

SYMBIOTIC DATA PLATFORM

A RECEPTIVE-RESPONSIVE TOOL FOR CUSTOMIZING THERMAL COMFORT & MAXIMIZING ENERGY EFFICIENCY

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*17 March, 2020
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SYMBIOTIC VERİ PLATFORMU

TERMAL KONFORU ÖZELLEŞTİRMEK
ve ENERJİ VERİMLİLİĞİNİ EN ÜST DÜZEYE ÇIKARMAK
İÇİN ALICI ve VERİCİ, DUYARLI BİR ARAÇ

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To my inner child...

ACKNOWLEDGEMENTS

AND

SPECIAL THANKS



ACKNOWLEDGEMENTS

First of all, I'd like to present my deepest gratitude to my parents; my mum **Fitnat Birgönül** and my dad **Prof. Dr. Mustafa Talat Birgönül**, for their existence, and for providing all the possibilities that allows me to follow my dreams. I love you unconditionally.

I would like to thank all the members of my family for always believing in me and appreciating the way that I am following. Also particularly, to **Ayda** and **Kaan**, for being my biggest motivation on the way of being a good example for them. To **Soledad Benet Perez** for always supporting me and being a second mother away from home and teaching me to stay strong no matter what happens.

Presenting the most important credits to my co-advisors **Dr. Ana Cocho-Bermejo** and **Dr. Vicenç Sarrablo**, for their invaluable collaboration, encouragement, help, assistance and contribution. Without you this project would be impossible.

I owe a debt of gratitude to **Prof. Dr. Gülen Çağdaş** for believing in me and opening the doors of ITU, and to **Dr. Sema Alaçam** and **Dr. Ethem Gürer** for their warmest welcome to AD-Computing Research Group and for giving me possibilities while including me to the projects.

Thank you for giving me the chance to be a part of it; I could not imagine a better visiting research period.

Also I'd like to thank **Prof. Dr. İrem Dikmen Toker** and **Dr. Güzide Atasoy Özcan** for sharing their knowledge with me, and also, to all faculty members from METU Civil Engineering Department for their collaboration, feedbacks and technical assistance upon BIM.

To my dear friend **Manuel De Iuliis** for his endless support, sharing his knowledge and never letting me lose my motivation, always inspiring me with better ideas, and most importantly helping me to start with coding, correcting my mistakes and dedicating his time on this project, and teaching me how to code.

To my uncle Arch. **Örge Ekin**, for sharing common interests, his toolbox and my passion in this project. Over and above, teaching me how to solder.

To Arch. **Emrullah Yıldız**, for teaching me the visual programming language 'Dynamo for Revit' and assisting me with the design of

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dynamo definition that we created for 'calculation of Room Thermal Value'.

To programmer **Gul Bakavali**, for being the problem solver, for her great contribution on development of the technical part of the prototypes and always finding a way to make it happen; giving me assistance, and sharing her knowledge with me.

To **Özlen Özses** and **Dr. Onur Karabatak** for their professionalism and counseling on the way of curing my 'self', and for teaching the way to find balance between heart, mind and soul.

To Arch. **Oriol Carrasco**, for being my role model and a great friend, for inspiring me with his marvelous mind & ambition, also for showing me that everything is possible.

To **Eylül Ishakoğlu, Beren Karaosmanoğlu, Burcu Tokgöz, Ezgi Ergenç, Ezgim Çelenligil, Kristina Urneva, Meropi Eleni Skordalou** and **Naz Göktan** for their friendship and constant support on the way that I am moving forward.

And lastly, to my partner of life, **Xavier Marti Benet**; for having the most beautiful soul I ever met, for his constant support in each and every case, specifically on this academic work, making me feel loved, for being my chosen family and home, for encouraging me with every step that I take and walking with me throughout this maturation journey.

ABSTRACT

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symbiosis & sensitivity

ABSTRACT

EN:

A RECEPTIVE-RESPONSIVE TOOL FOR CUSTOMIZING THERMAL COMFORT & MAXIMIZING ENERGY EFFICIENCY

'Symbiotic Data Platform' is a receptive-responsive tool for achieving 'personalized' and 'optimized' thermal comfort meanwhile addressing energy efficiency. The research focuses on developing a new interactive phase for BIM, as creating a possibility to use the existing BIM data during the occupation phase by the occupants of the building; without requiring any prior knowledge upon the design tools & BIM and IoT technology.

