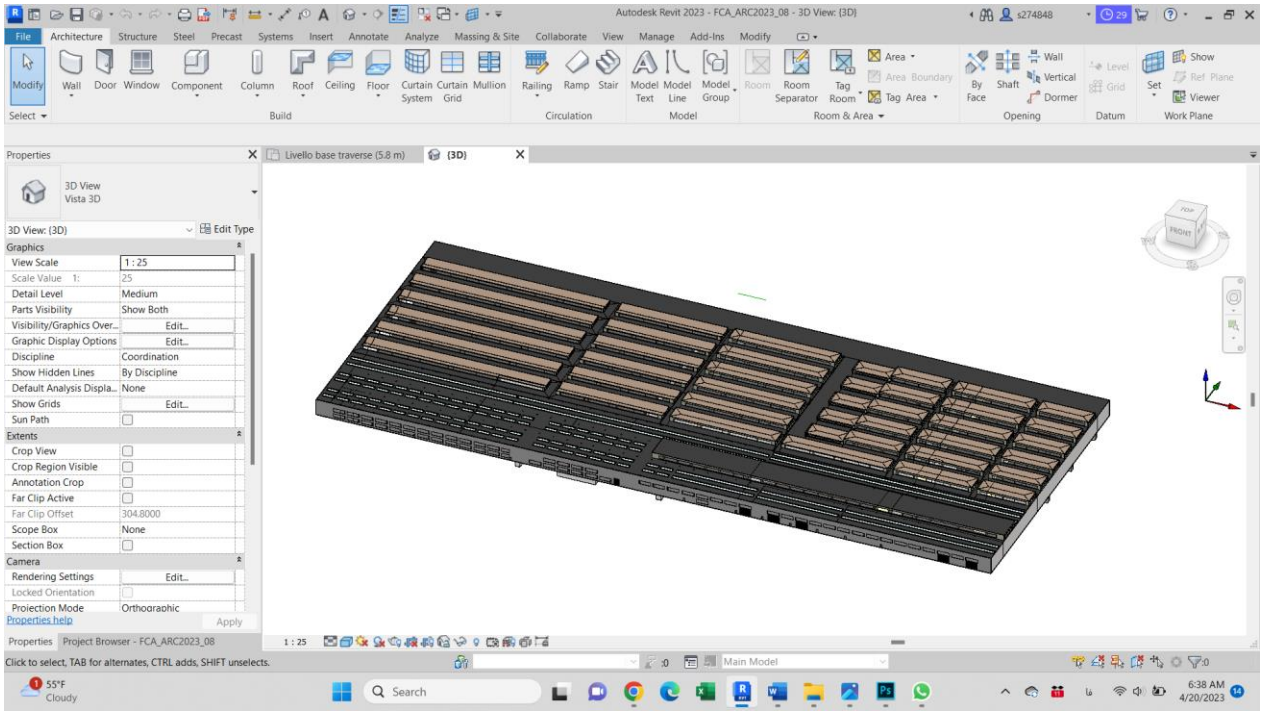


Figure1.4: BIM model of case study

The figure above shows a part of a FCA, and it is created by the Revit software, known as one of most useful BIM software in the world.

The part of building which I have chosen for the designing was dedicated to the offices of FCA in past, it is located between columns 20-24 in vertical axis and columns 60-64 in horizontal axis the purpose of designing remains for the office with the 11 rooms, but some changes have been taken into consideration like adding the test area for the cars in past uses to office.

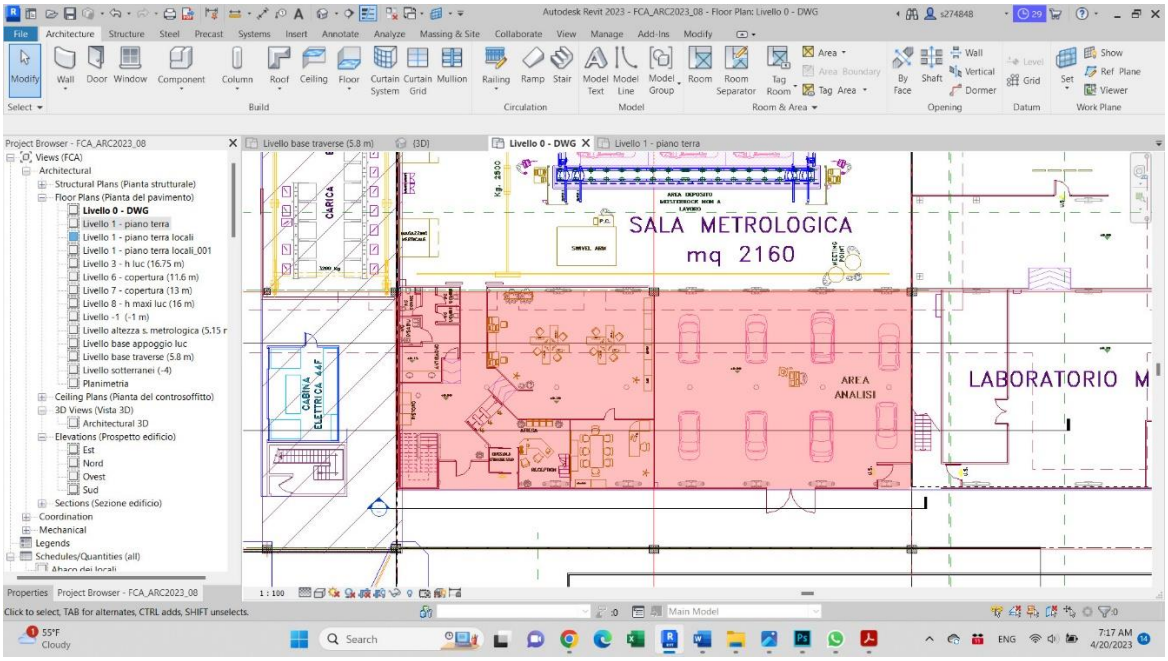


Figure1.5: The area of case study to design

Figure 1.5, highlighted by red, represents the previous situation of FCA consist of the area analysis of cars and an office which I have chosen to create the new office in two levels. It has been prevented to change or reconstructed the main walls, however, the interior walls changed and redesigned. Figures 1.6, 1.7 illustrate the plans of ground floor and the first floor after the design phase.

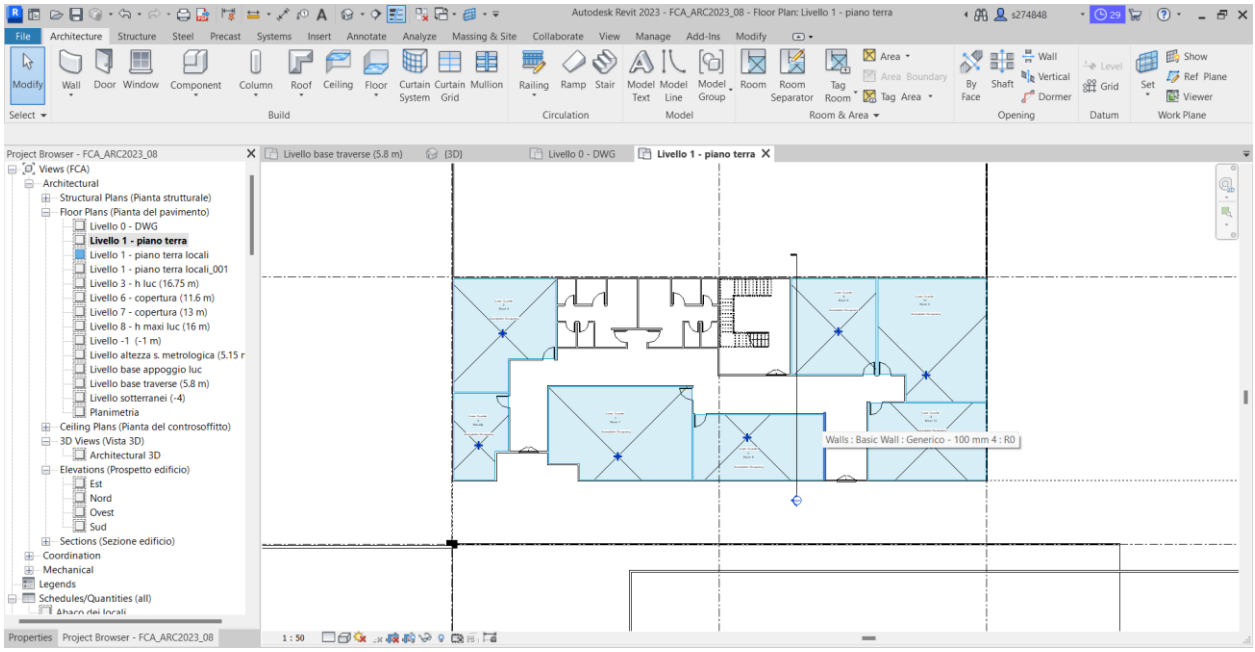


Figure1.6: post design of the area first floor

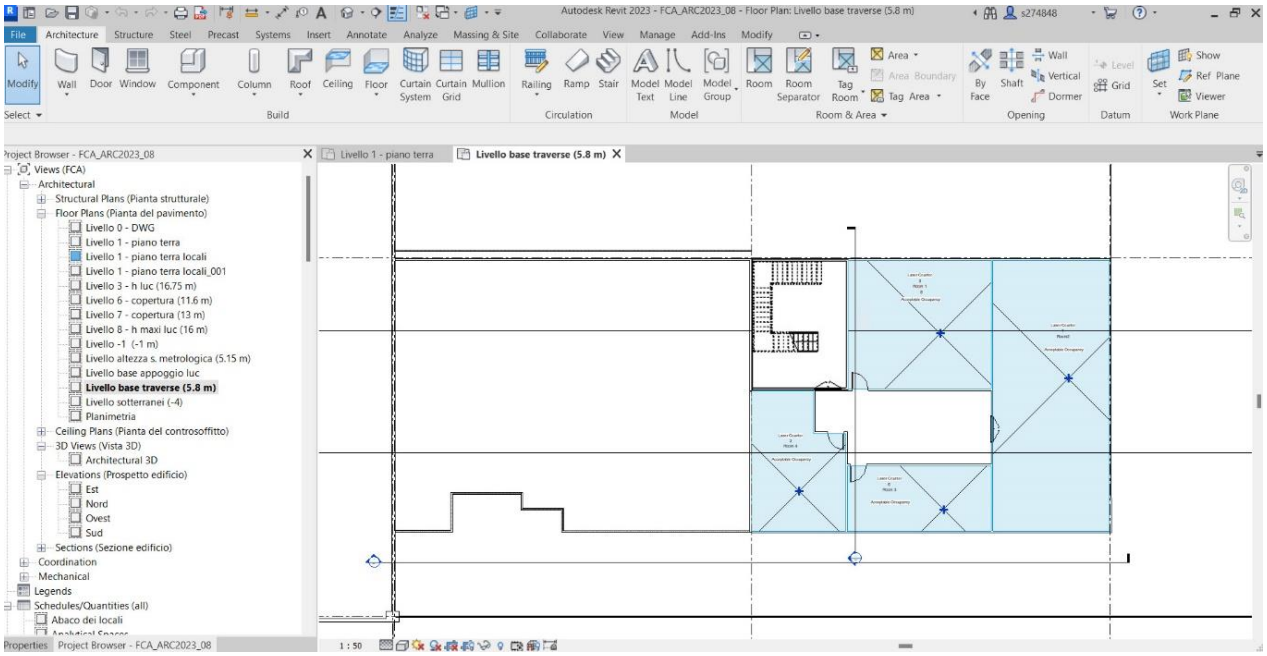


Figure1.7: post design of the area second floor

1.1.3. OVERVIEW OF INTERNET OF THINGS (IOT) USING SENSORS

In 1989, David Nichols and his colleagues at MIT invented the first IoT device, and this was shortly followed by John Romkey and Simon Hackett creating the Internet Toaster in 1991. The Internet toaster was a big milestone, as Romkey and Hackett successfully connected a toaster to the internet and managed to turn it on and off remotely.[8]

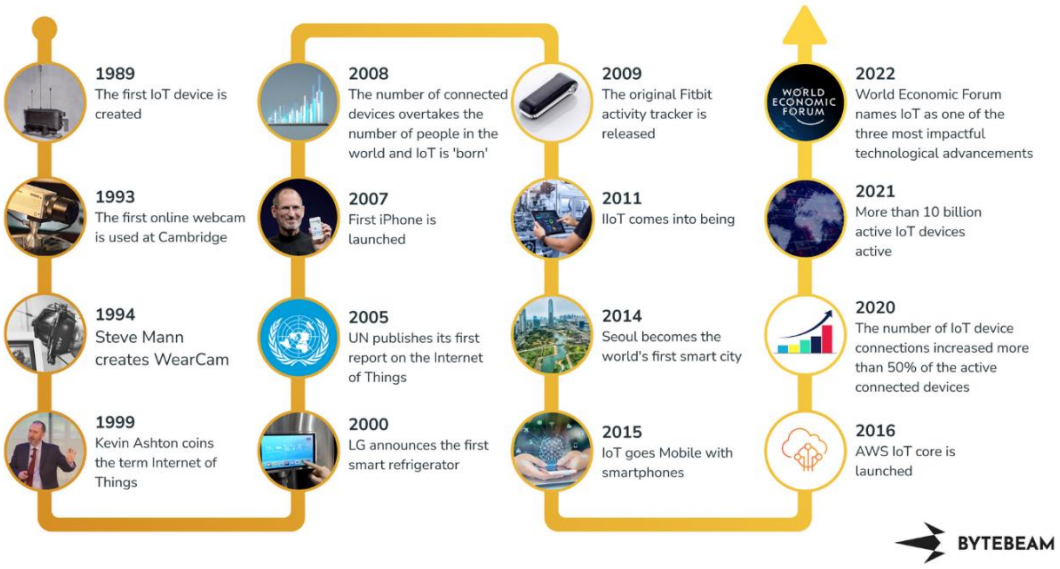


Figure 1.8: The history of IoT

The revolution of IoT will definitely change the whole world in few next decades in which machines will be grown enough to talk to each other and understand the process and keep doing the process without human-interference. Thanks to internet for leading to the human comfort, even these improvement could be sightly seen in the systems of HVAC in which the building core has a connection to the weather stations and get the data from sensors inside and the station to adapt the temperature of inside and even the position of shaders. It would be appreciated that; these movements are doing in a less than minuets. A good epitome of these kinds of buildings could be the Edge of Amsterdam building.

EDGE Amsterdam West is destined to become one of the most sustainable office buildings in the world. Located in Amsterdam West, the Netherlands, the 60,000m² multi-tenant office building is equipped with a smart, innovative heating and cooling solution where NovoCon® actuators guarantee a fail-free health-optimized indoor climate. EDGE Amsterdam West is an energy positive development based on its building consumption.[9]

Figure 1.9: The edge building sensors[10]

Also, there is another professional example which was done in one of the Torino hospitals. In this work the main idea of using the IoT was counting the users in each area and detection of accumulation of people. This project has been done after Covid-19 happened.

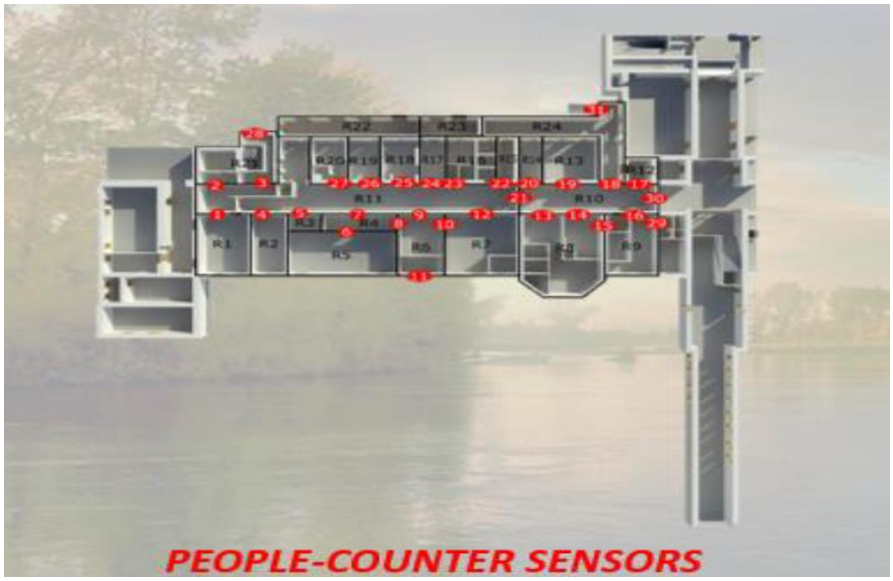


Figure 1.10: The BIM model of the hospital and the sensors' locations

The picture above shows the location of the sensors in a BIM model of building. After sensors calibration each door will have the own counting value that we are using this value to find exact number of the people in each dedicated place. In this way, the number of people could be controlled by the team to check the occupancy load of each area which leading to reducing the number of contaminated people by virus.

```
60 s1room1=s1
61 s1room2=s4
62 s1room3=s5
63 s1room4=s7-s6-s8
64 s1room5=s6
65 s1room6=s8+s9-s10-s11
66 s1room7=s10+s12
67 s1room8=s13+s14-s15
68 s1room9=s15+s16-sb
```

Figure 1.11: The algorythem of the sensors

In this simple algorithm s1room1 = R1 is the first room in the hospital and in this room we have just 1 door counting because of that the room value is equal to the s1(1.door calibrated sensor value).

When looking at the room4 = s7-s6-s8 that means dedicated directions of this room is inside (+) and outside is (-) and in this room we have s7, s6, s8 (door7, door6, door8).

1.Whenever a person come inside to the room4 with using s7 will increase the total number of the room4.

2. Whenever a person goes outside from with using s6 and s8 that will decrease the total people number in the room4.

Directions can be dedicated to whatever user wants so the algorithm can be modified based on the dedicated directions.[11]

They used two leaner sensors (S1, S2) and one multi-detection (T1) sensor in each door of rooms in which the leaner sensors can + or – the number of accommodations based on the direction of the multi-detection finds from movement of a person which wants to come in or out, moreover, this multi-detection sensor can define the temperature of the moving element. So, the sensor minimized the error of counting things instead of people.

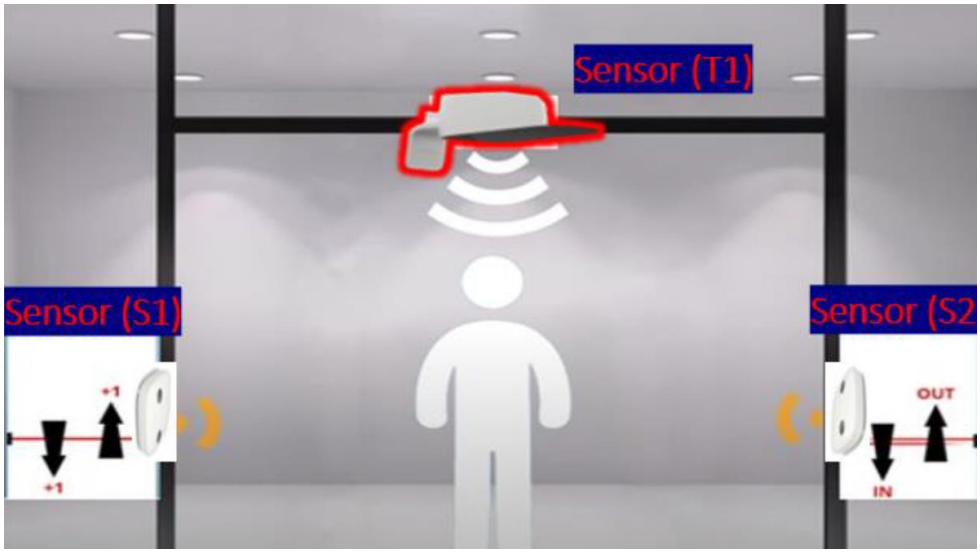


Figure 1.12: The sensors location on door

For S1, S2 linear sensors and T1 detection movement sensor there are some examples like

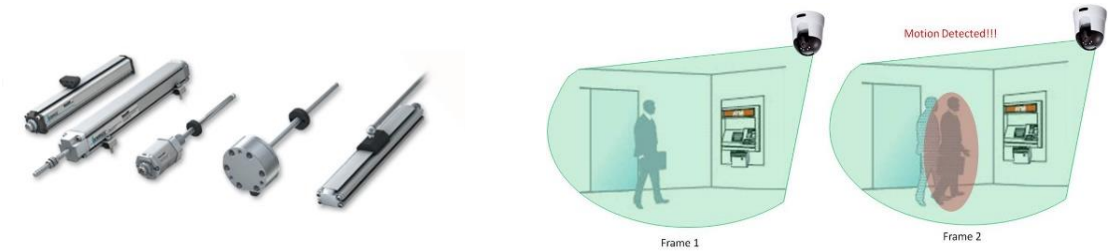


Figure 1.13: The sensor S1and S2 and T1 models

In this project all the sensors are connected to the gateway with MQTT protocol, and they are processed with some multithread C code to compute IN-OUT number.[12]

With the presence of gateway all the sensors could be connected to the chain network which is also connected to the main system.

The network e.g., IoT gateway, bridges sensor networks with the traditional communication networks. It settles the heterogeneity between various sensor networks, mobile communication networks, and the Internet (all computer networks).

The sensors also connected to the gateway through the wireless which is named Low-cost IoT-based sensing. The low-cost IoT sensors enable the use of wireless communications and computing for interacting with the physical world. The relevant sensors could sense indoor environmental parameters such as IAQ, comfort, lighting, and acoustic conditions.[13]

1.1.4.THE STRATEGY OF SUSTAINABLE VENTILATION IN IAQ

IAQ refers to the air quality within and around buildings and structures, particularly as it pertains to the health and comfort of building inhabitants. So, some of the strategies for having a sustainable ventilation system is to use low-emitting materials which means It is critical to utilize low-emitting materials whenever feasible to guarantee acceptable indoor air quality. Paints, adhesives, carpets, and other materials with low quantities of volatile organic compounds are examples of this. (VOCs). Moreover, appropriate ventilation is essential for ensuring healthy indoor air quality. In each building based on the environment, number of levels, structure, … sustainability has a special way for the ventilation system, and it is critical to have suitable ventilation systems in place and to have them maintained and cleaned on a regular basis. This includes air filters. Also, natural ventilation may be an excellent approach to enhance interior air quality while also lowering energy use. This might involve opening windows or utilizing other natural ventilation methods to breathe fresh air and finally the way that tested in this thesis is regularly monitoring the air quality to check the pollutant particles or accumulation of people over the HVAC potential system which cause the low quality of indoor air.

These mentioned technics could guarantee the qualification of the IAQ and the importance of these technics for the place that people are living or working is overweight of the place which people using as a temporary place like metro.

1.1.4.1. THE DEFENATION OF ACH AND ITS FORMULA

The amount of air exchanged in a room or space in one hour is measured in air changes per hour (ACH). It is used to quantify a room's or building's ventilation rate and is normally represented as the number of air changes per hour.

Simply said, ACH is a measurement of how frequently the air in a location is replaced with new air. For example, if a room has an ACH of 1, that indicates that once per hour, the whole volume of air in the room is replaced with fresh air. When the ACH is set to 2, the full volume of air in the room is replenished twice each hour.

The amount of carbon monoxide (ACH) in the air is a key indicator for ensuring appropriate indoor air quality, and it is determined by factors such as the number of people in the area, the size and form of the room, and the amount of time spent in the targeted area. In general, a greater ACH indicates better ventilation and a lower concentration of pollutants or toxins in the air. However, it's crucial to remember that ACH is only one of numerous elements that affect indoor air quality, and a high ACH isn't always required or desired. A high ACH can result in energy inefficiency and increased heating or cooling expenses in some instances, such as in extremely cold or hot climes.

Monitoring the number of people using IoT and embedded sensors results in two types of ACH in this thesis: one based on the laser counter and the other should be the ACH necessary based on the permitted occupancy load. These two variables indicate whether or not the ACH of actual time is enough.

Airflow rate for ventilation (IAQ)

$q_{r\text{-}IAQ} = q_{r\text{-}IAQ(p)} \times N_{occ} \times F_{occ}$ $[m^3/h]$

$ACH_{r\text{-}IAQ} = q_{r\text{-}IAQ} / Vol$ $[1/h]$

$q_{r\text{-}IAQ}$	*day-averaged required hourly volume airflow rate for indoor air quality [m^3/h]*
$q_{r\text{-}IAQ(p)}$	*minimum required airflow rate per person related to the considered space unit given in the Table 1 [m^3/h per person]*
F_{occ}	*occupancy factor [-] calculated as h_{occ} / 24 in which h_{occ} is the occupation duration*
$ACH_{r\text{-}IAQ}$	*day-averaged required Air Change per Hour for indoor air quality [1/h]*
Vol	*net volume of the considered space unit [m3]*

Figure1.14: The airflow rate formula [14]

Also, the amount of Qr-IAQ(P) could be found as below based on European standard EN 13779-2007

Airflow rate for ventilation (IAQ)

Table 1: $q_{r\text{-}IAQ(p)}$

Minimum $q_{r\text{-}IAQ(p)}$ for different space types	**m^3/h per person**
residence (bedroom, living, kitchen)	27
office	36
bar, restaurant	40
meeting room	32
gym	46
library	30

Figure 1.15: The minimum standard of Qr-IAQ [15]

In this thesis according to the design which is office the minimum required ACH per person considered as 36 and Focc also considered as 8 hours of working. Also, according to the ENE which is the combinations of European and American standards for the standard sq meter per person is considered as 7 sq meters equals to 85 sq feet.

In this work by the presence of the sensors which named as S1, S2, T1 before in this chapter, the Nocc will be the parameter that will be changed by the people enter or exit. Therefore, the parameter which the thesis will be focused on in this work will be this factor that makes the contamination of CO2, and other pollutant particles.

Another important factor which is calculated in the second formula is the volume or simply the geometry of the area of each room. What makes this formula different from current strategy of using HVAC system which are working according to the temperature, being set by a user, however, in this version the accumulation of people, the time of spending, and the area will be directly connected to the IAQ.

1.2. STATE OF ART IN DIGITAL TWIN FOR IAQ

The main idea of presenting this thesis was the reduction of the risks of human health while it is proved that people are working or living inside an area even more than 90 percent of daily time. As it is said that many dangerous risks, human are facing among the time that we are working or living by scientist, this fact that we are dealing with many risks in the daily routine, forced the architects and engineers to find a way to a stable strategy of the IAQ. The evidence shows also during the Covid-19 ventilation of each area and social distance play the most crucial role to avid the separation of the virus, as well as this, even CO2 or Radon which are produced during the breath of human and come from soil respectively cause the indoor air pollution. Moreover, there are some pollutant particles like VOCs which are toxic and will be discussed in detail in this chapter.

By the given vision, monitoring the number of occupancy load at real-time taken the priority due to the emission mentioned pollutions.

1.2.1. REDUCING THE SICK BUILDING SYNDROM (SBS) AND BUILDING RELATED ILLNESSES (BRI)

It is potentially necessary to separate the SBS from BRI because as the definitions say that SBS is not real illness, but BRI is a real sickness happen due to the chemical reaction of the elements in an indoor air, for having a better sense of each of them the definitions are defined as below.

Negative impact on health and on comfort due to prolonged stays (discomfort, illness, or real diseases) defined as “Building related illnesses” (BRI) or “diseases correlated to buildings”.

SBS (“Sick building syndrome”) happens when people feel uncomfortable when in offices, but it is not a real disease.[16]

Also, it is worth mentioning that both SBS and BRI are caused by the low indoor air quality and the accumulation of people. On the other hand, having a proper ACH in an area could help the reduction of these diseases and as illustrated in this thesis proper ACH needs the exact number of occupants. Therefore, monitoring the occupancy load could be one of the ways to reach this goal.

The most substantial pollution in an indoor air quality are the human metabolic activities, VOCs, Radon, equipment, and building materials.

1.2.2. REDUCING THE PRESENCE OF VOCs, CO2, RADON IN IAQ

Volatile Organic Compounds (VOCs) basically defined as (HC aliphatic, aromatic, chlorides, cycloalkanes, aldehydes, terpenes, olefins, alcohols, esters, and ketones)

They are produced from some building materials, finishings, furniture specially those made by wood, and in some especial temperature and RH microbes produce the MVOC (Microbial Volatile Organic Compounds)

They are also categorized in three different levels VOC, VVOC, and SVOC [17]

2.3.1 Volatile Organic Compounds – VOC

Organic compounds that are detected in the interval of n-hexane (n-C_6) to n-hexadecane (n-C_{16}) under the conditions specified in ISO 16 000 part 6.

2.3.2 Very Volatile Organic Compounds - VVOC

Organic compounds that are detected before n-hexane (< n-C_6) under the conditions specified in ISO 16 000 part 6.

2.3.3 Semi-Volatile Organic Compounds - SVOC

Organic compounds that are detected in the interval after n-hexadecane (> n-C_{16}) to n-docosane (n-C_{22}) under the conditions specified in ISO 16 000 part 6.

Figure 1.16: The VOCs definitions [18]

Above all, it is crucial that the VOCs are the one of the biggest groups which cause SBS.[19]

About Radon known as Rn in chemistry, the scenario will be different from VOCs because radon is created by some exchange in molecular of Radium which also called Radioactive and it is put in the carcinogenic group, means causes cancers.

Studies on underground mine workers showed the correlation between Rn exposition and the high eventuality of lung cancers.[20] So, it should be mentioned as a BRI element which comes from soil in the structure and then in the atmosphere of an area.

Figure1.17: The incoming Radon from soil [21]

Here is the concentration of Rn in Italy, showing the provinces situation.

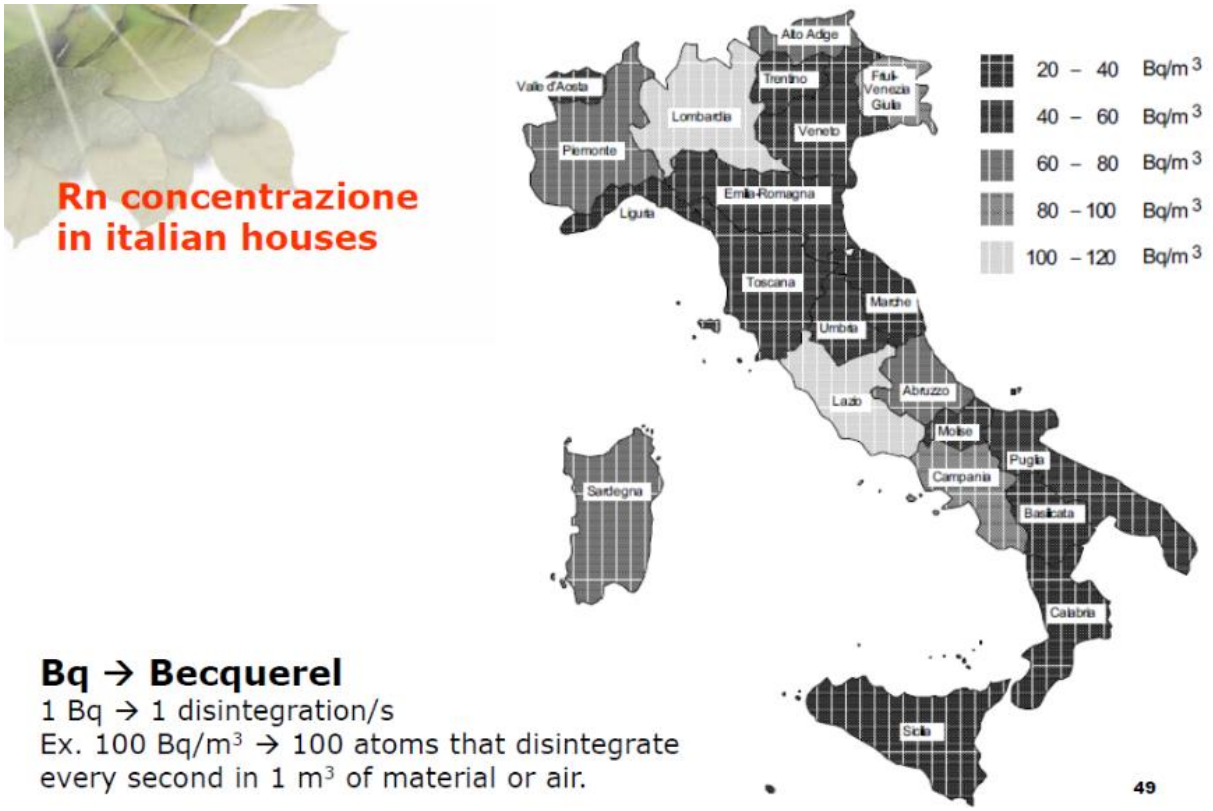


Figure 1.18: The concentration of Radon in Italy in 2017[22]

For VOCs and Radon, the effective ventilation system (a better ACH) is of the ways to get rid of those gases in indoor air.

2. METHODOLOGY

In this chapter we will see the methodology of the process of digital twin for indoor air quality. BIM model of FCA plays the static data and this model should be affected by the dynamic data of sensors. The first challenge was to find a common language between these two. After reading some articles I found excel so flexible to be a common language. This is coming from the fact that the excel is readable by many different software such as Revit as a BIM software or even Power Bi as a presenting software.

So, the data of sensors should be recorded in an excel file and the excel file should be as input data. However, Revit is not able to read the .xlm file which is the type of excel files. Thanks to creating the feature of Dynamo plugin in Revit by Autodesk to give the ability of reading this kind of files.

Due to the situation now, lack of time, and the cost of sensors, the dynamic data of sensor which is the number of people simulated and is not real.

After having complete data of each room these data should be represented in plans also. The final calculation will be done by the dynamo and the first output will be a file of excel and this file also calculates the second output and define the rooms which have more ACH based on occupancy load than the standard ACH based on the acceptable occupancy. Finally, the third result would be presenting and saving the data in a graphical way by using Power Bi.

The integration between BIM model and sensor simulation could be mentioned as a key of reaching the monitoring system of occupancy load which results in the ACH define in real-time and the indoor air quality at the end.

So, the hole process from starting point to the end could be divided into 3 different areas of input data, analyzing process, and the output data.

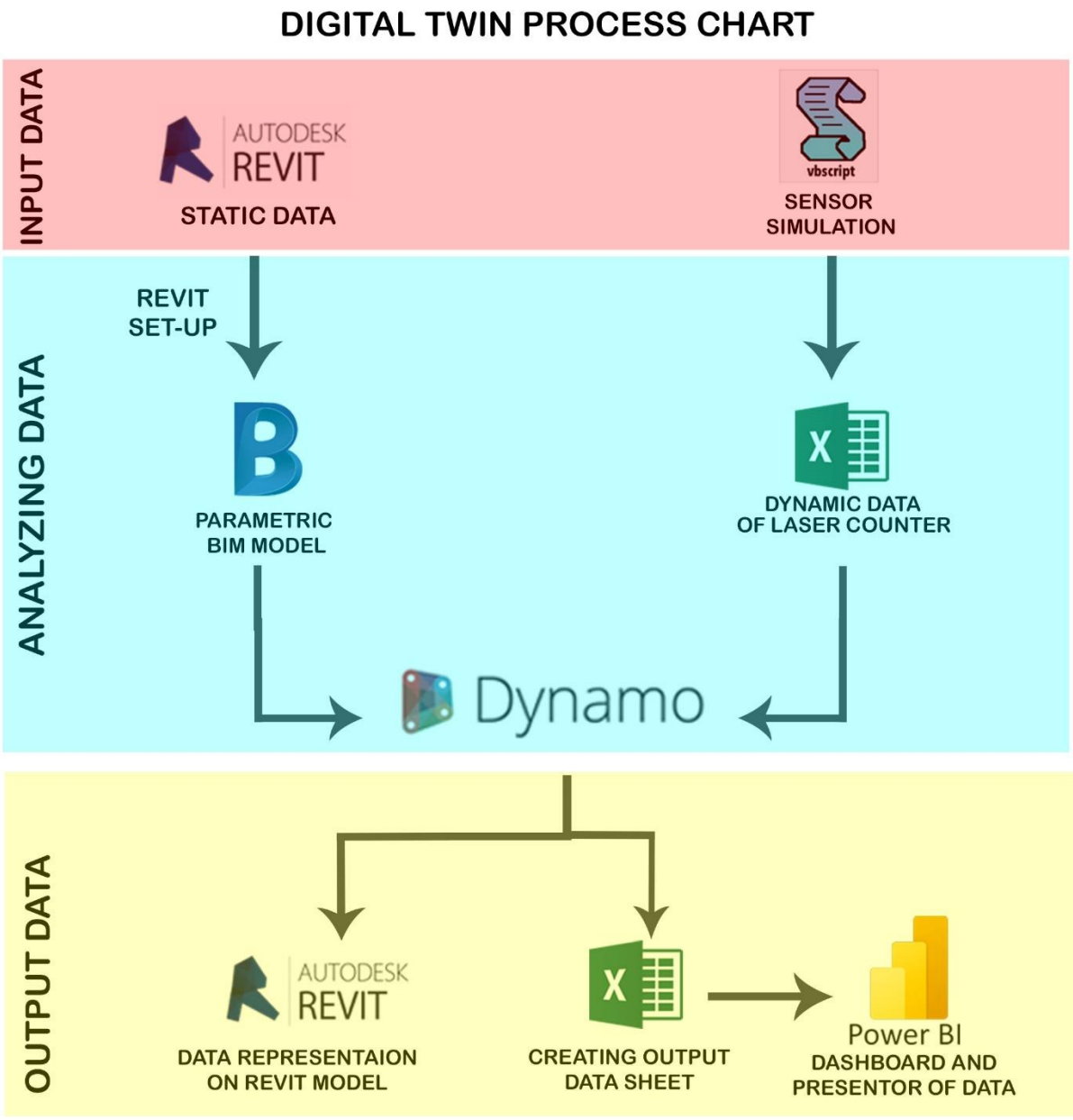


Figure 2.1: The thesis process

2.THE INTEGRATION BETWEEN STATIC DATA(BIM) AND DYNAMIC DATA (IoT)

2.1.THE SIMULATION OF LASER COUNTER (DB)

As mentioned before, due to the lack of time, lack of budget and the fact that the case study was closed, we could not apply real sensors to get the data. Therefore, we need dynamic data in real-time to change the number of people which is the parameter of my studies in this thesis. After having a lot of research, I found that the excel could be run also a dynamic data and it could give a random number of people for each room. This possibility is called My Macro in excel which uses VBScript (Microsoft Visual Basic).

VBScript is an Active Scripting language developed by Microsoft created in 1996 that is modeled on Visual Basic. It allows Microsoft Windows system administrators to generate powerful tools for managing computers without error handling and with subroutines and other advanced programming constructs.

In this case, although it would be better to use the real sensors and having a real data of number of people it is not necessary by the existence of my macro feature to have random number.

For doing the this, I have started to create an excel file and manage it into three different columns which is rooms, number of laser counter and the date of record. In this case study I have designed an office with 11 rooms.

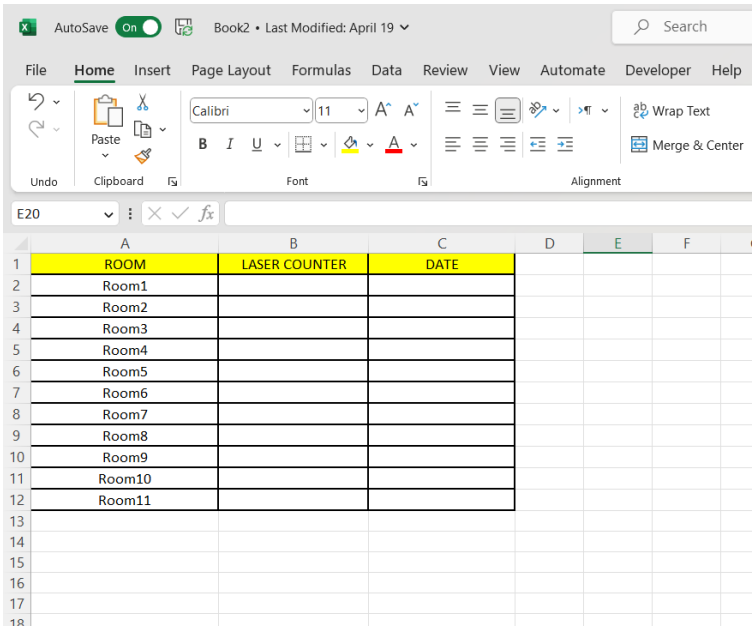


Figure 2.2: The excel for laser counter occupancy

After creating the excel file, it is time to use my macro to create the laser counter columns as dynamic data and generating random number for each room. First you should be sure that your

developer tab is working in some excel files, you should manage it manually. You can find the tab at the top of the page in the toolbar.

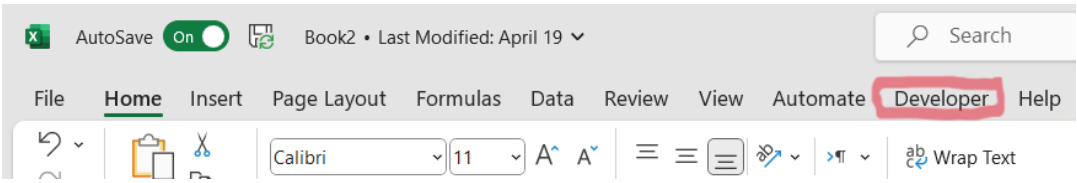


Figure 2.3: The applying developer tab in excel

If you cannot see the developer tab, first go to the File and then at the end of page click on Options and then Customize Ribbon. From the page find the developer and click on that. Make sure that the check box is checked.

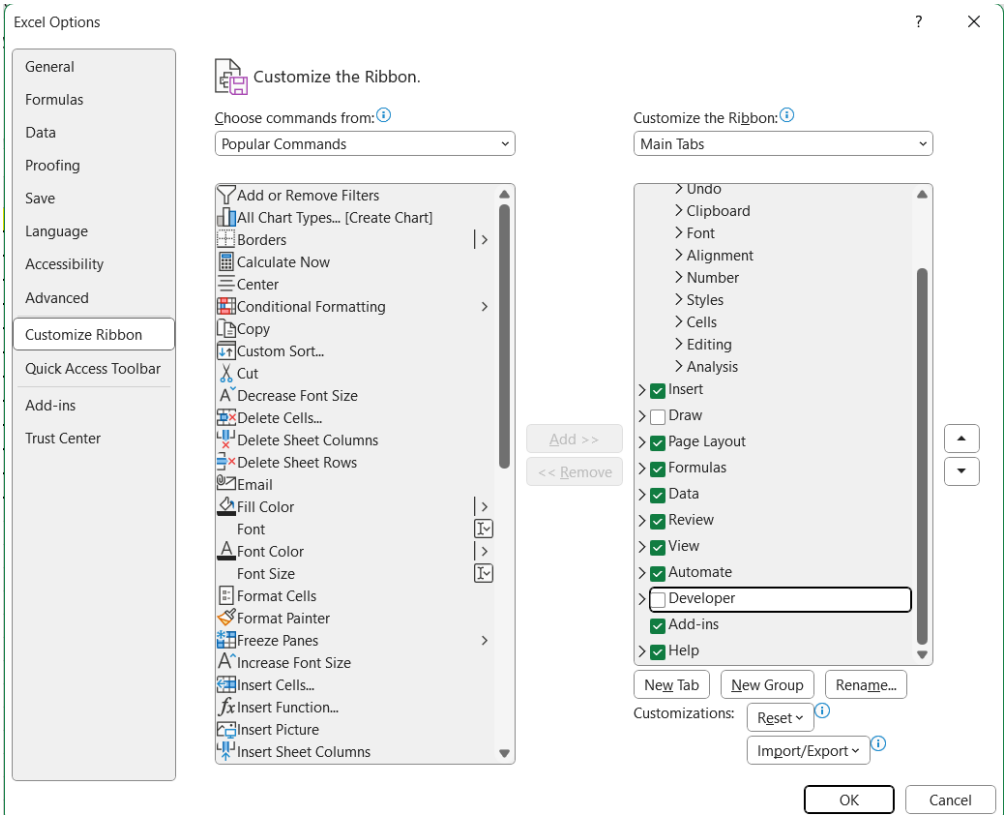


Figure 2.4: The developer customizing manually

After reaching the developer page from the toolbar open the Macros.

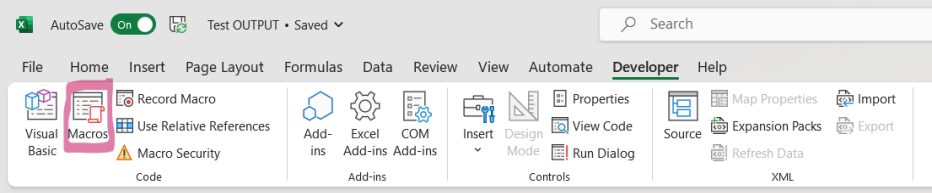


Figure 2.5: Active the Macro in excel

The page coming up is the macros reading files where you can create a macro and order to run or stop or uploading other macros that have been created before. Just give a name to the macro and click create. In my studies I need two macros. So, I have created my macro which I code to generate the random number for each room and another one macro timer.

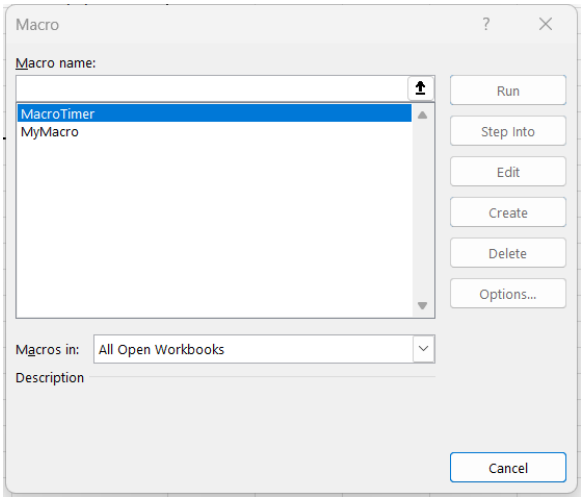


Figure 2.6: Creating two Macros

For the creation of macros, you need to know VBScript. In the script of My Macro, I explained to macro to generate the 11 random number between 1 to 10 and put the numbers in columns B which is related to the laser number counter and at the end of this script I call macro timer because in this script I ask the macro to regenerate and do my macro in every 30 seconds. Finally, we can have an excel file developed by VBS using macro to generate every 30 seconds a random number as a laser counter data for each room.

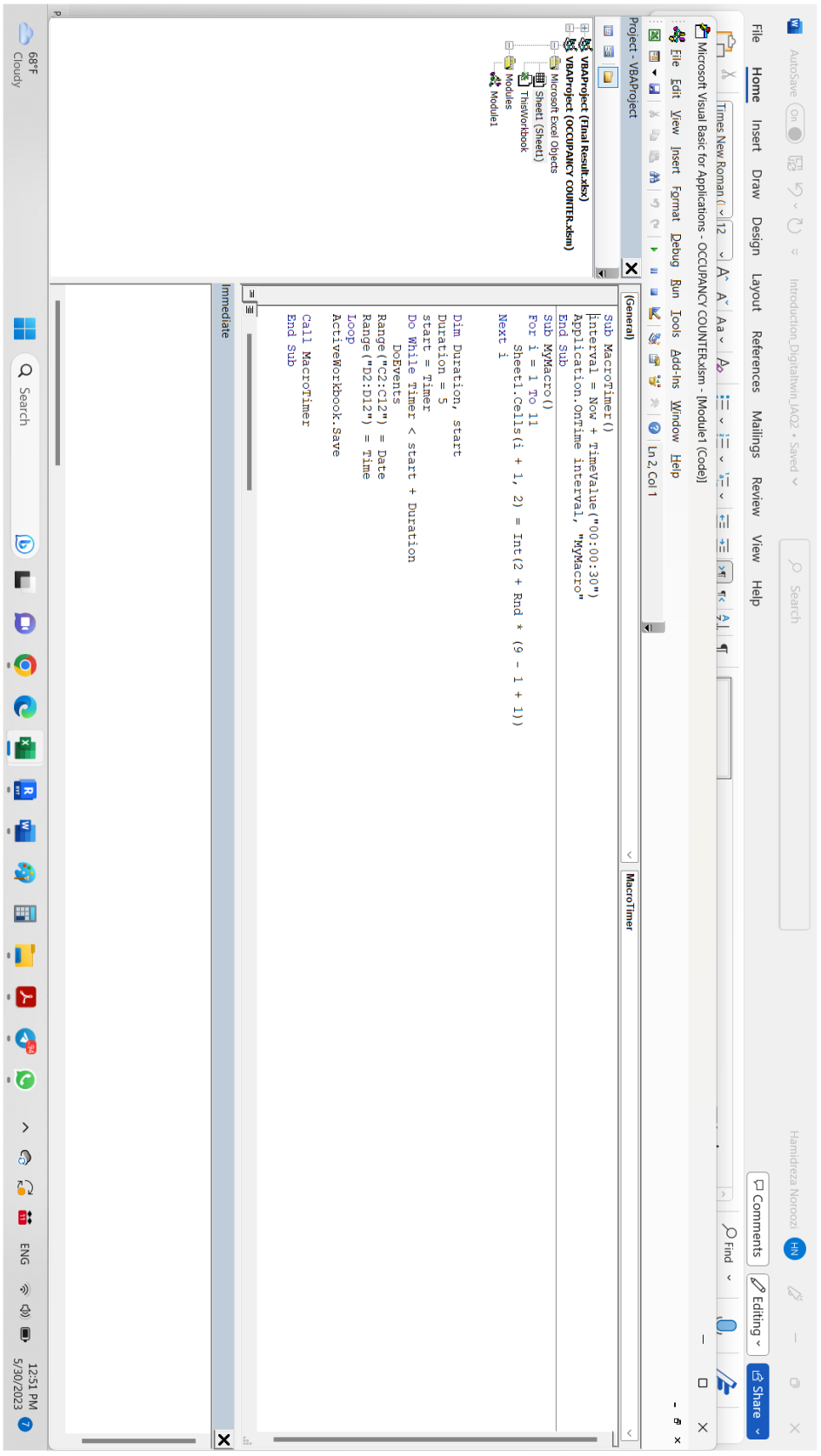


Figure 2.7: The Macros Codes

2.1.2. BIM MODEL SET-UP

As it is emphasized a lot in BIM system of construction, one of the most powerful software is Revit created by the Autodesk and It has been using for a long time to model the physical mass, buildings electricity, building structure, and building architecture. The key role of using Revit is the flexibility and adaptation of the rvt files even for those who work in a group, and they must do their job separately. The transmission of these files is much easier than another group of BIM model engine. However, the power of getting the new parameter and creation of elements based on the modeling of information was the main, biggest, interesting feature in Revit.