The platform is an interdisciplinary artifact that is designed as an everyday 'wearable object' to collect data, and on the other side, as an 'interactive interface,' by processing the collected and existing information by blending various technologies and techniques.

The main contribution of the project is to propose a user-centered tool for occupants with the function that takes benefit of the massive data that is embedded in Building Information Models by exporting the

information and using it in other mediums as input and process all of it in real-time. The research addresses energy efficiency, user comfort, and sustainable environment concerns due to augmenting the accuracy of analysis by material data and real-time information while focusing on personalized comfort optimization. Therefore, the final product is a platform that arises a solution proposal both for environmental concerns and also for the daily needs of contemporary society in relation with each other. The research project is developed by designing and testing via 'prototyping' thanks to IoT technology, and investigating the possibilities of adding BIM data to the prototypes' algorithm.

KEYWORDS:

Building Information Modeling (BIM), Internet of Things (IoT), Interaction, Real-Time Information, Responsive Architecture, Human-Computer Interaction, User-Centered Design, Post-Occupancy Analysis, Thermal Comfort Optimization, Occupant Thermal Comfort, Energy Efficiency, Sustainability.



ES:

El proyecto de “Symbiotic Data Platform” es una herramienta interactiva diseñada con el objetivo de personalizar el confort térmico optimizando a la vez la eficiencia energética.

La presente investigación se ha centrado en el desarrollo de una nueva fase interactiva de BIM, consistente en hacer posible el uso de sus datos por parte de los habitantes de los edificios sin la necesidad de conocimiento previo alguno de la tecnología BIM o IoT. Dicha plataforma, de carácter interdisciplinar, ha sido diseñada en forma de sensor portátil para la recopilación de datos, y, por otro lado, como una interfaz interactiva que procesa la información recopilada gracias a la combinación de diversas tecnologías y técnicas. La principal contribución del proyecto es proporcionar a los habitantes de los hogares una nueva herramienta que ayude a personalizar y optimizar el confort térmico mejorando a la vez la eficiencia energética gracias al uso los datos de BIM y la información en tiempo real (IoT). El funcionamiento de la plataforma consiste en exportar los datos masivos que se encuentran en BIM a otros medios digitales para que procesen la información en tiempo real del análisis de los datos de los materiales de los edificios. El producto final, por tanto, es una plataforma que surge como respuesta a las preocupaciones medioambientales y a las necesidades cotidianas de la sociedad contemporánea. El proyecto se ha basado en el desarrollo de prototipos que han sido testados usando la tecnología IoT y en la investigación de la posibilidad de agregar los datos extraídos de BIM en los algoritmos de los prototipos.

CAT:

‘El projecte de “Symbiotic Data Platform” és una eina interactiva dissenyada amb l'objectiu de personalitzar el confort tèrmic optimitzant al mateix temps l'eficiència energètica. La present recerca s'ha centrat en el desenvolupament d'una nova fase interactiva de BIM consistent a fer possible l'ús de les dades que aquest sistema ens proporciona per part dels habitants dels edificis, sense necessitat de cap coneixement previ de la tecnologia BIM o IoT.

Aquesta plataforma, de caràcter interdisciplinari, ha estat dissenyada en forma de sensor portàtil per a la recopilació de dades, i, d'altra banda, com una interfície interactiva que processa la informació recopilada gràcies un la combinació de diverses tecnologies i tècniques. La principal contribució del projecte és proporcionar als habitants de les llars una nova eina que permeti personalitzar i optimitzar el confort tèrmic millorant a la vegada l'eficiència energètica gràcies a l'ús les dades de BIM i la informació processada en temps real (IoT). El funcionament de la plataforma consisteix a exportar a altres mitjans digitals les dades massives que es troben a BIM perquè processin la informació en temps real de l'anàlisi de les dades dels materials dels edificis. El producte final, per tant, és una plataforma que sorgeix com a resposta a les preocupacions mediambientals de la societat contemporània i de les seves necessitats quotidianes.