In this thesis set-up the BIM model is a one of the stages which should be completed, but what it means the set-up in BIM model, it means that creation of the variables and parameters which should be existed in a project and readable for the engine and the other related softwires.

Now it the time to set up the parameters. For doing this first we have to know what kind of parameter we want to create, and in which categorize it should be included. In Revit we have two kinds of parameters. There is one just as a project parameter for a project that you need for temporary time and a shared parameter which you can be able to share among different projects.

In this project because of the plugin of dynamo we need to create the shared parameters. So, first we must identify the parameters and the features of them in advance. In addition, it is important that the parameters in Revit will be created in a text file like note, so the text file should not be modified at all.

The first parameter No110, which is the dynamic data of laser counter and second parameter No111 which represents the number of acceptable occupancies loads for each room should be created both in a one group of categories. The creation of parameters would be as following way. (The name of parameter has been given as I like it)

First, we open the shared parameters from the manage tab which is the icon below.

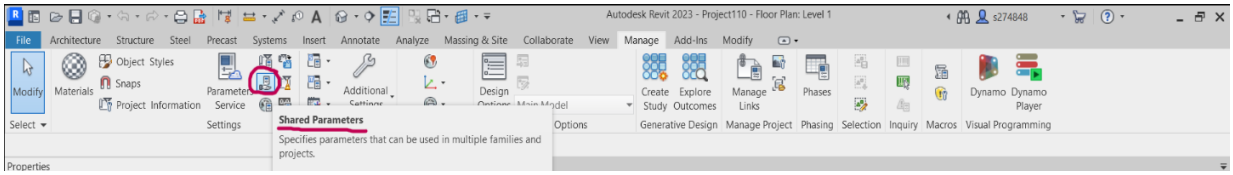


Figure 2.8: Creating shared parameters

Second, we must give a name to the group and create the group parameter, I named it shared parameter OCC. By clicking on the create group a note file will be created automatically in the file location, that is the one of the powers of BIM engine to model your case with different characteristics.

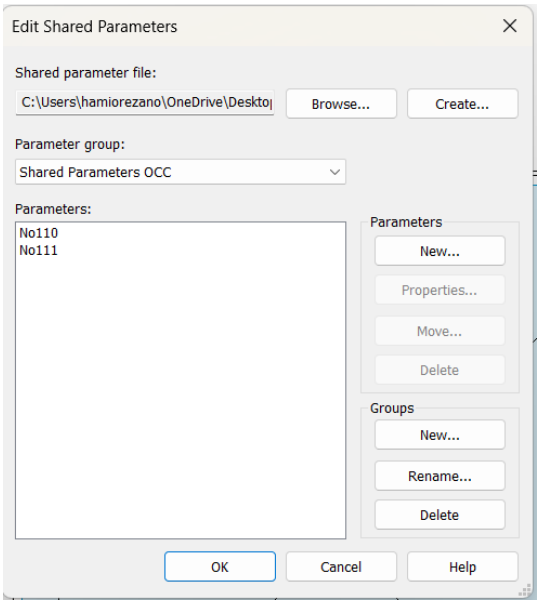


Figure 2.9: Creating parameters group

Now we must create each of parameters by clicking on “New” in the “Parameters” part which will be saved in the note file that mentioned before. As you are creating each parameter you should name it and tell the discipline of the parameter so the Revit can understand to put the parameter in correct category. Also, the type of the parameter is very important, and you must choose that this parameter type comes from string, text, and extra options. Once you have done the process you can click on OK.

It is noticeable that you cannot use the same name of one parameter for more than once. In my case I used common discipline and the type of the parameter both are text.

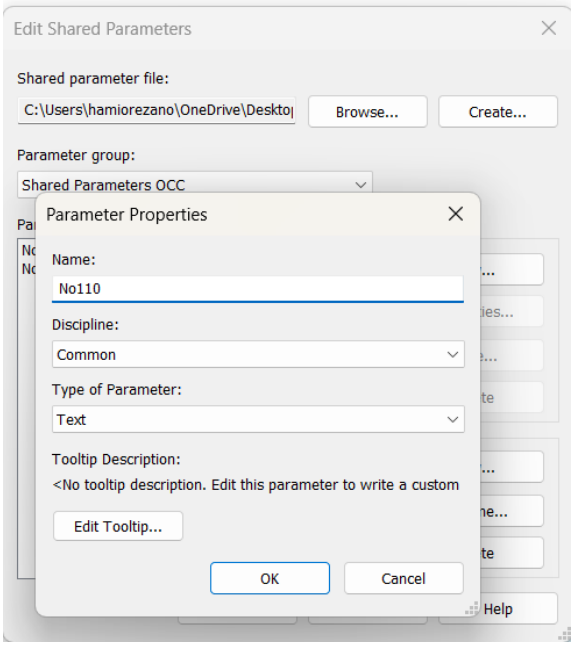


Figure 2.10: Creating parameters type

In the next stage the created parameters should be identified for an especial use in the project. So, until now Revit knows the parameter, but it cannot put it in a specific category of project elements by itself. For doing this stage we should open the project parameter from the manage toolbar. After opening the project parameter by clicking on the new parameter, the page in figure 2.11 will be seen.

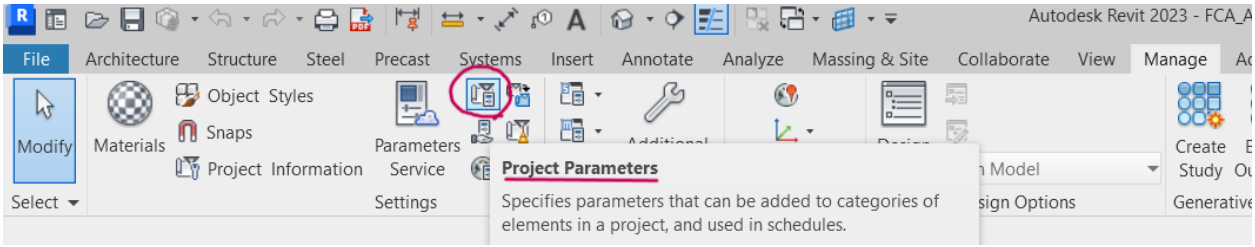


Figure 2.11: Applying parameters in project parameters

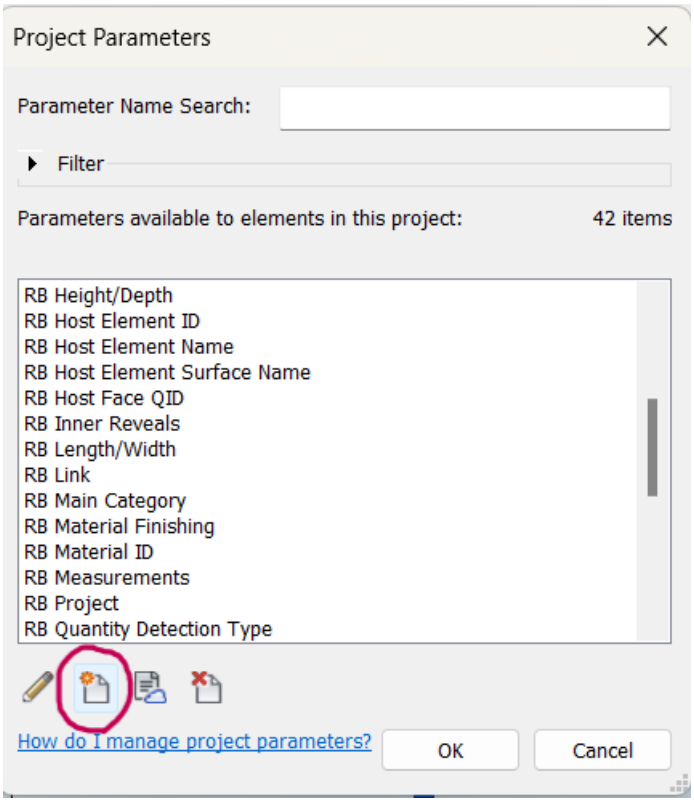


Figure 2.12: Creating a new project parameters

Once you select the new parameter you can choose the shared parameter instead of project parameter, then click on select and choose the parameter which created before in shared parameter and from the box highlighted by the green rectangle, the parameter should be given

in a specific category or categories. In this project because I am giving the parameter to the rooms, I checked rooms from the box.

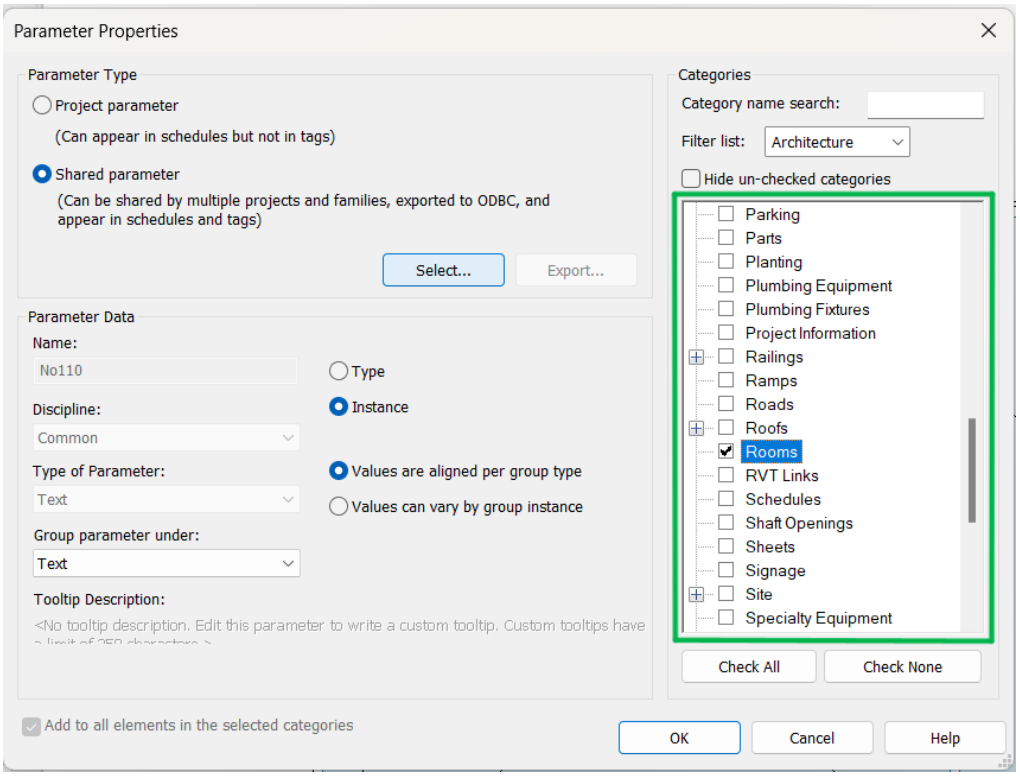


Figure 2.13: choosing the project parameters type and category

Now the parameter is ready to use in the specific area of your interest in the project. The only set-up remaining is to give the room tag the created parameter No110 and No111 and save it as a family and load it in project. It can be done by editing the family of room tag and adding a label from the “create” panel and choose the parameters and move them in to the right box by clicking the highlighted red bottom, then clicking on “Apply” and “OK”. It could also mention that I create parameters in different labels and give the name to each of them by using text.

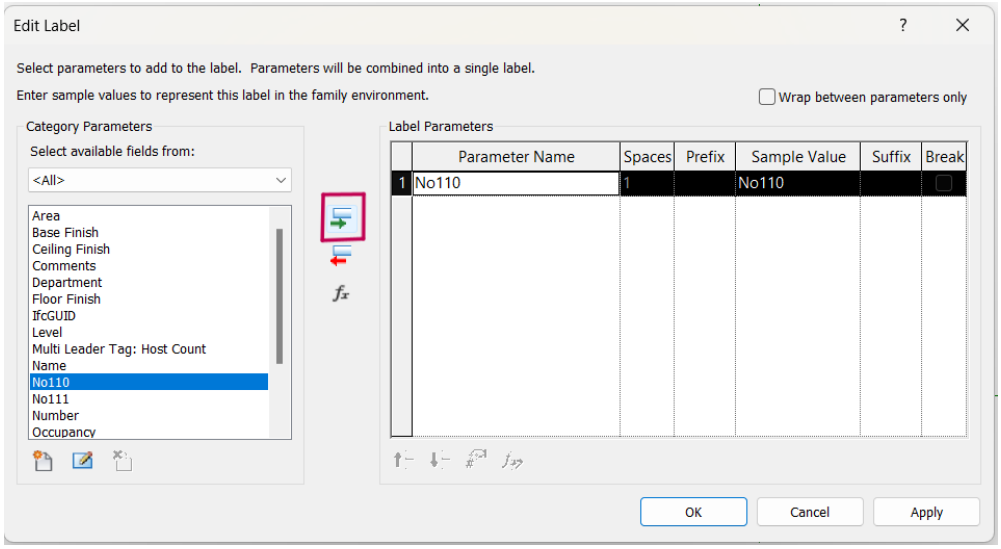


Figure 2.14: Applying the parameters in room tag

Finally, the result of the room tag will be as the image below and you can load it in your project 2as easy as clicking on the “Load into Project.”

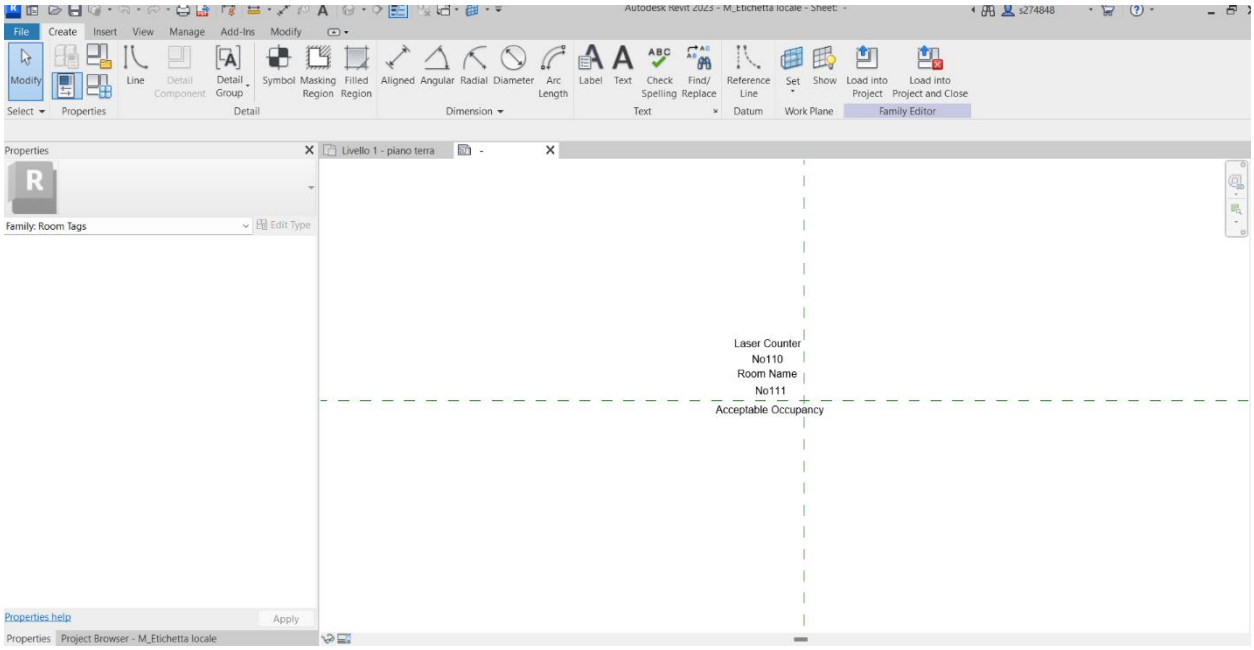


Figure 2.15: Editing the room tag and loading in project

2.1.3. USING VPL FOR DATA ENETRY OF BIM

Visual Programming Language, known as VPL, is a programming language that allows users to develop programs by manipulating graphical components rather than inputting text-based commands. Users in VPL interact with visual components such as icons, flowcharts, and diagrams to represent programming constructs such as loops, conditionals, and variables. These graphic elements may be dragged and dropped into a canvas or workspace and then linked together to form a program. Because VPLs are more intuitive and easier to understand than traditional text-based languages, they are frequently used to introduce programming concepts to beginners and non-programmers. They can also be handy for swiftly building complicated programs since the visual representation allows you to examine the structure of the program and spot any mistakes. There is much software even in fields completely different from the construction world. In fact, there are VPL software for the world of music, art, video editing, app and game development, etc. However, Dynamo BIM was born specifically first for the construction program in 2014 by Autodesk. Nowadays Dynamo not only is a program for the Revit and construction apps but also it roles have been greatly increased in almost all the engineers software like AEC, Fusion 360, and Autodesk civil 3D.

Also, in this thesis its roles are like playing a common language between the data of laser counter and static data of BIM model. I found the Dynamo BIM with a very friendly environment, easy use for users and flexible, although, many people are on the believe that text base languages are more flexible such as VBS or LabVIEW.

Basically, Dynamo is created with the nodes and wires. Each node plays a crucial role and according to the aim of use. In the other hand, it employs a node-based interface in which users drag and drop nodes onto a canvas and connect them to form a program.

Dynamo is very useful for building parametric designs and automating repetitive activities in Revit. Users can design custom nodes that interface with the Revit database and manipulate building elements such as walls, floors, and ceilings. Dynamo also contains a library of pre-built nodes for typical activities like shape creation and data handling.

The explanation of nodes and wires of data analyzing for one room will be explained in this chapter, So the other rooms follow the same nodes and wires and at the end of the chapter the whole dynamo script can be seen.

It is important that to know the green groups represents as an input data and the blue groups are related to the parametric data, the purple groups are the analyzing data, the gray groups illustrate the sorting of data and finally the dark group is the output data.

First, it is important to import the dynamic data as an input data, So we need the “file path” and “file from path” to get the exact location of the excel file which contains the laser counter data.

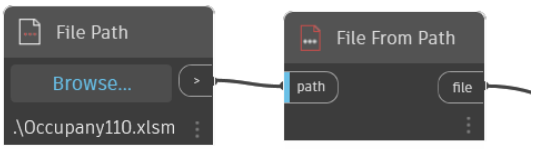


Figure 2.16: Using file path for importing the excel file

Now from the browser we can choose the excel file and we must connect the file from path to an import excel node and tell the exact sheet name that we used in excel. By adding a watch list, we can see the accuracy of the imported data.

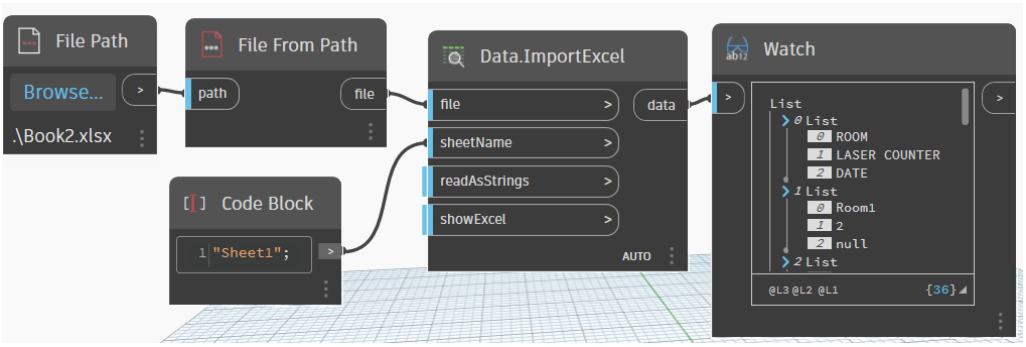


Figure 2.17: Importing the excel file

So, as we can see from the “Watch” each row is located in a one list but we do not need the first row as it is just the title of them so by using the “List remove Item” node we will remove the list 0 which was only the titles by using “Code Block” and writing [0].

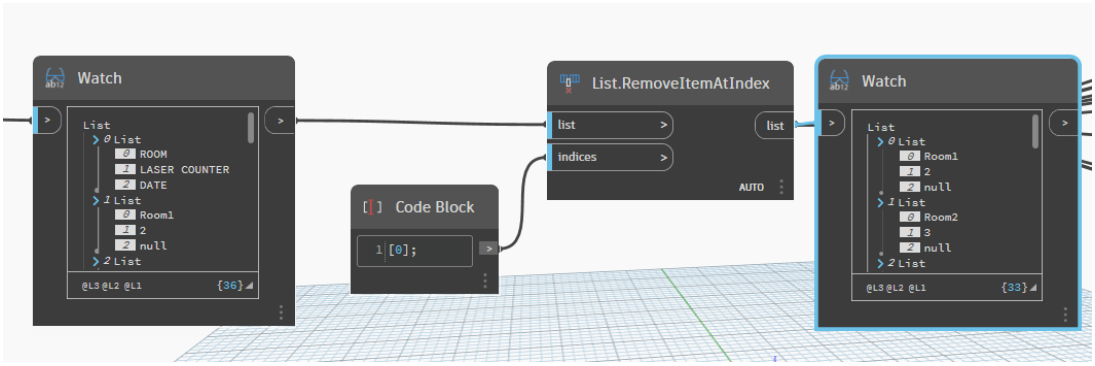


Figure 2.18: Using remove list for the list 0

In last watch we can see all the rooms and numbers imported correctly so we can creat the nodes as a group by drag and selecting them and left click, then creat a group and name it as we wish.

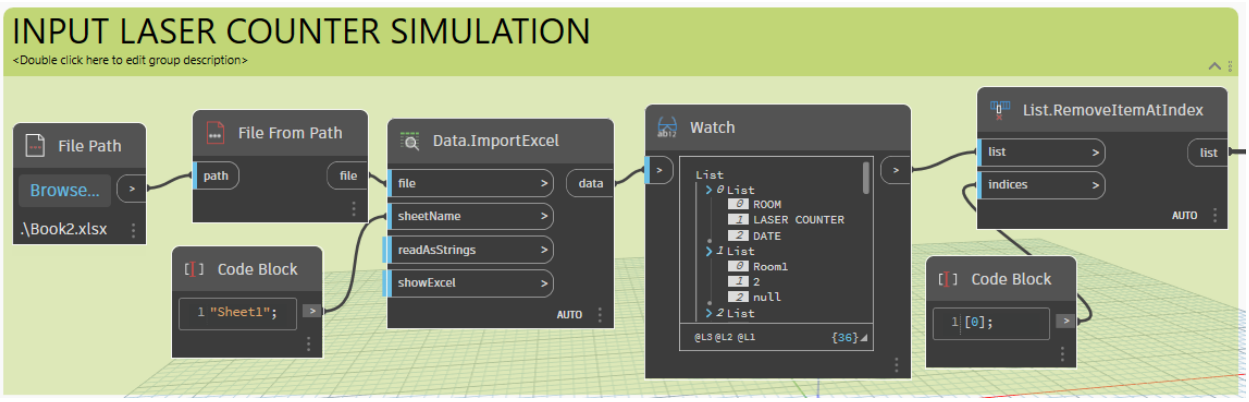


Figure 2.19: Creating input laser counter simulation

This is the first input data so now we need to creat a group of nodes to input the rooms. By using “categories” node and select the rooms and connect the “all categry element” node to that by wires we can input all rooms taged in file.

Figure 2.20: Importing the rooms

The third action would be gathering the input datas which are the specific room from the elements and the laser counter list number of the mentioned room from the input data of excel. It could be done by creating code blocks and write the “x[]” in code block and between the brackets write the exact number of element and the list number from the excel.

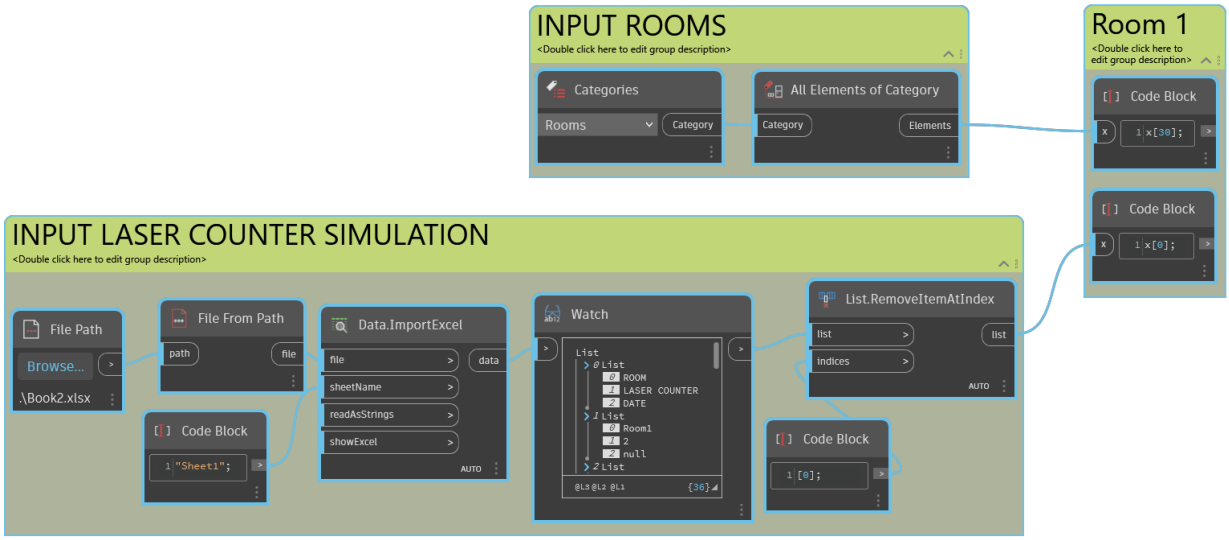


Figure 2.21: Connecting the rooms to imported excel

The room 1 in the elements is number 30 so one code block is x[30] and will connect to the elements and the x[0] is the number of the list of excel for room 1. Now we must give these values to the parameters which have been created in Revit.

To begin, we may begin with parameter No110, the laser counter parameter, and connect the code block to a get parameter by value. But first, we should know that code block x[0] comprises three strings: room1, laser number, and date of data recording. We need another code block to separate these three parts and must write x[1] to acquire the precise laser number. In addition, we must convert the string to a number using the string from number node. Then it should be passed to the node get parameter by value, and the name No110 in a string code should be assigned to it. As a result, the outcome will be as follows.

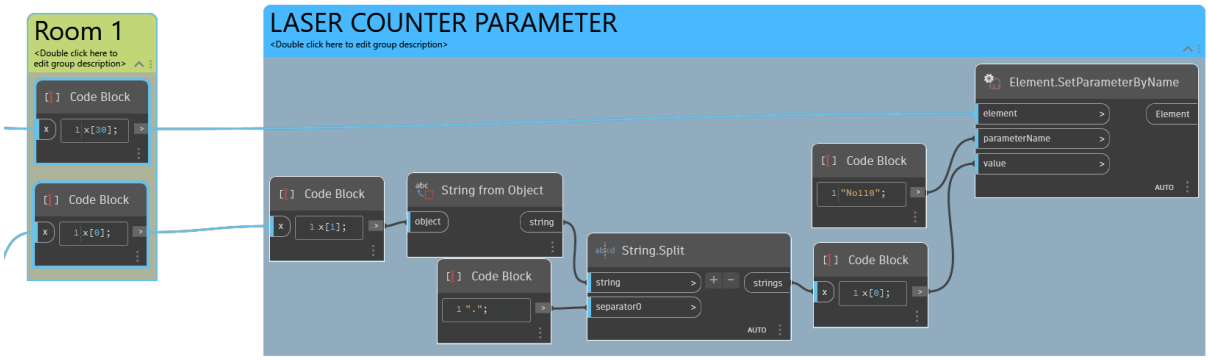


Figure 2.22: Getting the data of LOC

By doing this right now we can see that the parameter of No110 is getting the value and it will be seen in the room1 tag.

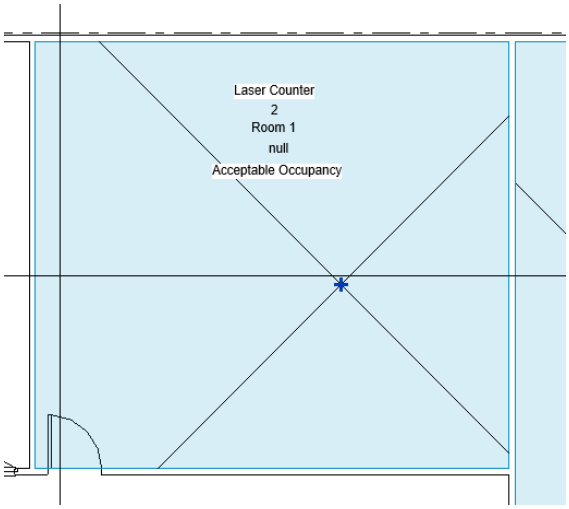


Figure 2.23: Representing the laser counter in room tag

The next stage is to give the No111 parameter to the room tag as an acceptable occupancy load based on the standards of offices. For this parameter first we must find the area of the room 1 and divide it to the standard occupancy square meters. So, we use the node named element get parameter value by name and the element should connect to the room 1 mentioned before and the parameter should be written area as a string then we can divide the result to 7 m2 as a standard offices per person based on …… by using divide node. Now we can give the parameter as we did to room 1 tag, but instead of No110 we must use No111 and connect the element to the room 1 again.

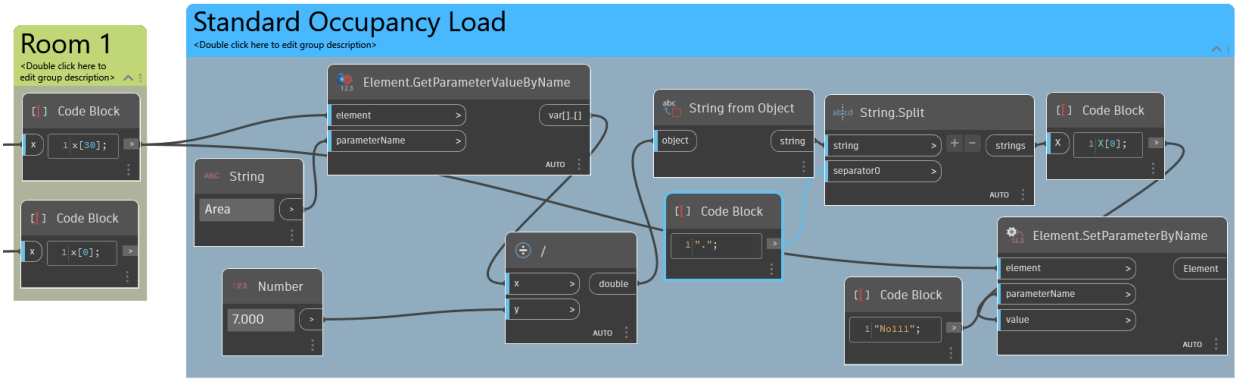


Figure 2.24: Creating the standard occupancy load

Finally, you can see that the number of No111 parameter is getting value in room tag.

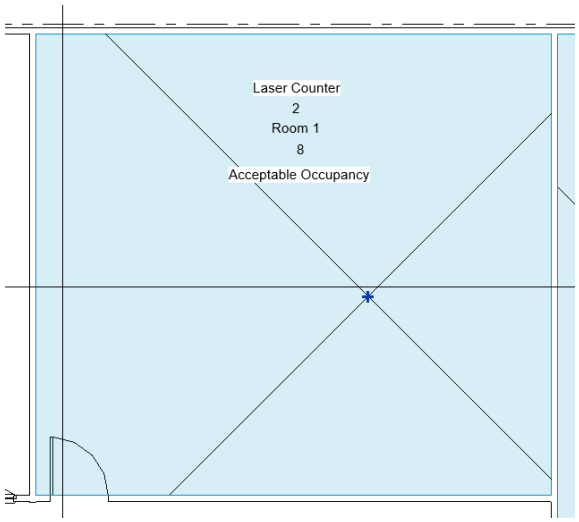


Figure 2.25: Representing the acceptable occupancy in room tag

Now we can start to compare these parameters to monitoring the occupancy load and, in this thesis, I used a conditional order to divide the finalizing result of comparison in to three situations:

1. the LCO is more than AOL then the result must be “no”

2. the LCO is equal to AOL then the result must be “Limit”

3. the LCO is less than AOL then the result must be “yes”

This conditional order could be done by Phyton script node and clicking ton + to add another parameter. So, the string which is the LCO number and AOL number must be converted to the number by using the string to number and give them as In[0] and In[1].

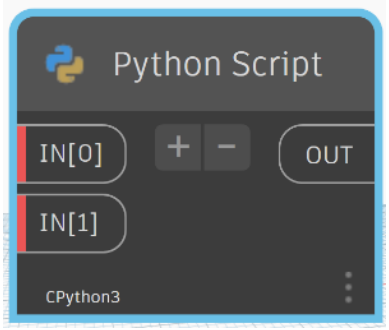


Figure 2.26: Using python script for conditional situations

By double clicking on the node a script platform will be open and according to the explanation of above the conditional order will be a below. It is important that do not exit the script before saving or running the code.

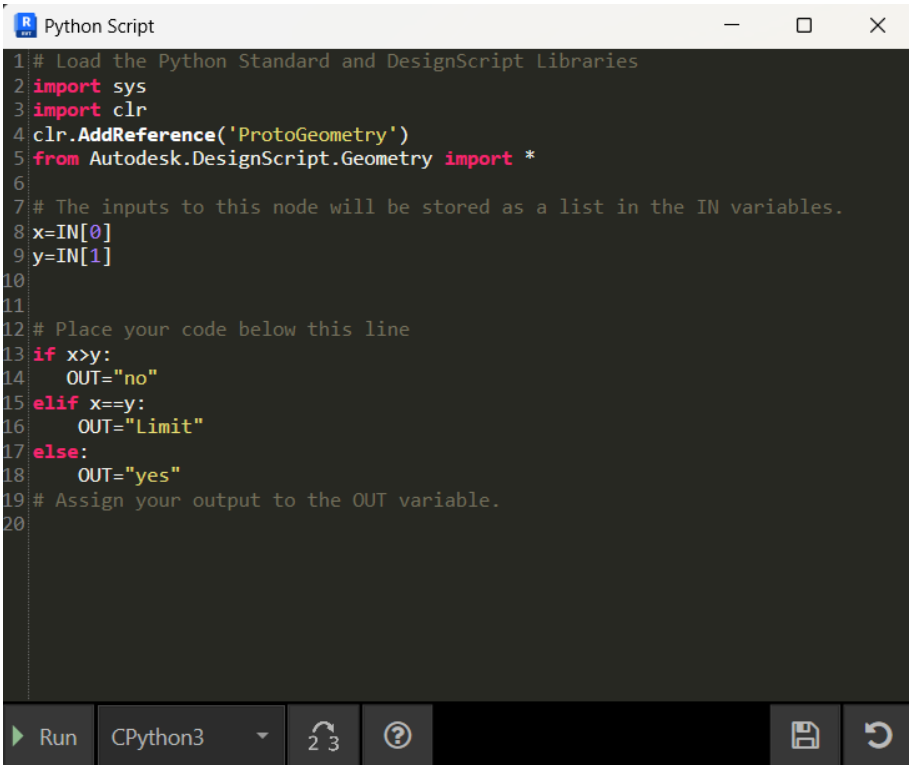


Figure 2.27: The script of python

One of the factors that the room tag already has is the comment, so we need to utilize the result of this comparison done by the phyton to provide it to the comment to express the outcome in

the plans that will be explained after this phase. To add a new parameter, I prefer to use the comment. So, the result is passed as a string to the node element set parameter by name, and the element is room1, the parameter is comment, and the result is the value.

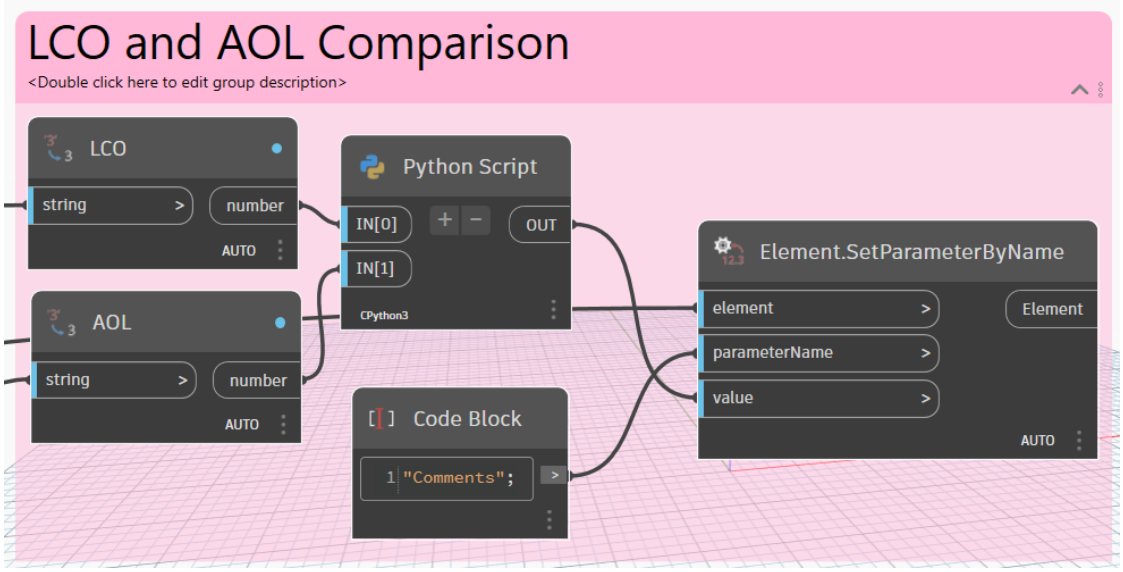


Figure 2.28: The LCO and AOL comparison

The result could be seen in each room tag properties and the comments should be according to the three different situations.

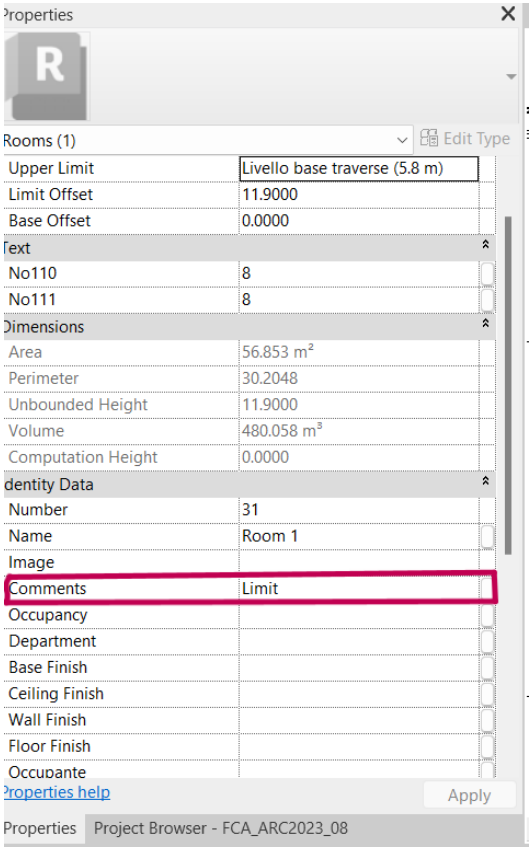


Figure 2.29: Representing the conditions in comments of room

The next thing to do is to find the ACH based on the LCO and AOL. ACH, which mentioned in the introduction chapter is a formula contains the number of occupancy load multiples by the minimum $q_{r\text{-}IAQ}$ per person based on the standard number EN 13779-2007 and multiples by the time spent in the area/24. After having the answer, we can divide the answer by the volume of room to find the ACH.

For doing that we need to use the nodes for the calculation and named “formula” and define each parameter to it. The number of occupancy load defines as N and the qr-IAQ per person defines as Q and the time spent in area/24 could be named as F.

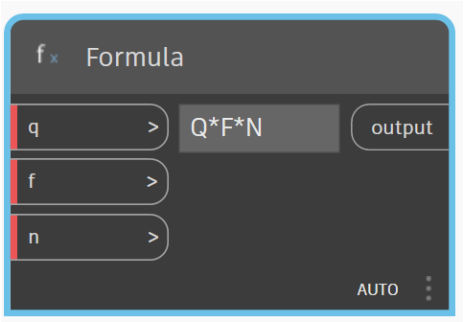


Figure 2.30: Creating the airflow rate formula in VPL

As you write the formula in the box the parameters in the left will be created so just, we need to give the exact values to them. Regarding the q, according to the standard for offices is 36 and the f value considered 0.33 which means that people spend 8 hours every day in the office. However, for parameter n we must create two nodes of same formula, one for the LCO and the n would be the number of laser counter or the excel file and another is based on AOL which comes from the minimum standard of area in offices. So, for q and f we can create a code block or number node.

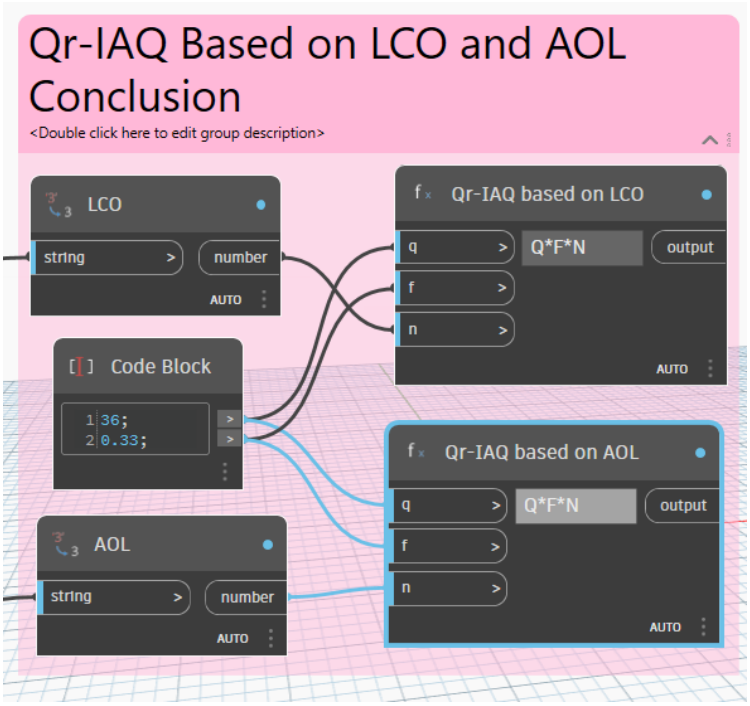


Figure 2.31: Airflow rate conclusion based on LCO and AOL

After getting the result the Qr-IAQ each should be divided by the volume of the room. First, we should find out the volume of the room, Therefore, we must use the node of element get parameter value by name and the element will be the room1 and the parameter name will be the volume which should be written as a string node.

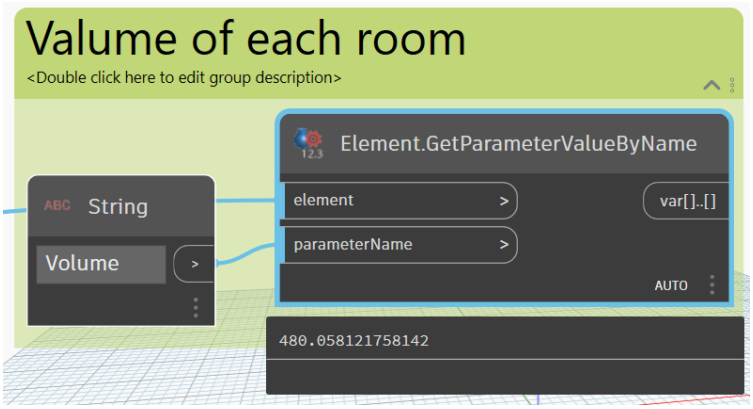


Figure 2.32: Importing the volume room 1

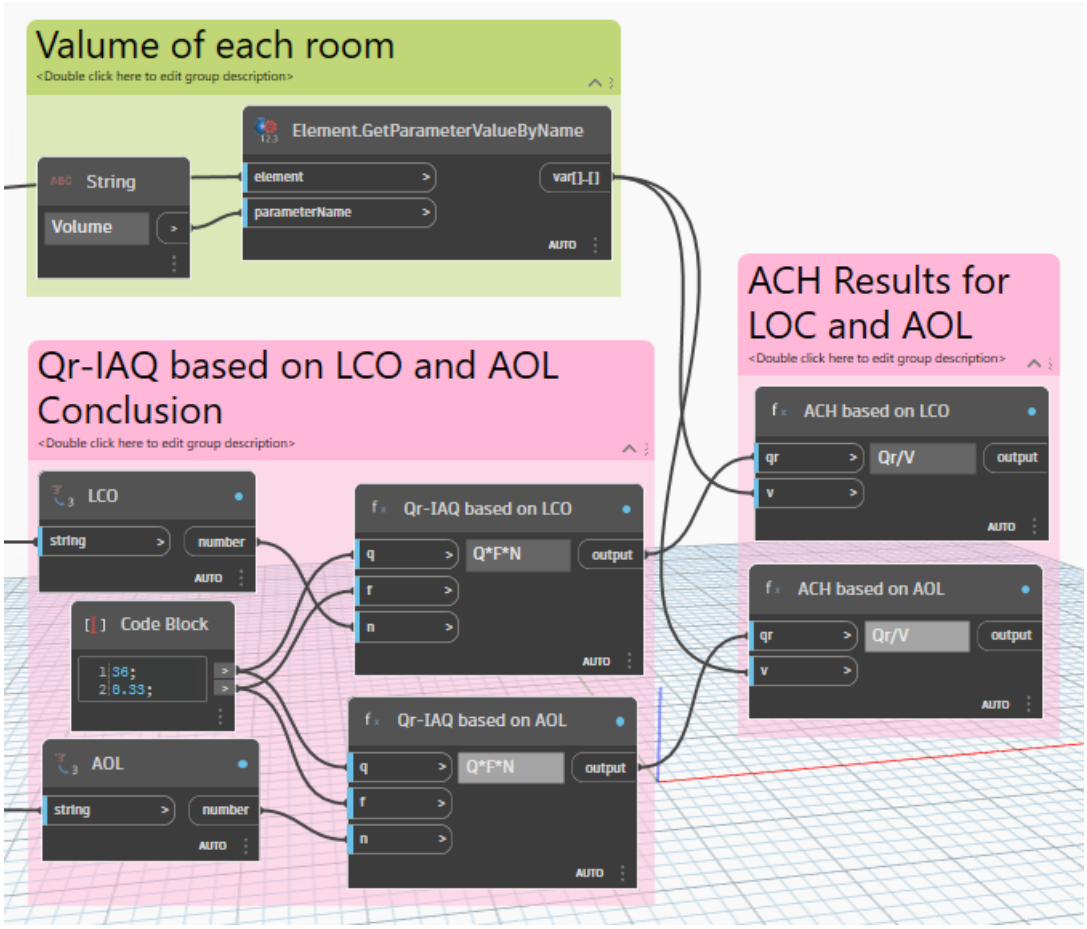


Figure 2.33: Final ACH results based on LOC and AOL

Finally, we have done all calculations to get the output, which are the ACH based on the real-time occupancy load (LCO) and the ACH based on the acceptable occupancy load (AOL).