El projecte s'ha basat en el desenvolupament de prototips que han estat testats usant la tecnologia IoT i en la recerca de la possibilitat d'agregar les dades extretes de BIM en els algorismes dels prototips.

SYMBIOTIC DATA PLATFORM

symbiosis & symbiote

TR:

"Symbiotic Data Platform" enerji verimliliğini ve aynı zamanda "kişiselleştirilmiş" ve "optimize edilmiş" termal konforu elde eden alıcı ve verici bir araçtır. Araştırma, kullanıcıyı tasarım araçları ve BIM ve IoT teknolojisi hakkında önceden bilgi sahibi olmalarına gerek olmaksızın, bina sakinleri olarak belirleyerek, binanın kullanım aşamasına odaklanmaktadır.

Platform, veri toplamak için günlük 'giyilebilir nesne' olarak ve diğer yandan mevcut bilgileri çeşitli teknolojiler ve tekniklerle harmanlayarak 'etkileşimli bir arayüz' olarak tasarlanan disiplinlerarası bir çalışmadır. BIM için yeni bir interaktif aşama öneren bu proje, BIM'den elde edilen ve hali hazırda dışarıya aktarılabilen verilerin gerçek zamanlı verilerle bir arada, en verimli sonuçlara ulaşmak amacıyla işlenmesini araştırmaktadır. Bu şekilde, enerji verimliliği, kullanıcı konforu ve sürdürülebilir çevresel endişeleri ele alırken kişiselleştirilmiş konfor optimizasyonuna da çözümler sunar. Bu nedenle, son ürün, hem çevresel kaygılar hem de çağdaş toplumun birbiriyle ilişkili günlük ihtiyaçları için bir çözüm oluşturan bir platform olarak da tanımlanabilir.

Araştırma projesi, IoT teknolojilerini kullanarak 'prototipleme' yöntemiyle tasarlanmış ve test edilmiştir. Tasarlanan aygıt prototiplerin algoritmasına BIM verileri ekleme olasılıklarının araştırılması doğrultusunda geliştirilmiştir.

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INTRODUCTION

1. INTRODUCTION

1.1. STATE OF THE ART

When only the form and function is considered as the reference point; the new understanding of architecture was defined 'modern architecture' at late 1800's and early 1900's. Le Corbusier¹, Frank Lloyd Wright², Gustave Eiffel³ and many invaluable architects had their own standpoints for creating a new way of design thinking. Modern architecture was coined within the use of new materials, structural systems and innovative technologies of construction. Particularly glass, steel and reinforced concrete were the materials that have been introduced as new possibilities for architecture and construction; that the idea "*form should follow function*" also known as "*rational functionalism movement*". Simplifying the ornament and

enhancing the functionality by a minimalist perspective brought a new understanding to architecture back to those days.

The idea of '*architecture as a machine*' was proposed regarding to the 'rational functionalism movement' coined by Le Corbusier, especially by the statement '*The house is a machine for living in.*' in his book '*Towards a New Architecture*' (Corbusier, 1986). This statement was revolutionary, by not only proposing a new link between industry and architecture, but also was proposing an approach to the evolution of the world by architectural design thinking.

Following the inclusion of the importance of 'function' in architecture, discussion of more humanistic contexts has arisen. On 2006, Alain de Botton⁴ in his book '*Architecture of Happiness*' (De Botton, 2006), discussed the links between buildings and our well-being as well as his own exploration upon the importance of beauty in architecture. Architecture was no longer just a structure, not a machine to live in. By the new era, it has another new understanding and it evolved to require sensitivity. Architecture creates the place where the life

¹ He was a Swiss-French architect, designer, painter, urban planner, writer, and one of the pioneers of what is now called modern architecture.

² He was an American architect, interior designer, writer, and educator, who designed more than 1,000 structures, 532 of which were completed.

³ He was a French civil engineer.

⁴ He was a Swiss-born, British philosopher and author.



happens, and this is the reason why it is evolving through the transformation of contemporary life style.