For the result it is important to do what is shown in dynamo for all the rooms and gather the data of ACH LCO and ACH AOL by the creating list node and add as many as rooms you have in this case 11 rooms so the number of added is 11. In this part we must separate the results into two lists, one for ACH LCO and ACH AOL and connect the number of ACH of each room to the list, it is prohibitively important to connect them in order. For the better understanding have a look to the figure below

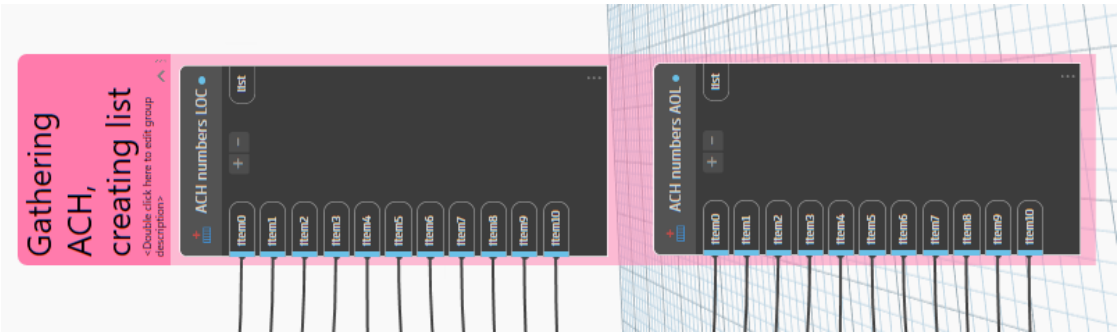


Figure 2.34: Gathering the ACH of all rooms

Now for the managing the list which have been created, we must use the list “transpose” node since at the end we need an excel, so, it is important that the excel understand that these numbers should be put in a column not in rows so we will create again two transpose nodes for each ACHs and connect the result to the nodes. Now in this step we must accumulate the results for ACHs in one list, so again we use the create list node. Also, the first row, which should be the room names, should be selected and sorted in another list. Figure2.34

So, the only thing that remains for the output is the data. For creating data for the output, we need to excel give the all the parameters that have been created as No110 and No111. Therefore, we need to create a list of these data and give the data based on the row and columns created in the output excel. It is worth mentioning that the element comes from all categories and category element which is rooms. Figure2.35

For this part we should give the parameters by the vale node with the element which is the rooms in these terms in front of each room we can see the LOC number and the AOL in the result excel

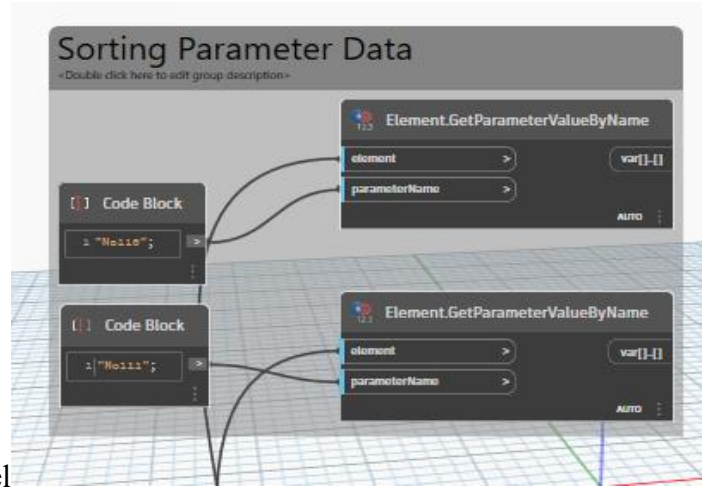


Figure 2.35: Sorting the data of parameters

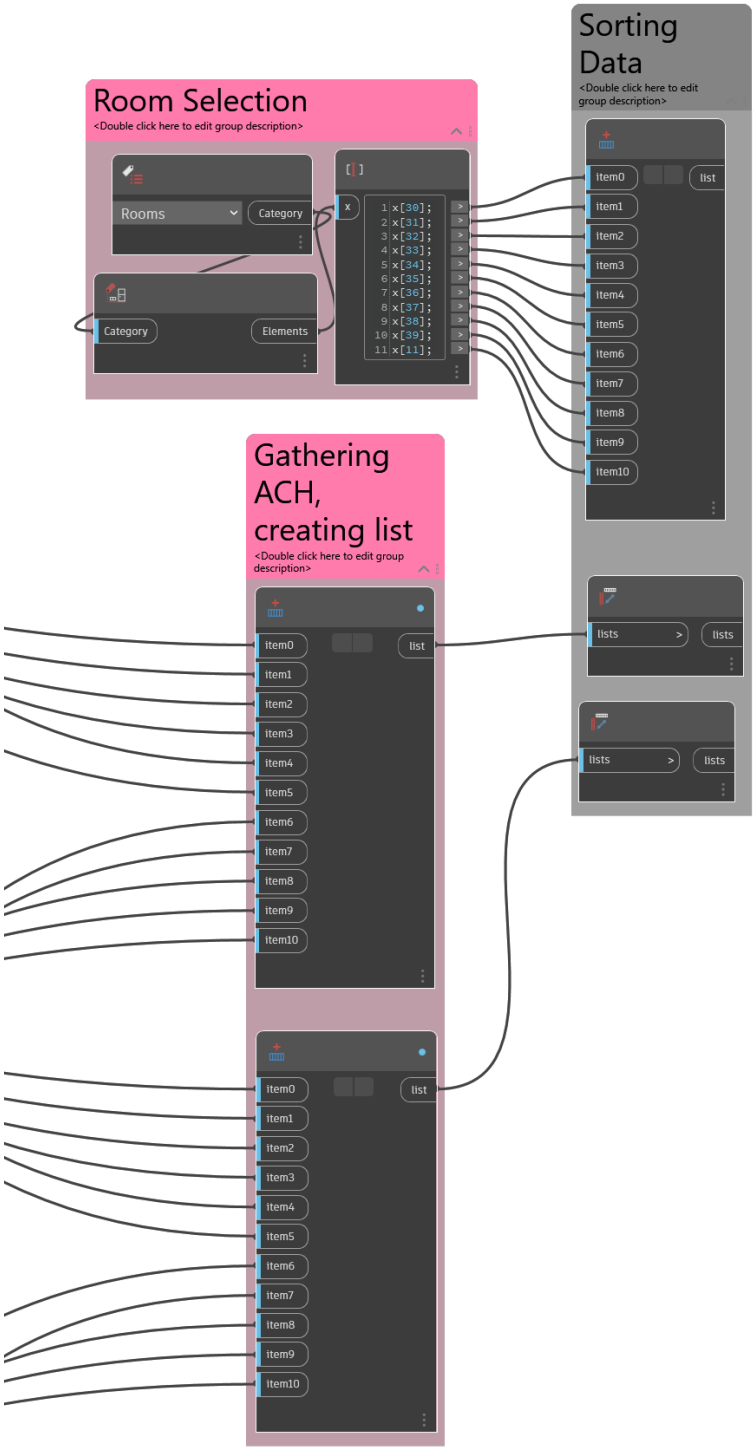


Figure 2.36: Sorting the data of ACH of rooms

It has seen the data collected in a create node in a group of data sorting. The final step is to transpose the data since the data should be in one row specialized for a room. And as the flowchart illustrates for the conclusion as an output, we need to create again an excel file to write the number of laser counter occupancy and its ACH and the acceptable occupancy load and its ACH in one file. For this result we need to use the" data export to excel".

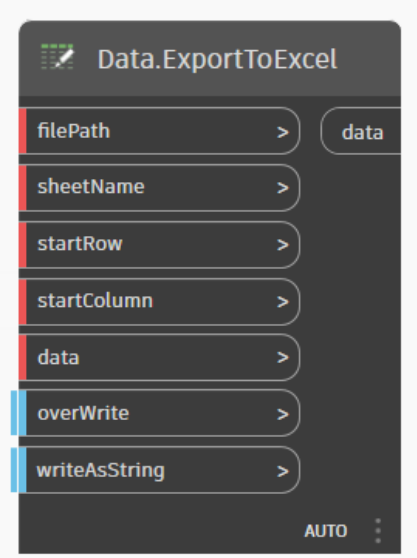


Figure 2.37: Using exporting excel node

This node needs a file path which shows where you want to save your output data and the sheet name that you will input the data and even the starting column and row, Finally the data.

So, the first thing to do is to create an excel file and give the file location using file path and connect it to the node export. Also, the sheet name and the starting row and column should be given as number to the node.

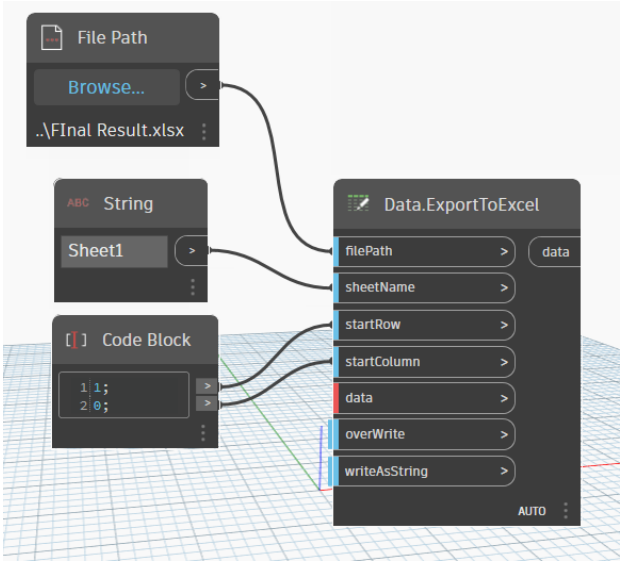


Figure 2.38: Giving the file initial information to excel

As you can see from the figure above the only thing, we must add is the data which has been sorting, however, the excel does not understand the flow chart of data, thus we must create a list again to give the that exact rows and columns which are the names and numbers should be put. In addition to this, the list which has been created should be transposed.

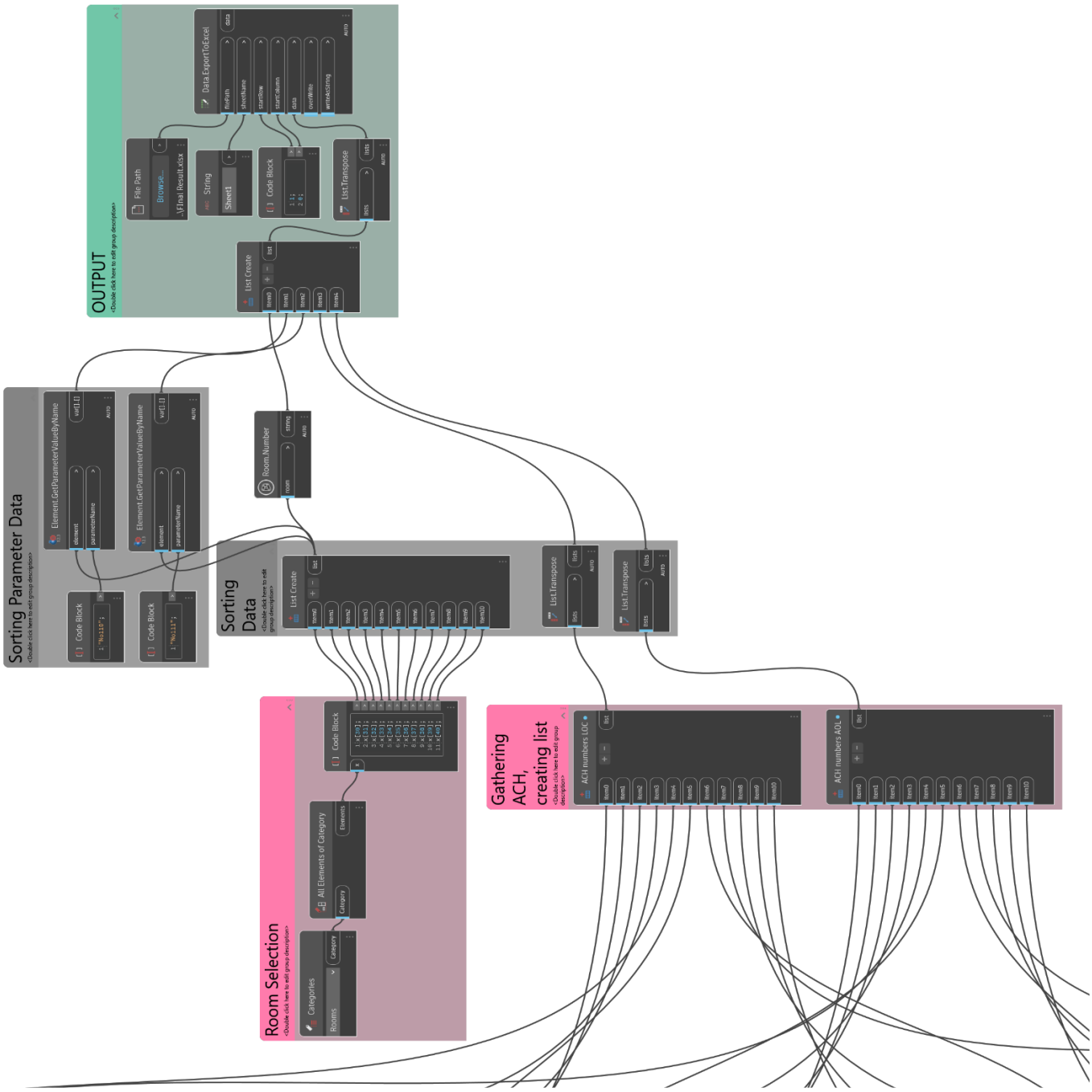
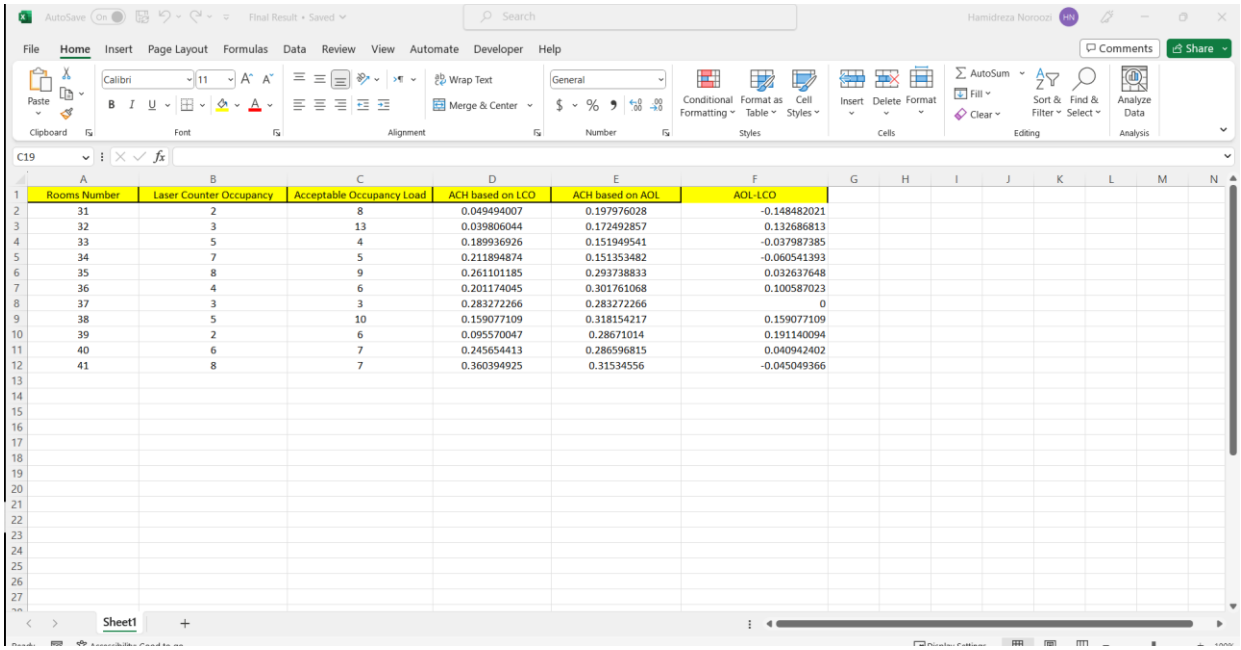


Figure 2.39: Connecting the all data sorted to the exported excel

Now one of the outputs which should be created has been done, thanks to VPL, especially Dynamo. As soon as run the Dynamo in Revit we can see the two excels will be opened. Ine the input data of laser counter and another is the rooms, laser counter, acceptable number, ACHs based on ACO and ACH based on AOL and the last columns is the differences between ACHs shows that the status of ACH in each room.



Rooms Number	Laser Counter Occupancy	Acceptable Occupancy Load	ACH based on LCO	ACH based on AOL	AOL-LCO
31	2	8	0.049494007	0.197976028	-0.148482021
32	3	13	0.039806044	0.172492857	0.132686813
33	5	4	0.189936926	0.151949541	-0.037987385
34	7	5	0.211894874	0.151353482	-0.060541393
35	8	9	0.261101185	0.293738833	0.032637648
36	4	6	0.201174045	0.301761068	0.100587023
37	3	3	0.283272266	0.283272266	0
38	5	10	0.159077109	0.318154217	0.159077109
39	2	6	0.095570047	0.28671014	0.191140094
40	6	7	0.245654413	0.286596815	0.040942402
41	8	7	0.360394925	0.31534556	-0.045049366

Figure 2.40: Exported excel view

This system works automatically and there is no need to open the excel each time. The main result in this system is to find the AOL-LCO. The negative number shows that the number of occupancy load at real-time is more than the standard or the positive number represents the occupancy load is less than the standard or in 0 situation it shows that the occupancy load is on the limit or board red line of standard.

So, the whole VPL language which done by the nodes and wires of Dynamo could be as it is shown in the figure 2.41

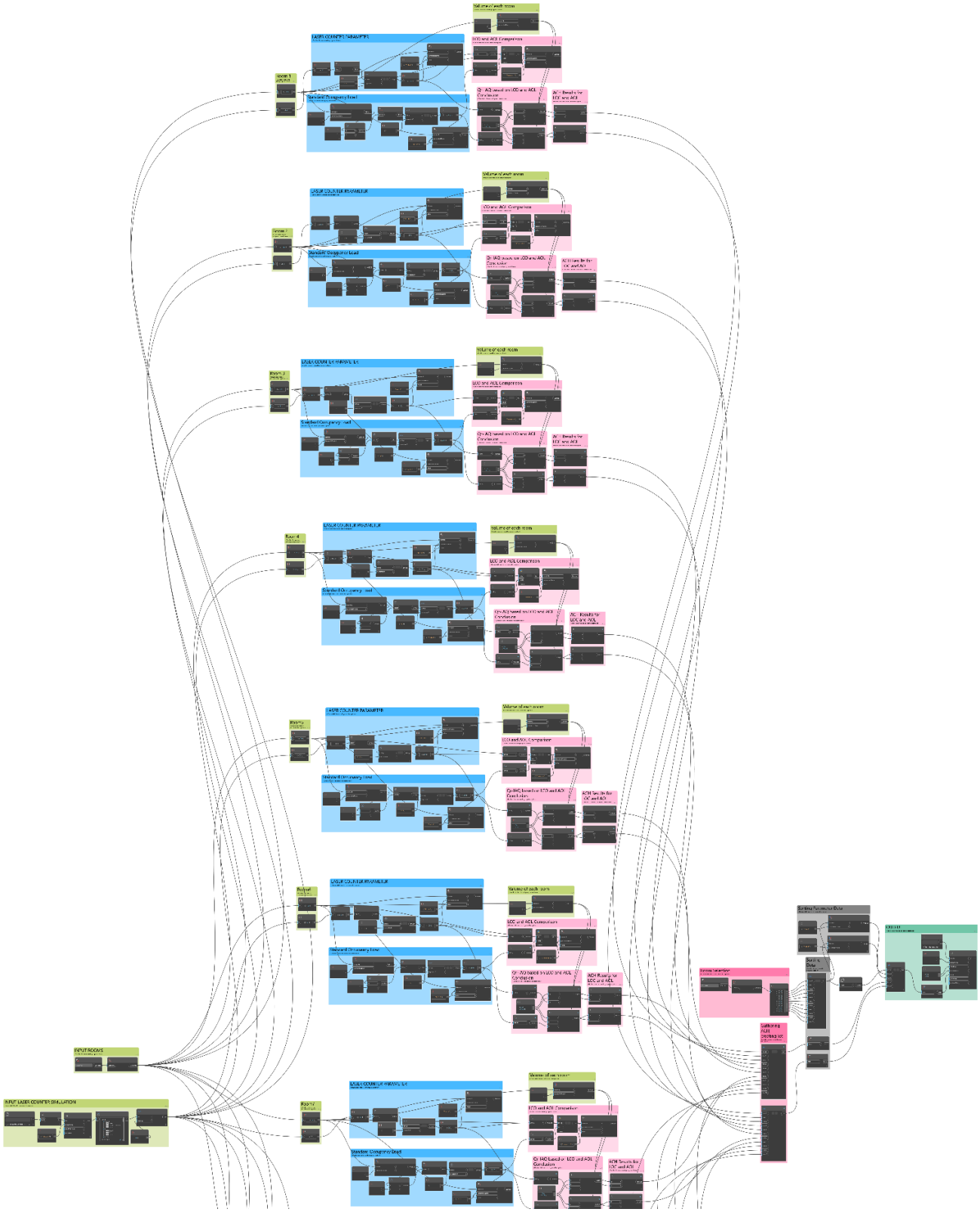


Figure 2.41: Whole system of VPL in Dynamo

2.1.4. CREATION OF FILTER TO CONTROL THE OCCUPANCY LOAD OF EACH ROOM

Another output of this thesis is the presentation of the room occupancy status in three different colors according to the number of LCO and AOL in each room. This Pite the room occupancy parameters which have already added to the room tag in Revit. One of the other challenges of this thesis was representing the occupancy in red, yellow, and green for the situations LCO is higher than AOL, LCO is equal to AOL and the LCO is less than the AOL. When it comes to separation in Revit, there is a power of separation in different fields by using filters which allows Revit to work as a dynamic system. Based on the parameter of comments in room tag it could be possible to apply a filter to define the strategy of representing the colors mentioned above and thanks again to Dynamo Phyton Script node because of the transmission of the data and conditional situation.

For the starting point we must create a filter in the Visibility Graphic tab in Revit by clicking the V and G on keyboard we can access to the different parameters of Revit model. Now click on the filter tab to create the filter of parameters.

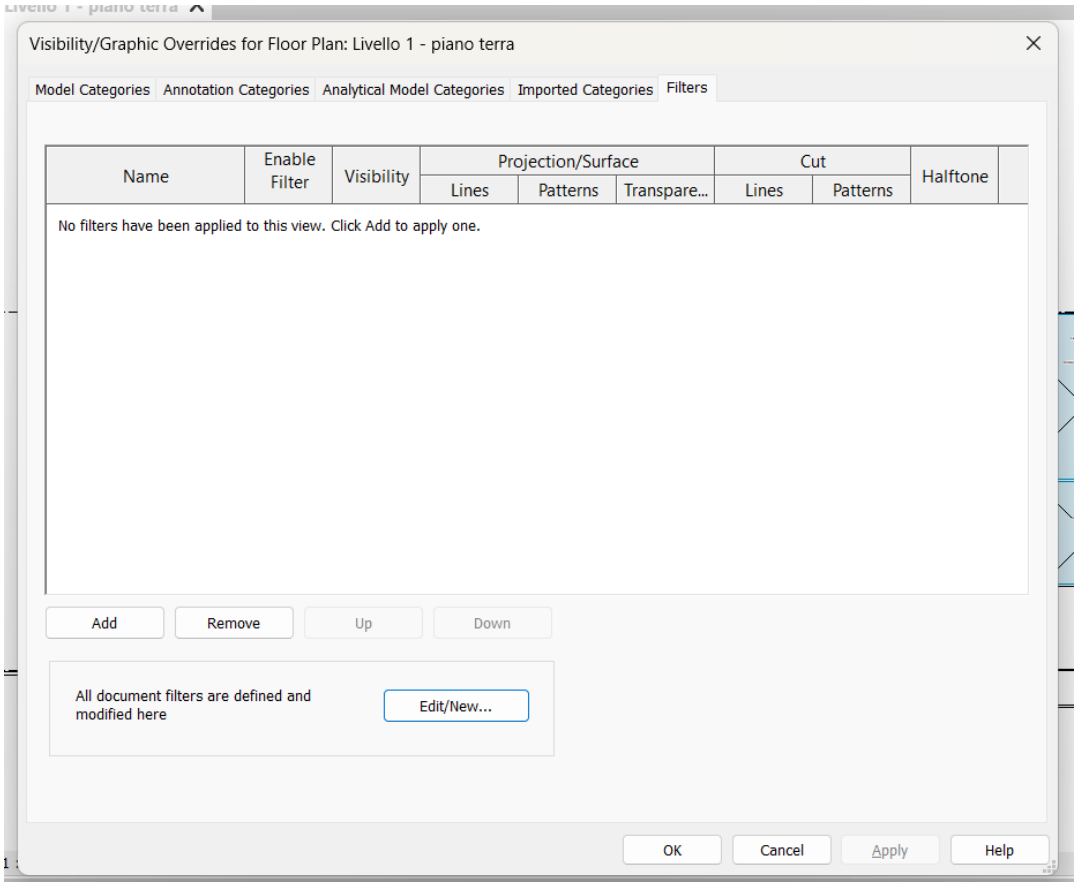


Figure 2.42: The view of Visibility/Graphic

In this tab by clicking on the Edit/New button we can access all filters created for the plan levels and we can see in the bottom left there is a creation button and by clicking on that a new tab will be open to name the filter.

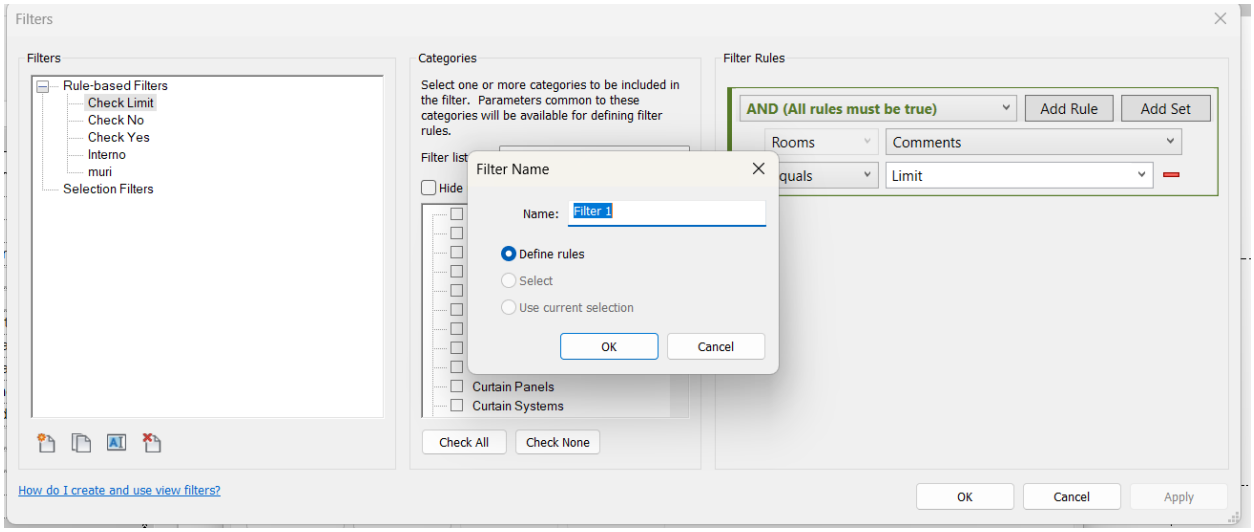


Figure 2.43: Creating the filter in VG

As you can see for this thesis, I have created three different filters Check Limit, Check No, and Check yes and from filter rules I specified the rules only for the Rooms and the parameter of Comments because the comparison between LCO and AOL will be applied on the comment parameter of room tag and for each of them I write the exact string oof dynamo phyton script.

Once it is done, we can manage the colors based on the filter created from the visibility graphic tab and by click on add and select the filter and give them colors by the override pattern, line, and transparency. Here is the example of limit situation which means the LOC and AOL are equals.

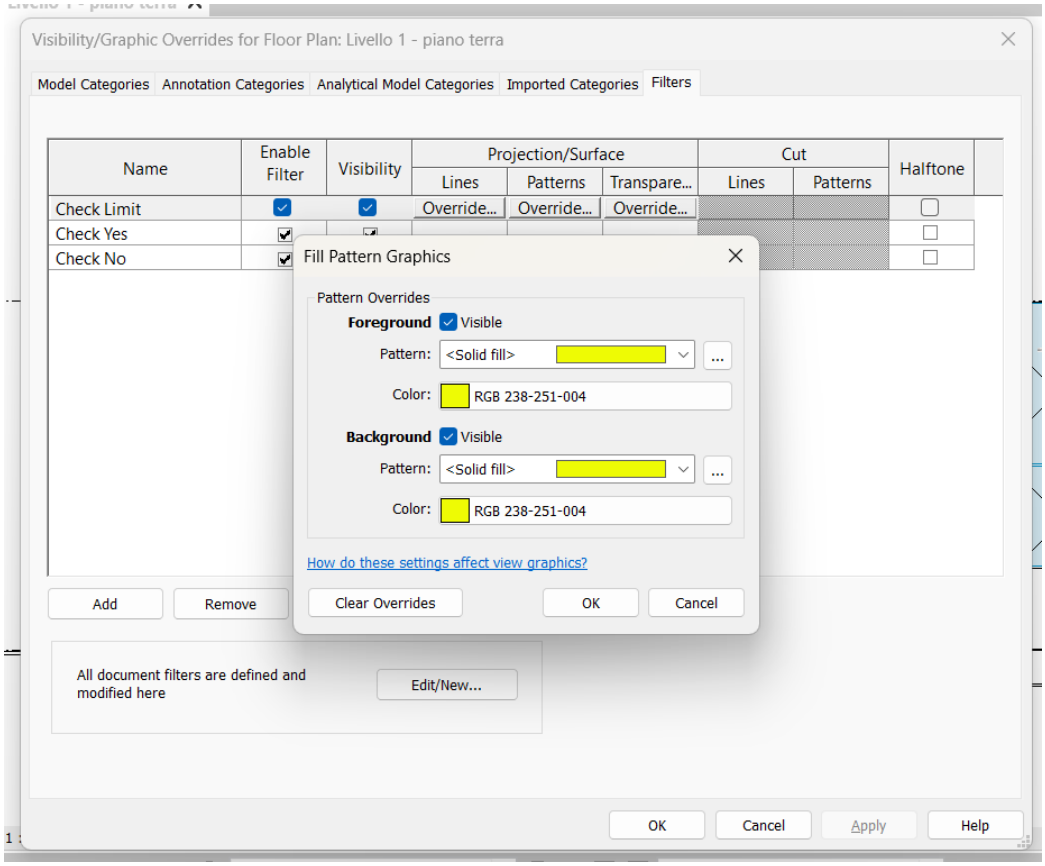


Figure 2.44: Creating the filter color in VG

We must repeat all these for other two filters and it is noticeable that after doing the filter and the creation of that it will just applies in one level and for other levels, we must just add the created filter to the visibility graphic tab of each level.

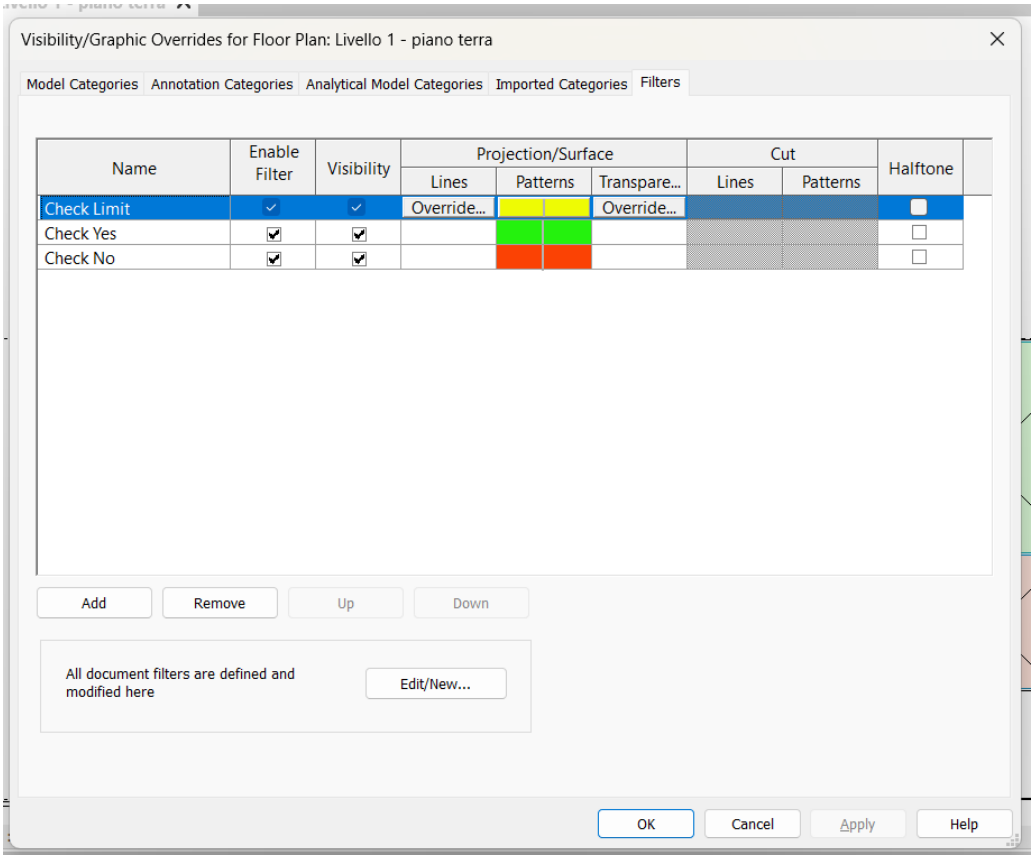


Figure 2.45: Final result of applying filters in VG view

Finally, after clicking on ok, you can see that all the rooms of the level get its color by the filter check. This goal was one of the aims of project to make an integration between the BIM model and the Dynamic data which is IoT. Now by changing the number of LCO not only the room tag will represent the new number on the room, but also the filter changing the color of each room based on the ratio of LOC to AOL.

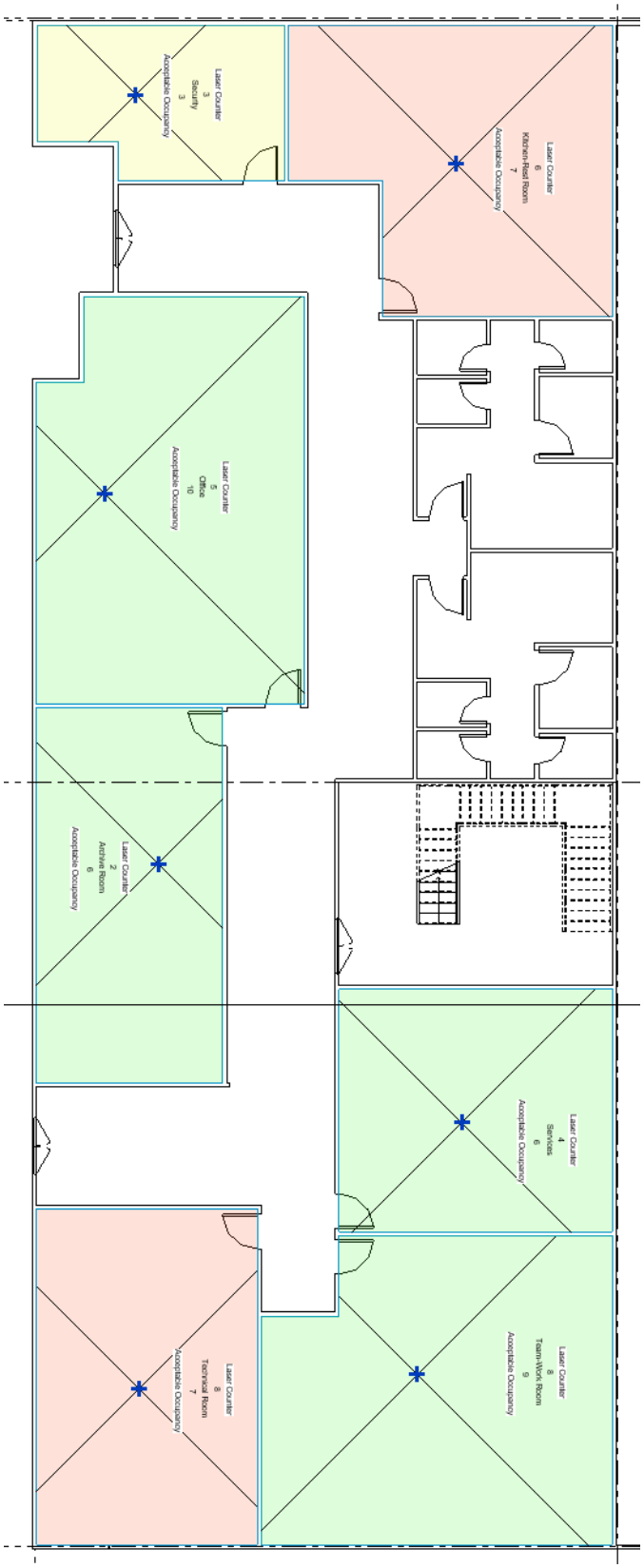


Figure 2.46: Final result of applying filters in first floor plan

2.2. PRESENTING DATA WITH GRAPHICAL USER INTERFACE

The Graphical User Interface (GUI) is a graphical user interface that allows users to interact with software and devices via the use of graphical components such as icons, windows, and menus. When compared to command-line interfaces, it provides a more intuitive and user-friendly manner of communicating with computers. GUIs let users conduct activities by interacting with graphical components directly, such as clicking on icons, dragging, and dropping files, and picking options from menus.

Hereby, because of being user friendly in terms of data from the ACHs and simpler to represent the result in the graphics which has always been a way of interesting in architecture, I had to use a one of the GUI software which in this case I use the Power BI to not only get the benefits from the pointed mentioned, but also using the software as a dashboard to keep the recorded data in specific area. Power BI Desktop is a windows program that is used to create reports and dashboards. It provides more comprehensive data modeling capabilities, interactive data exploration, and customization choices than the Power BI service. Power BI integrates a variety of data sources, including Excel files, databases, cloud services, and web sources like Salesforce, Google Analytics, and others. It can connect to both on-premises and cloud-based data sources. This includes the accessibility of the users to the data at different times and the ability to compare the data as they wish. Also, Power BI has data transformation tools that enable you to clean, restructure, and integrate data from many sources. To prepare data for analysis, you may construct links between tables, specify computed columns and measurements, and use various transformations.

To start linking the data in Power Bi it is necessary to connect the data and create a presentation sheet. In this case I chose to create a sheet based on the selection of rooms.

First, we must load the data in software both the excel as input and output. Figure 2.45 represents how we can upload the data.

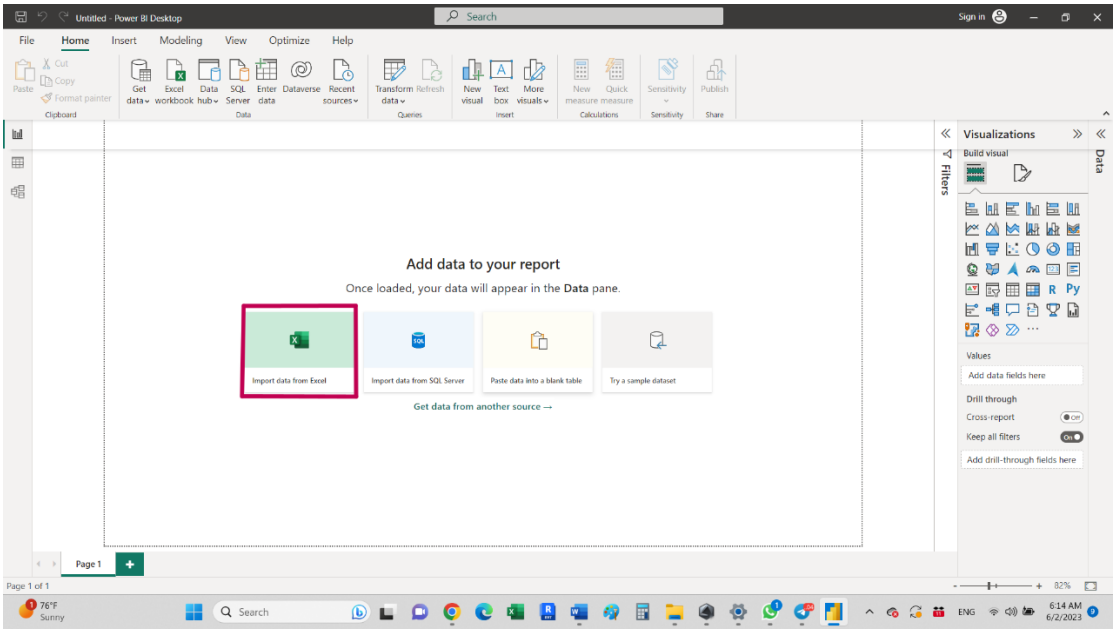
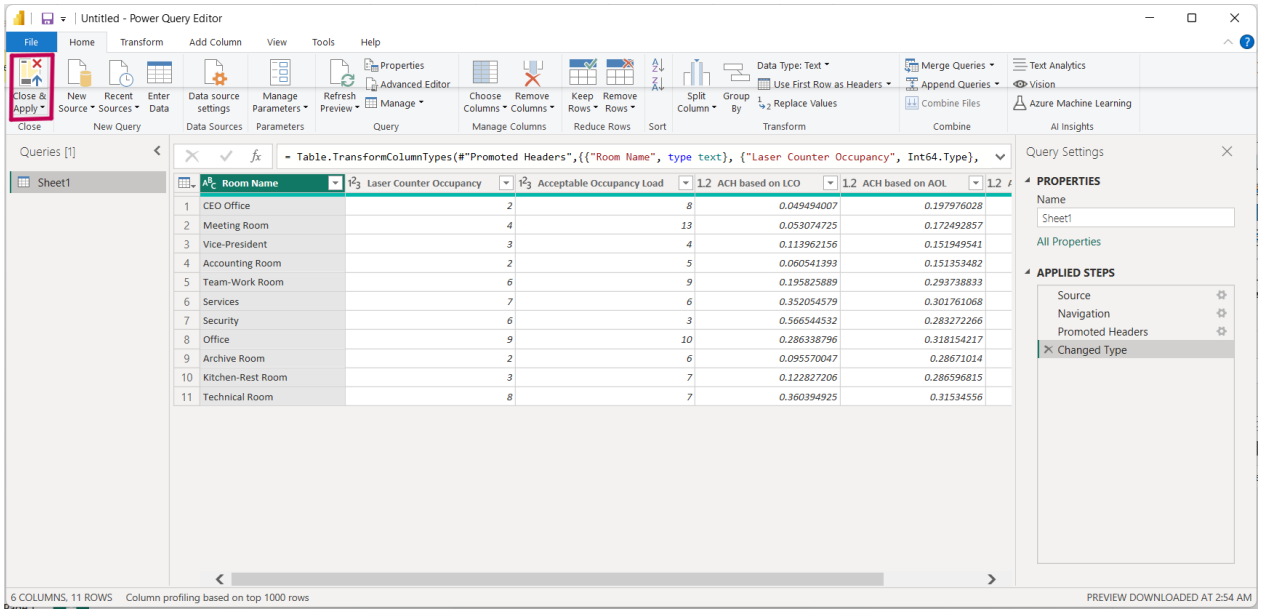


Figure 2.47: Importing the excels in Power BI

As the file location has been selected, we must check the sheet and click on “Transform Data.” Then the Power Bi reviewed the excel data to make sure that the columns and raw transformed successfully. If the type of the data is correct, we can continue by clicking on.



	Room Name	Laser Counter Occupancy	Acceptable Occupancy Load	ACH based on LCO	ACH based on AOL
1	CEO Office	2	8	0.049494007	0.197976028
2	Meeting Room	4	13	0.053074725	0.172492857
3	Vice-President	3	4	0.113962156	0.151949541
4	Accounting Room	2	5	0.060541393	0.151353482
5	Team-Work Room	6	9	0.195825889	0.293738833
6	Services	7	6	0.352054579	0.301761068
7	Security	6	3	0.566544532	0.283272266
8	Office	9	10	0.286338796	0.318154217
9	Archive Room	2	6	0.095570047	0.28671014
10	Kitchen-Rest Room	3	7	0.122827206	0.286596815
11	Technical Room	8	7	0.360394925	0.31534556

Figure 2.48: Loading the data of excels in Power BI

Now it is time to upload the input excel as well and we should do all the processing again. So in the left part of the view, we can see the both data uploaded.

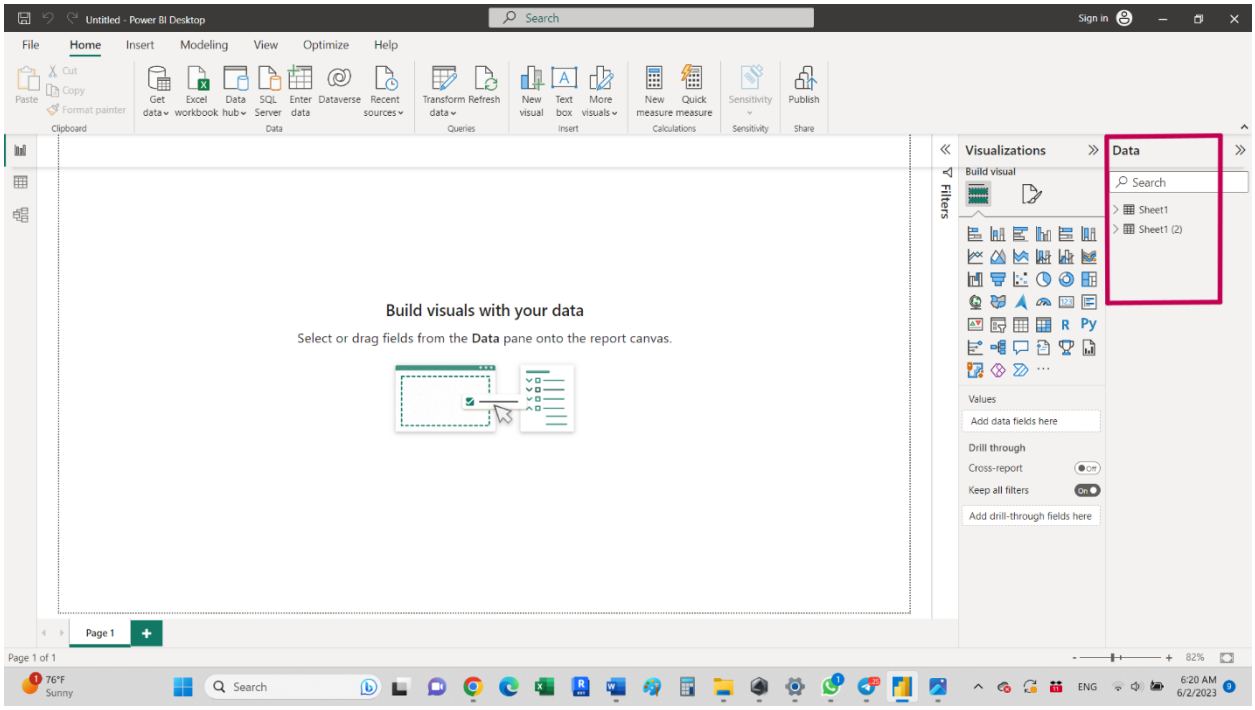


Figure 2.49: Uploaded sheets in Power BI

There is one challenge here because the software is so smart. We must create the co-relation between these two data, and it would be done by clicking on common data integration. Usually, the software does it on its own, and in this case room name and room are common data sources founded by the software. If the software does not recognize the common data in both sheets, you can select it manually.

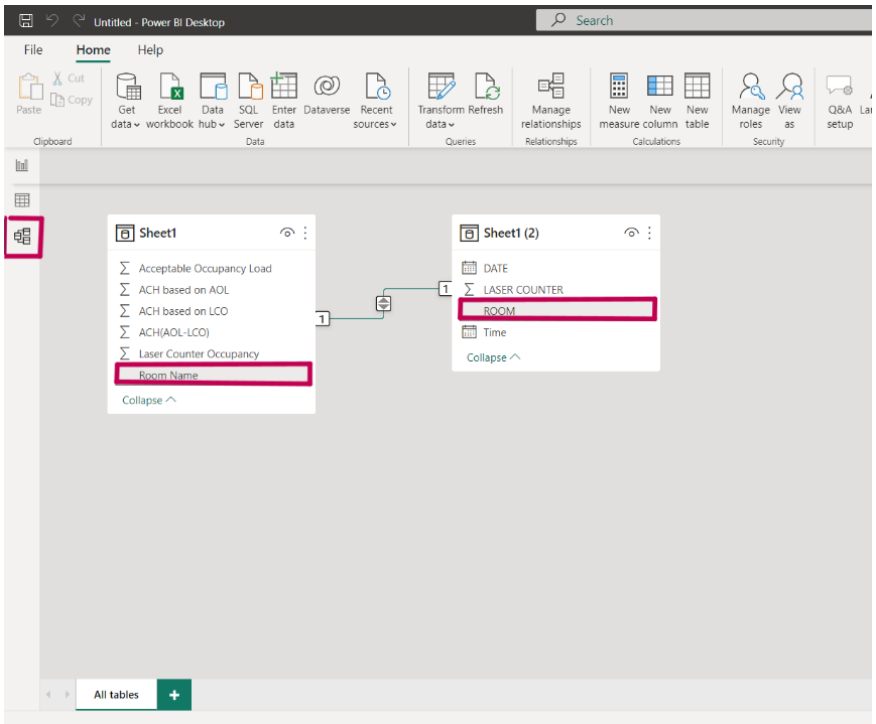


Figure 2.50: Creating the co-relation between sheets

After finishing this process, we can start to give the data according to what you want to present. In my thesis I start with the slicer and give the filter the data of all rooms and the feature of that is the rooms can be selected separately.

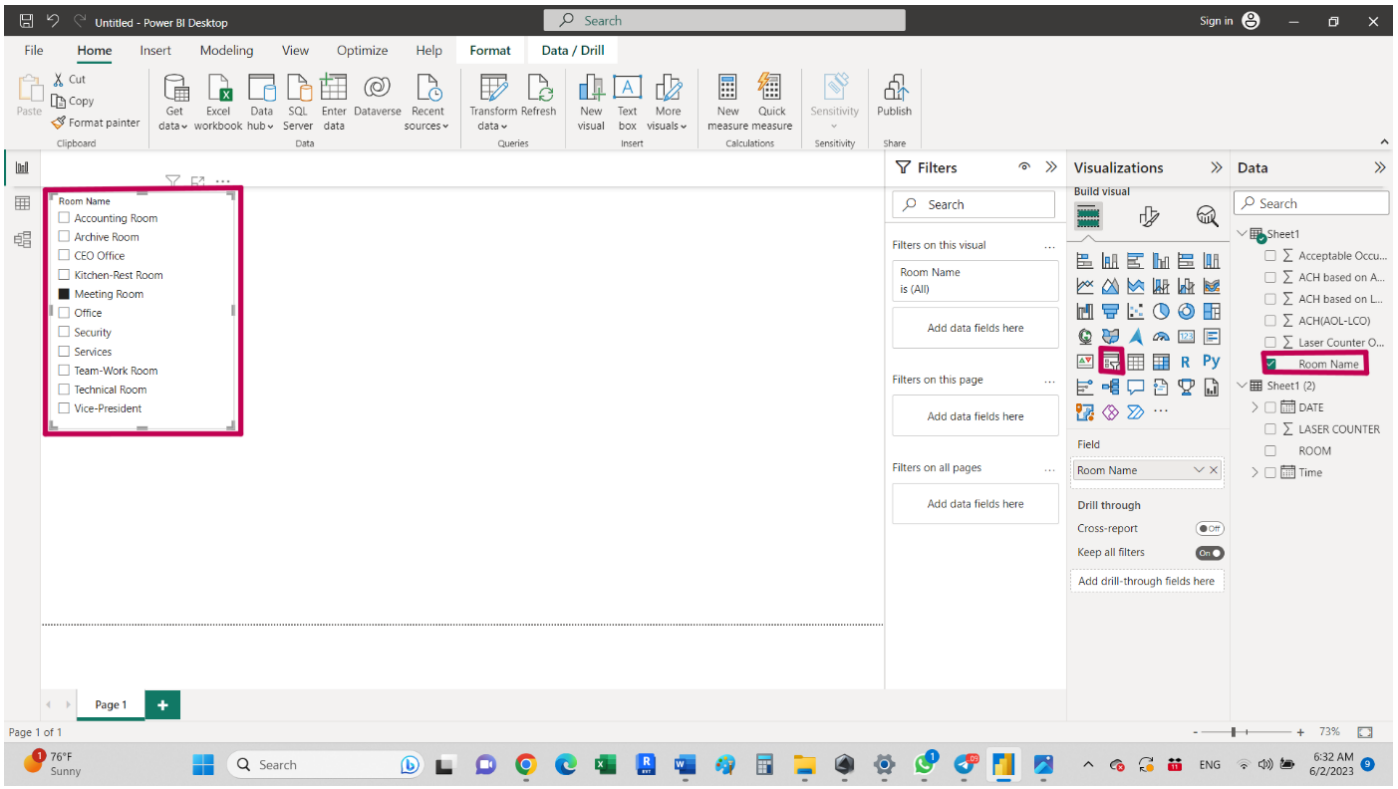


Figure 2.51: Using filters to present the Rooms

After that by using the slicer again, I gave the data of the time of recorded laser counter from sheet 1 both the date and time.

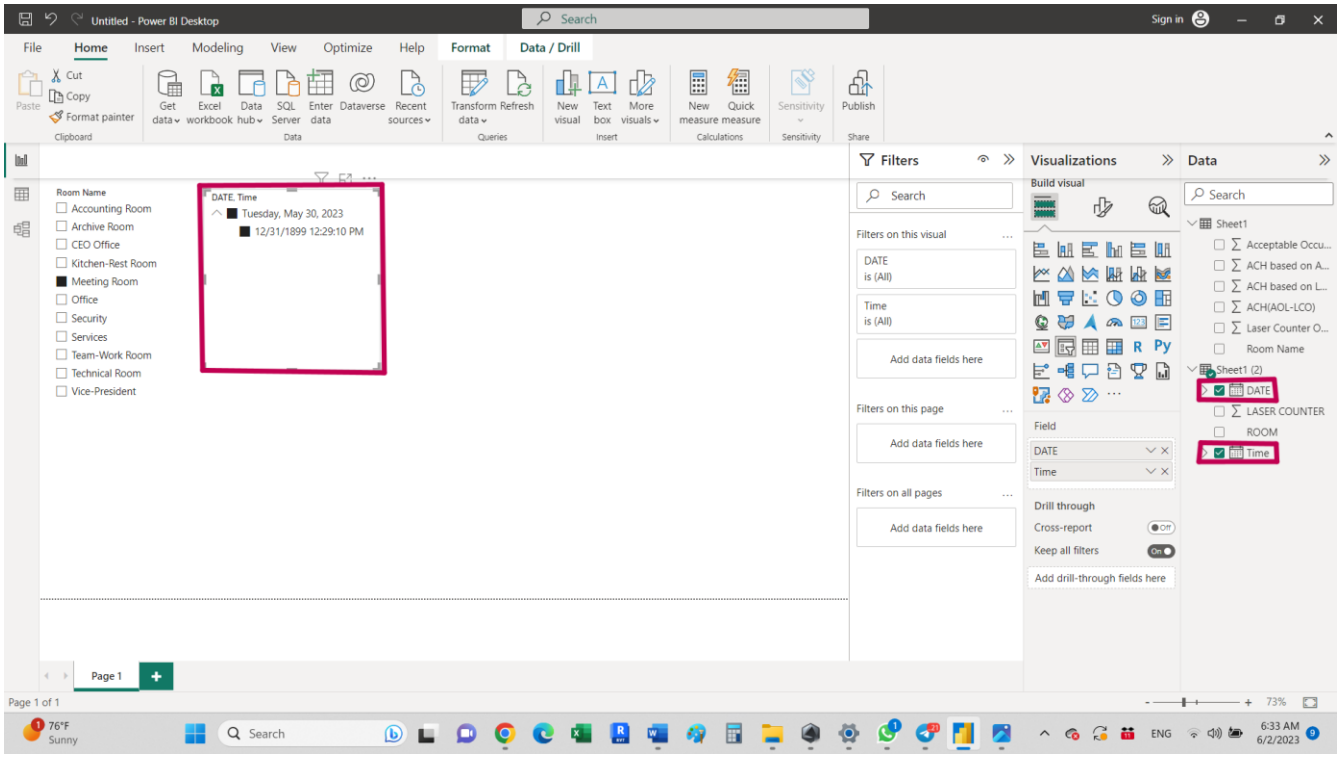


Figure 2.52: Using filters to present the times

Now I want to show the laser counter occupancy in ratio to the acceptable occupancy load by using the percentage. In these terms we can understand that the percentage below 100 is acceptable and above that means the occupancy load is over the acceptable one. For doing this I prefer to use the funnel data analyzer. This feature also gives us a chance to understand how much percentage of the acceptable occupancy load is occupied.

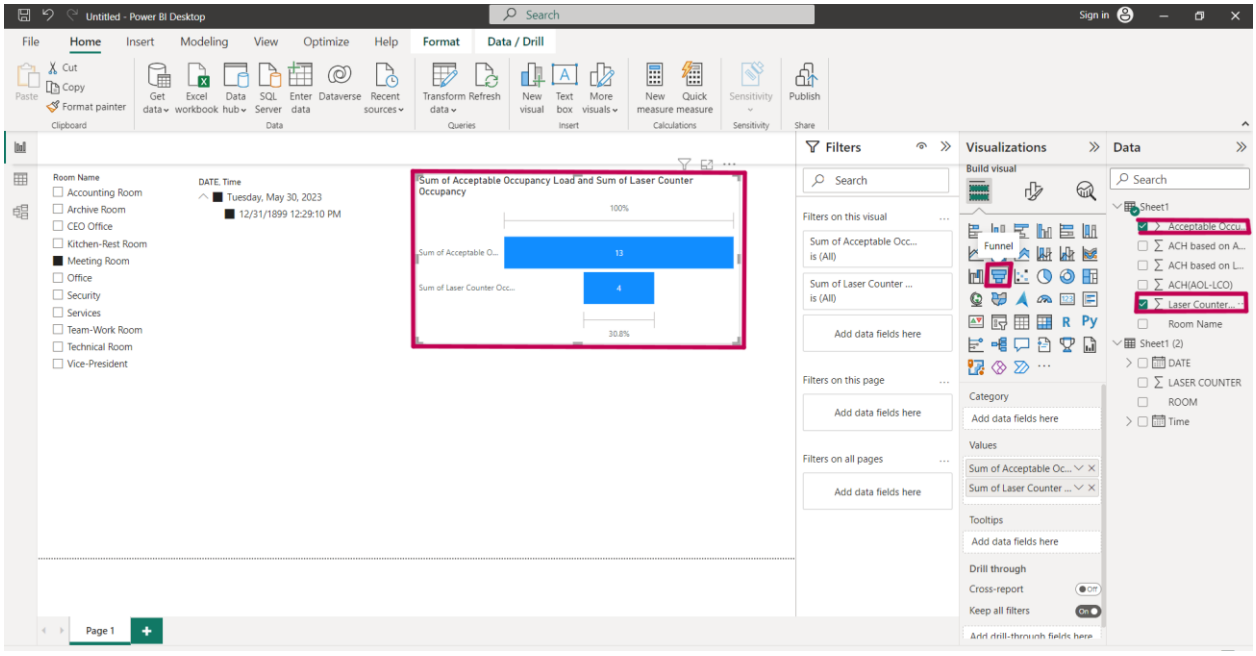


Figure 2.53: Using funnel data analyzer to present the LOC and AOL

The next data for this sheet is to understand the number of ACH LOC and ACH AOL which can be represented by the clustered column chart.

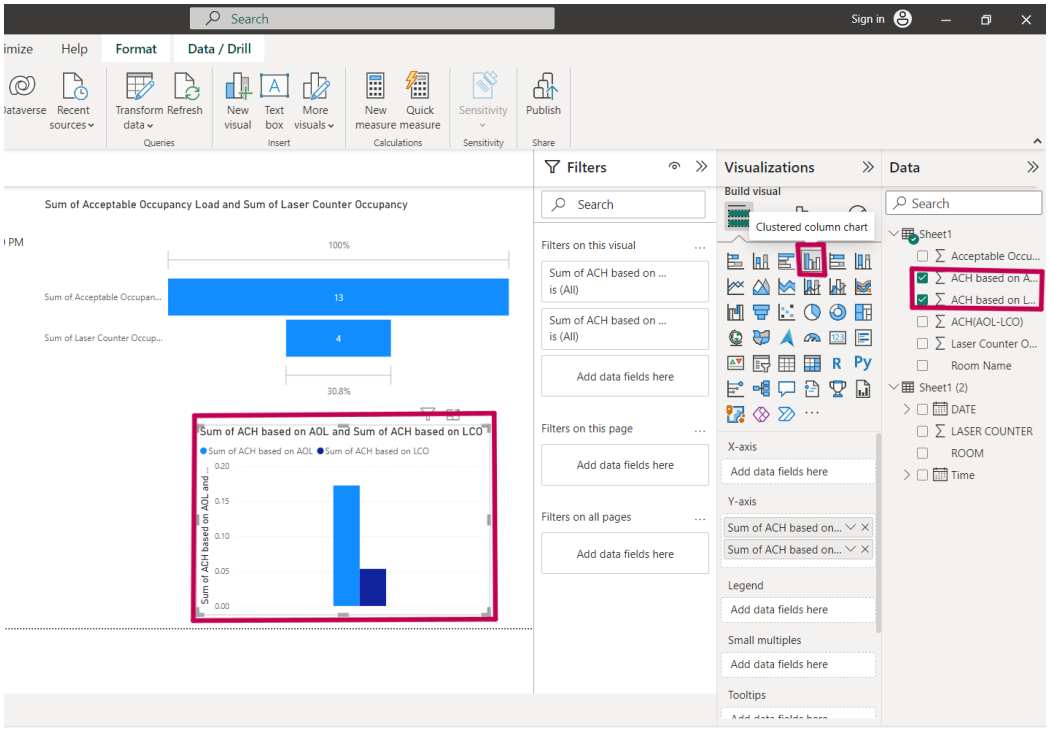


Figure 2.54: Using clustered column chart to present the ACH LOC and ACH AOL

And finally, the ACH AOL – ACH LOC is the final data that I want to add as the result. So, it is obvious that if the number of the formula is negative it means that the over occupancy load happened and if the number is positive, it means that the occupancy load is acceptable. However, if the number is equal to 0 it means that the ACH AOL and ACH LOC is on the limit board red line. For doing that I have chosen to use the card which indicates only a single data.

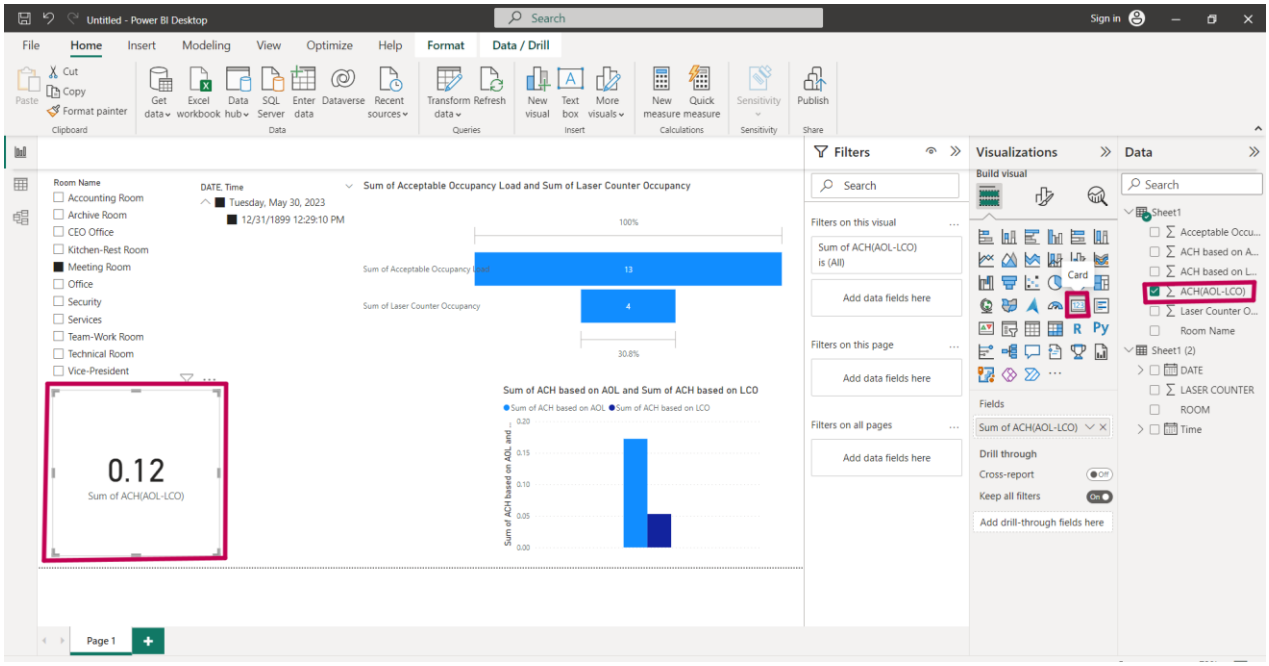


Figure 2.55: Using single number to present the ACH(AOL)-ACH(LOC)

So, the only thing is remains is that we can give a name to the sheet and manage the data position on sheet. After that it is only necessary to save the file in a location and refresh the data whenever possible. Here is the final sheet based on the input and output data coming from excels.

It is noticeable that according to the data server costs around 2000 euro I could not report the Power Bi in the Microsoft dashboard specialized for Power Bi. So, the data should be refreshed manually because the feature of auto refresh sheet needs to be connected to the main server. Thus, the data you will see in Power Bi sheet refreshed by my own.

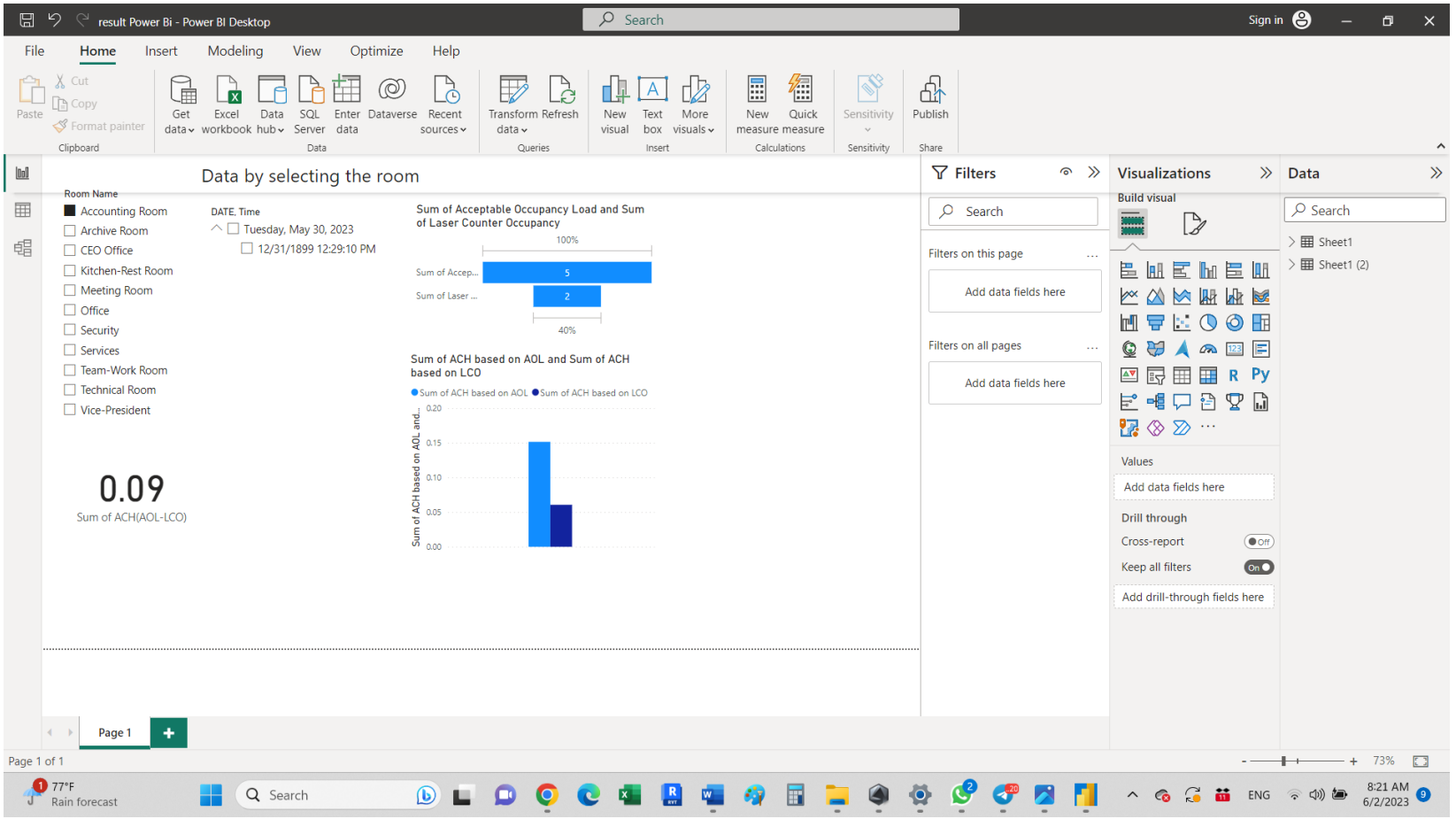


Figure 2.56: Final sheet 1 design in Power BI

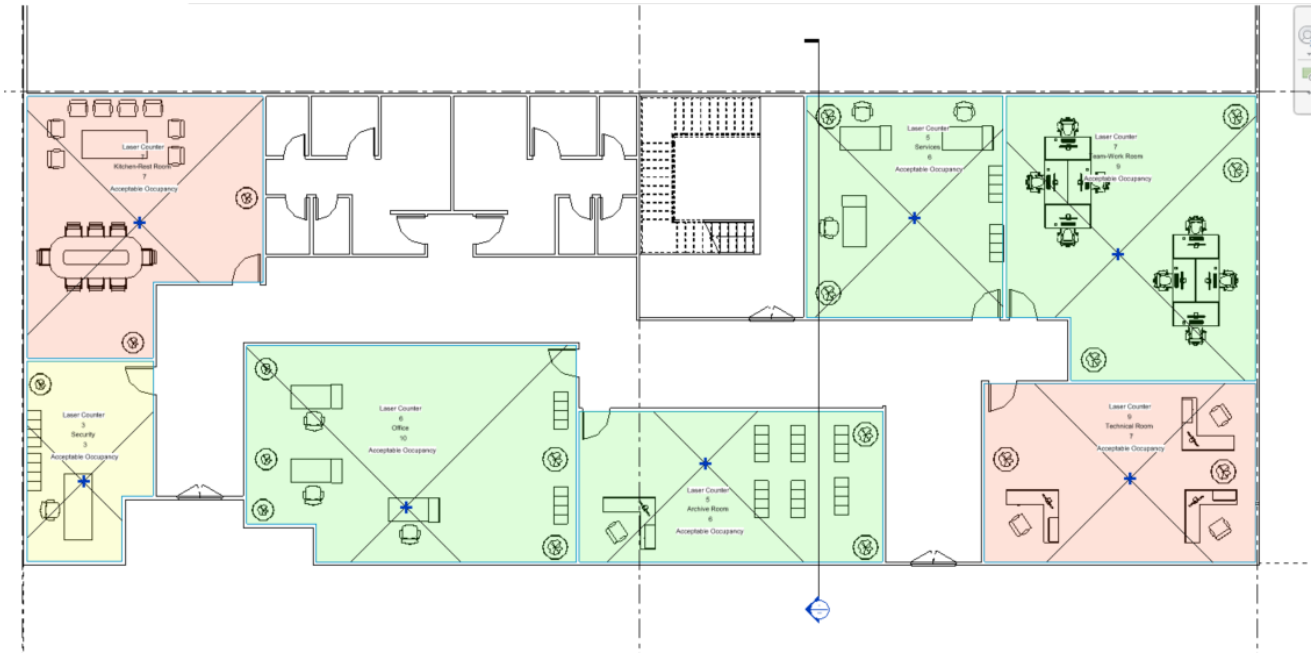
3. RESULT AND DISCUSSION

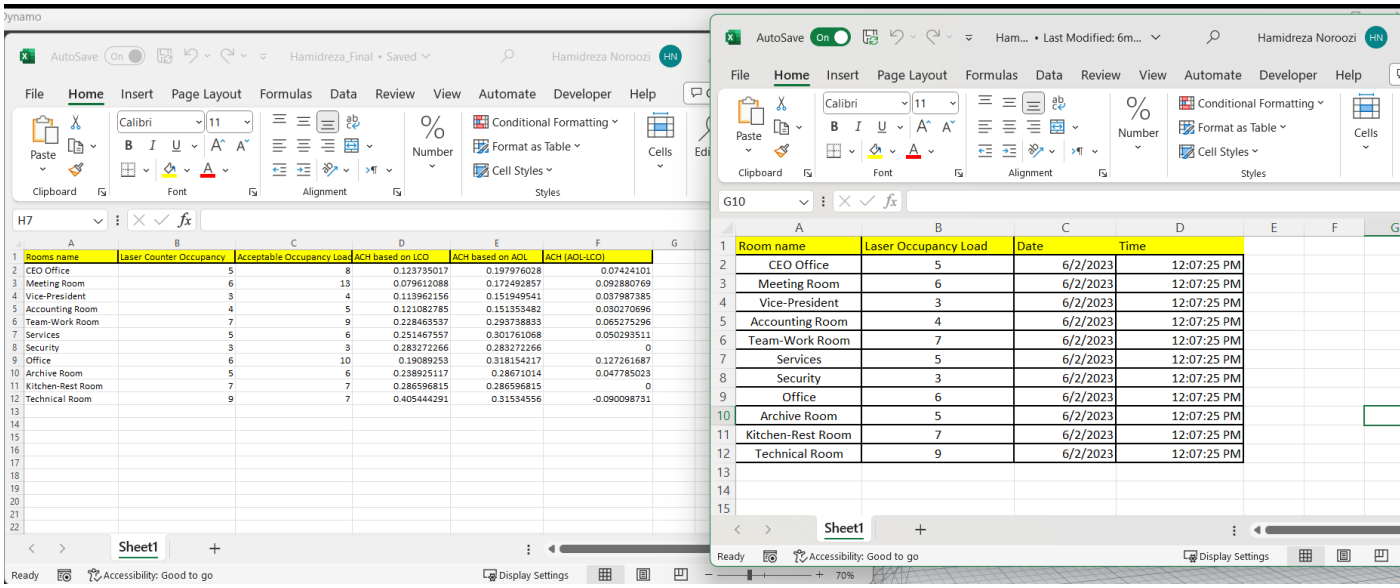
3.1. INTERROPERABILITY VALUE FOR DIGITAL TWIN

The value of interoperability of digital twin for IAQ shows an acceptable result as the monitoring of people and the relation between mentioned feature and IAQ has always been a permanent problem which has a direct relation to the health of people. The whole system and method were to create a connection between the static data which is the BIM model of the FCA and the dynamic data which is the laser counter system enables to control the income or outcome of people in an area. According to the cost and time spending of applying the process of sensors for the laser counter system, instead I preferred to simulating the process with the excel VBScript as we know that the real sensor test has been applied and proven in one of the hospitals in Torino. The connection between these two happened by using VPL language specially Dynamo which is one of the strongest VPLs. The simulated excel file was input into the Dynamo and the whole process takes less than one second to apply the changes into the output which was an excel file as well. The result of the this studies should be divided into three parts, including the representation of the occupancy load into red, green, yellow in BIM model according to the ratio of the LCO and AOL and then output excel which contains the LCO number, AOL number and the ACH based on both of them to understand the ACH (AOL-LCO) which represents the IAQ in those areas and finally the GUI which convert the data in graphical way and sort them in better way. The results which will be presented below captured in three times.

One of the biggest problems in results was the Power BI because as the simulation and whole process of VPL working the excels are used, the Power BI cannot get the back up and refresh the data and gives the error. So, in this part time we could not get the result of Power BI.

Overall, we can see that the whole process of digital twin for monitoring the people which include the integration of BIM model, and the laser counter simulation works well.

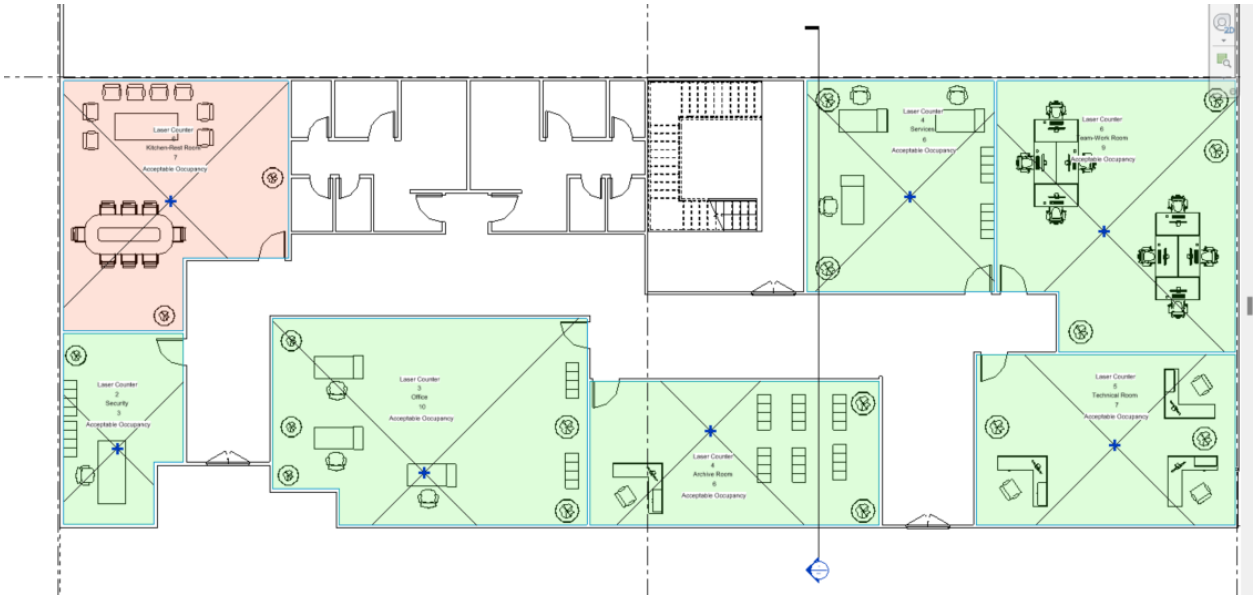




Rooms name	Laser Counter Occupancy	Acceptable Occupancy Load	ACH based on LCO	ACH based on AOL	ACH (AOL-LCO)
CEO Office	5	8	0.123735017	0.197976028	0.07424101
Meeting Room	6	13	0.079612088	0.172492857	0.092880769
Vice-President	3	4	0.113962156	0.151949541	0.037987385
Accounting Room	4	5	0.121082785	0.151353482	0.030270696
Team-Work Room	7	9	0.228463537	0.293738833	0.065275296
Services	5	6	0.251467557	0.301761068	0.050293511
Security	3	3	0.283272266	0.283272266	0
Office	6	10	0.19089253	0.318154217	0.127261687
Archive Room	5	6	0.238925117	0.28671014	0.047785023
Kitchen-Rest Room	7	7	0.286596815	0.286596815	0
Technical Room	9	7	0.405444291	0.31534556	-0.090098731

Room name	Laser Occupancy Load	Date	Time
CEO Office	5	6/2/2023	12:07:25 PM
Meeting Room	6	6/2/2023	12:07:25 PM
Vice-President	3	6/2/2023	12:07:25 PM
Accounting Room	4	6/2/2023	12:07:25 PM
Team-Work Room	7	6/2/2023	12:07:25 PM
Services	5	6/2/2023	12:07:25 PM
Security	3	6/2/2023	12:07:25 PM
Office	6	6/2/2023	12:07:25 PM
Archive Room	5	6/2/2023	12:07:25 PM
Kitchen-Rest Room	7	6/2/2023	12:07:25 PM
Technical Room	9	6/2/2023	12:07:25 PM

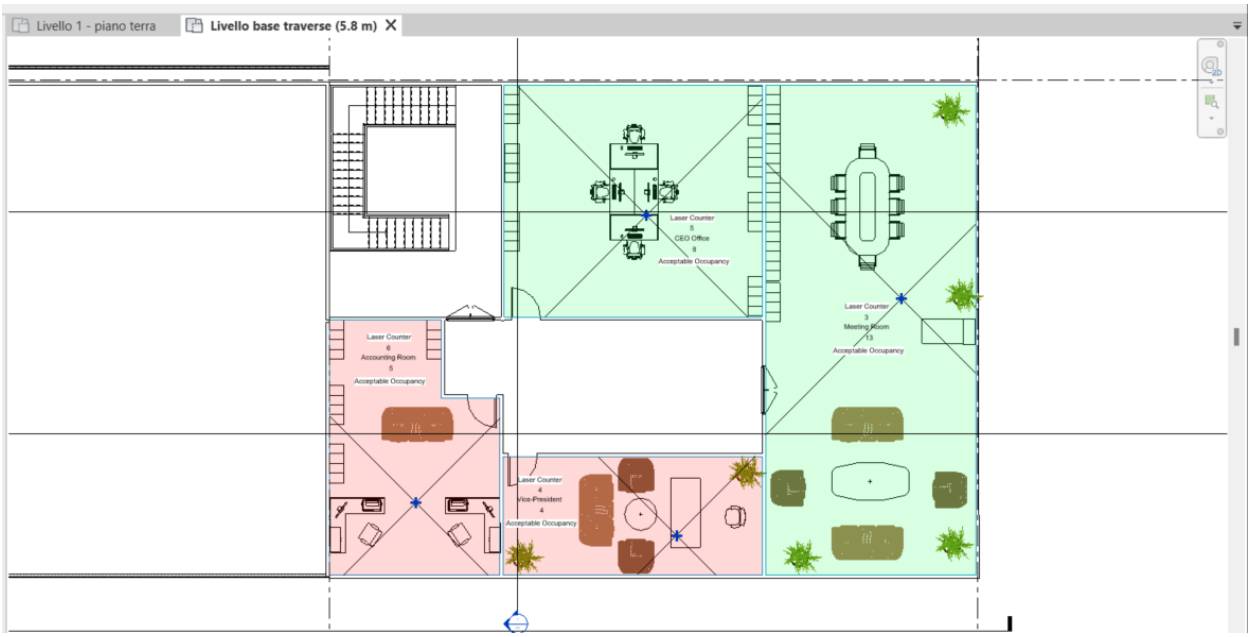
Figure 3.1: First result in on first floor

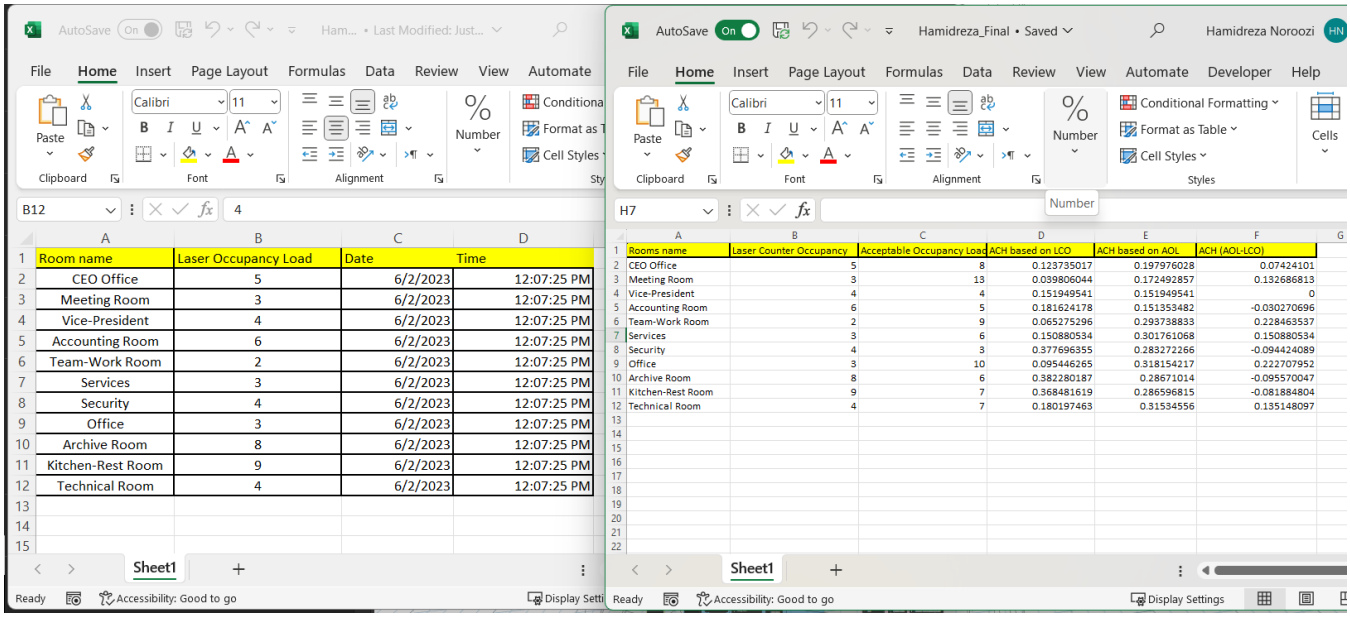


Room name	Laser Occupancy Load	Date	Time
CEO Office	2	6/2/2023	12:07:25 PM
Meeting Room	4	6/2/2023	12:07:25 PM
Vice-President	5	6/2/2023	12:07:25 PM
Accounting Room	5	6/2/2023	12:07:25 PM
Team-Work Room	6	6/2/2023	12:07:25 PM
Services	4	6/2/2023	12:07:25 PM
Security	2	6/2/2023	12:07:25 PM
Office	3	6/2/2023	12:07:25 PM
Archive Room	4	6/2/2023	12:07:25 PM
Kitchen-Rest Room	6	6/2/2023	12:07:25 PM
Technical Room	5	6/2/2023	12:07:25 PM

Rooms name	Laser Counter Occupancy	Acceptable Occupancy Load	ACH based on LCO	ACH based on AOL	ACH (AOL-LCO)
CEO Office	2	8	0.049494007	0.197976028	0.148482021
Meeting Room	4	13	0.053074725	0.172492857	0.119418132
Vice-President	5	4	0.189936926	0.151949541	-0.037987385
Accounting Room	5	5	0.151353482	0.151353482	0
Team-Work Room	6	9	0.195825889	0.293738833	0.097912944
Services	4	6	0.201174045	0.301761068	0.100587023
Security	2	3	0.188848177	0.283272266	0.094424089
Office	3	10	0.095446265	0.318154217	0.222707952
Archive Room	4	6	0.191140094	0.28671014	0.095570047
Kitchen-Rest Room	6	7	0.245654413	0.286596815	0.040942402
Technical Room	5	7	0.225246828	0.31534556	0.090098731

Figure 3.2: Second result on first floor

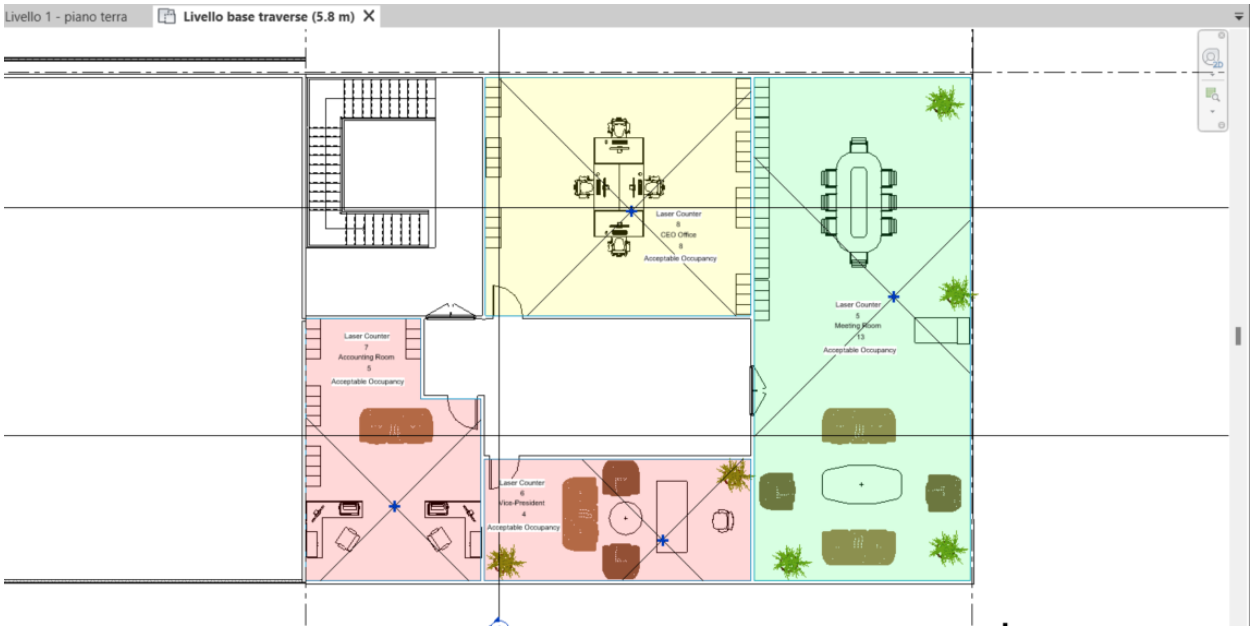


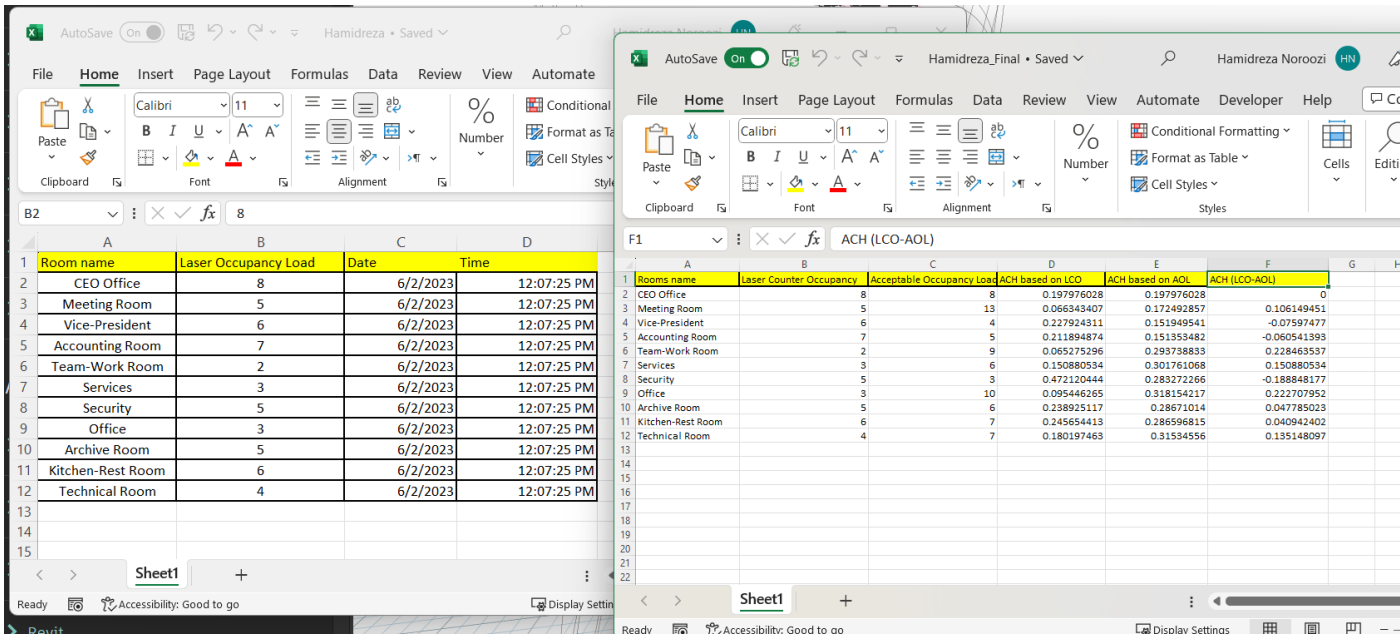


Room name	Laser Occupancy Load	Date	Time
CEO Office	5	6/2/2023	12:07:25 PM
Meeting Room	3	6/2/2023	12:07:25 PM
Vice-President	4	6/2/2023	12:07:25 PM
Accounting Room	6	6/2/2023	12:07:25 PM
Team-Work Room	2	6/2/2023	12:07:25 PM
Services	3	6/2/2023	12:07:25 PM
Security	4	6/2/2023	12:07:25 PM
Office	3	6/2/2023	12:07:25 PM
Archive Room	8	6/2/2023	12:07:25 PM
Kitchen-Rest Room	9	6/2/2023	12:07:25 PM
Technical Room	4	6/2/2023	12:07:25 PM

Rooms name	Laser Counter Occupancy	Acceptable Occupancy Load	ACH based on LCO	ACH based on AOL	ACH (AOL-LCO)
CEO Office	5	8	0.123735017	0.197976028	0.07424101
Meeting Room	3	13	0.039806044	0.172492857	0.132686813
Vice-President	4	4	0.151949541	0.151949541	0
Accounting Room	6	5	0.181624178	0.151353482	-0.030270696
Team-Work Room	2	9	0.065275296	0.293738833	0.228463537
Services	3	6	0.150880534	0.301761068	0.150880534
Security	4	3	0.377696355	0.283272266	-0.094424089
Office	3	10	0.095446265	0.318154217	0.222707952
Archive Room	8	6	0.382280187	0.28671014	-0.095570047
Kitchen-Rest Room	9	7	0.368481619	0.286596815	-0.081884804
Technical Room	4	7	0.180197463	0.31534556	0.135148097

Figure 3.3: Third result on second floor





Room name	Laser Occupancy Load	Date	Time
CEO Office	8	6/2/2023	12:07:25 PM
Meeting Room	5	6/2/2023	12:07:25 PM
Vice-President	6	6/2/2023	12:07:25 PM
Accounting Room	7	6/2/2023	12:07:25 PM
Team-Work Room	2	6/2/2023	12:07:25 PM
Services	3	6/2/2023	12:07:25 PM
Security	5	6/2/2023	12:07:25 PM
Office	3	6/2/2023	12:07:25 PM
Archive Room	5	6/2/2023	12:07:25 PM
Kitchen-Rest Room	6	6/2/2023	12:07:25 PM
Technical Room	4	6/2/2023	12:07:25 PM

Rooms name	Laser Counter Occupancy	Acceptable Occupancy Load	ACH based on LCO	ACH based on AOL	ACH (LCO-AOL)
CEO Office	8	8	0.197976028	0.197976028	0
Meeting Room	5	13	0.066343407	0.172492857	0.106149451
Vice-President	6	4	0.227924311	0.151949541	-0.07597477
Accounting Room	7	5	0.211894874	0.151353482	-0.060541393
Team-Work Room	2	9	0.065275296	0.293738833	0.228463537
Services	3	6	0.150880534	0.301761068	0.150880534
Security	5	3	0.472120444	0.283272266	-0.188848177
Office	3	10	0.095446265	0.318154217	0.222707952
Archive Room	5	6	0.238925117	0.28671014	0.047785023
Kitchen-Rest Room	6	7	0.245654413	0.286596815	0.040942402
Technical Room	4	7	0.180197463	0.31534556	0.135148097

Figure 3.4: Forth result on second floor

3.2. ANALYSIS OF DATA OUTPUT

As you can see the minimum error happened in the process it is noticeable that the result should be refreshed to Power BI by the user to be submitted but all other data and whole process of the digital twin for IAQ works as an acceptable for the target of monitoring the number of people and finding the ACH of each area for the better result in saving energy and the health problem.

As you can see the minimum error happened in the process it is noticeable that the result should be refreshed to Power BI by the user to be submitted but. Also, there is a video to prove the workability of the system, linked below:

https://www.dropbox.com/s/gnwv7j7wqk26mha/video_2023-06-14_00-13-53.mp4?dl=0

4. CONCLUSION

As conclusion it is obviuos that without technology specially IoT know as digital twin which will be a main feature of saving energy, accurcy, human health, and other good features in furure, we are just consuming the energy and surroundings with a lots of daily problems. What we can say about the total global warming total CO2 emmission and what we can do? Techology always has a good solution for the world which should be pereserved fo the next generations.

4.1. SUMMARY OF THE STUDY'S FINDING

The whole process of the Digital twin for IAQ begins by conducting an in-depth literature review to establish a foundation of knowledge regarding IAQ parameters in which the number of occupancies was the main factor of it. So, monitoring the number of occupancies enables us to understand the ACH and the effect such as reducing the risk of BRS containing real diseases like the Covid-19 and unreal sicknesses like sick building syndrome. The methodology section outlines the process of developing a digital twin framework for IAQ. It includes steps such as data collection, sensor simulation with excel VBScript, BIM model, and the implementation of machine learning algorithms for predictive analytics which is done by VPL and Dynamo plays the main core of the process. The study also discusses the challenges and considerations involved in creating an accurate and reliable digital twin model. The results show that the whole process is perfectly reliable, and the accuracy of the process was worth doing more studies on this process. It could be mentioned that it would be better to use the real sensors to get the real data which needs to allocate more budget and the time of at least one month to gather them.

4.2. FUTURE DEVELOPMENTS

As it is mentioned in this thesis for several time first, it is better to work and analyzing the real-time data by using the real sensors instead of simulation of that, so one of the further developments could be done by the ICT engineers to create a real data base using the Java Script and another developments could be done by the mechanical engineers to use the ACH (ALO-LCO) number to do the mathematical system of HVACs. By doing this the HVAC system could adapt the ACH of area based on the mentioned number developed in this thesis.

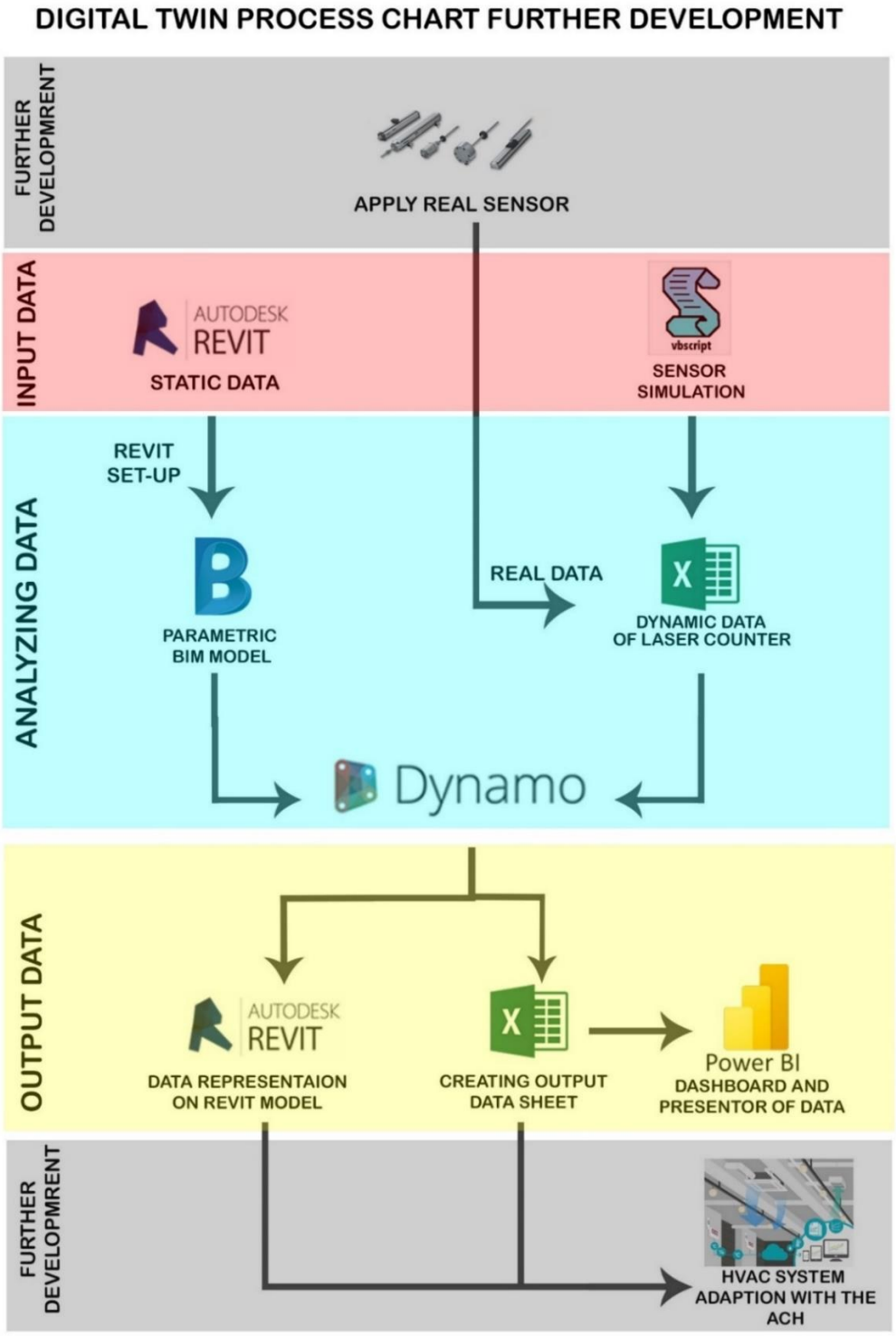


Figure 4.1: Further development possibility

5. REFRENCES

[1] Burden of disease from Ambient Air Pollution for 2012 — Summary of results,

World Health Organization

http://www.who.int/phe/health_topics/outdoorair/databases/AAP_BoD_results

_March2014.pdf) accessed October 16th, 2017.

[2] https://www.https://www.acgih.org/

[3] https://en.wikipedia.org/wiki/Digital_twin#cite_note-2

[4] BIM handbook for building and civil engineering students/ chapter 00 by Matteo Del Giudice

[5] BIM handbook for building and civil engineering students/ chapter 02 by Matteo Del Giudice

[6] advancedsolutions.com

[7] https://en.wikipedia.org/wiki/FCA_Heritage

[8] https://bytebeam.io/blog/a-brief-history-of-internet-of-things-iot-

cl8ipnm83212891kphdhq3845m/

[9] https://www.danfoss.com/en/service-and-support/case-stories/dhs/hvac-flexibility-energy-monitoring-in-edge-amsterdam-multi-tenant-healthy-smart-office/

[10] https://www.youtube.com/watch?v=JSzko-K7dzo

[11], [12], [13] https://www.researchgate.net/publication/352907638_IoT_Solutions_for_Smart_Management_of_Hospital_Buildings_A_General_Review_towards_COVID-19_Future_Pandemics_and_Infectious_Diseases

[14], [15] Design of indoor climate control passive systems in buildings: experiences for a PhD course/ course by Prof. Grosso/ Polito

[16] Lesson2/Material course Polito/ Architecture for sustainable design/ by Prof. Jean-Marc Tulliani/ page 23

[17],[18],[19] Lesson2/Material course Polito/ Architecture for sustainable design/ by Prof. Jean-Marc Tulliani/ page 27, 28

[20] Lesson2/Material course Polito/ Architecture for sustainable design/ by Prof. Jean-Marc Tulliani/ page 47

[21],[22] Lesson2/Material course Polito/ Architecture for sustainable design/ by Prof. Jean-Marc Tulliani/ page 48, 49