In conjunction with this transformation, on the last decade, there is a stubborn evolution in each and every industry. Today's world is executed between human and machines and the daily life have been totally adapted to a new dynamic. By the Fourth Industrial Revolution, not only the machines and systems, but also all the Architecture-Engineering-Construction (AEC) industry and the technology & computation industry got their share. *"The Fourth Industrial Revolution, however, is not only about smart and connected machines and systems. Its scope is much wider. Occurring simultaneously are waves of further breakthroughs in areas ranging from gene sequencing to nanotechnology, from renewables to quantum computing. It is the fusion of these technologies and their interaction across the physical, digital and biological domains that make the fourth industrial revolution fundamentally different from previous revolutions"* (Schwab, 2017). Today, industry and technology in AEC inseparable, therefore, the built environment has also being transformed to be a better-managed infrastructure.

'Digitalism' was a term that is coined on 1995, by Nicholas Negroponte, in his book 'Being Digital', (Negroponte, 1995) which is a current necessity; it is believed by the new generation

designer that the futuristic applications and solutions of architecture and urbanism lays on this way (Birgonul, Cocho-Bermejo, & Sarrablo, 2018). Manuel Gausa⁵, in a critical paper, commented that the evidence of a spectacular change in the definition of our spaces of interaction and sociability of our own habitats, and also, pointed out that, we have faced with the progressive infrastructural and informational dimension of evolving territory, which is defied by layers of information, and networks of interchange (Gausa, 2015). Today's world relies on complexity of systems, and 'new' and 'advanced' architecture has to align to this synergy. Interrelation between disciplines and concepts are vital in design and application.

Right along with the digitalization movement on every industry; the possibilities of creation have been extended its limits too. Currently, architecture is not a 'tree', (Alexander, 1965) not a 'space' nor a 'machine' (Corbusier, 1986). It is a system that augments and promotes the 'living experience'. As the synthesis of the current development of technology and progression of industry, the requirement and necessities of contemporary society have also evolved. *"Architecture should become an integral and responsive part of human life. Architecture must do*

⁵ Manuel Gausa is a Spanish writer, teacher and architect

more than just look like a living organism: it should perform as a living system” (Ratti & Claudel, 2016).

All the developments and contribution of industry and technology creates a massive amount of information that is called ‘Big Data’. By the *Fourth Industrial Revolution*, accessibility of sensors in each field, and application of sensor networks, media, internet, connectivity formed this massive cloud of data, and this data is the mine for power in the current day, and more in the future. The question is how to use data in design & architecture for better futures, and ethical responsibilities as new generation designers.

Despite causing tremendous global issues such as climate crisis, pollution, and overgrowth of urban sprawl, the marvelous creativity of humankind developed sensational artifacts as well in the 21st century. In the last decades, society already regenerated their cognition by the ‘*Collective Consciousness*’⁶ that leads humanity to moral attitudes and in a responsible manner upon global concerns. Likewise as in the design industry; the designers have set up a sensitive approach to sustainability and empowerment. The new generation designers are the current change-makers that are shaping the future.

For enhancing design innovation; current technology augments the creativity along with diversity and eligibility of applied techniques, and it enables the designer to work interdisciplinary. Any context or inspiration that stands in the edges of creativity is not out of the realm of possibility; only if it covers up social, environmental, or cultural concerns. On the way of achieving distinctive results, the empirical approaches in the design should be encouraged for solution-oriented and revolutionary projects.

As a consequence of this perspective and cognition shift, the new understanding of architecture have shaped as a more responsible and more conscious manner. Attendant, the new generation designer is challenged by various concerns, such as energy efficiency, sustainability, global warming, waste, recycling, and economy. The responsibility as a human, and moreover as a designer in practice require holistic approaches to compass the future. *“The 21st century engineer and architect must be able to deal with a rapid pace of technological change, a highly interconnected world, and complex problems that require multidisciplinary solutions”* (Becerik-Gerber & Kensek, 2010). Now, knowledge is advanced and eligible thanks to world-wide-web and connectivity. Complex problems that exist in current day bring interdisciplinary research to the stage, and moreover, brought more responsibility to the researchers and practitioners. On this way, blending existing technologies led us

⁶ Collective Consciousness is a term coined by sociologist Émile Durkheim on 1893.



for further possibilities. In conjunction with the interdisciplinary; new concepts emerged such as 'Responsiveness' and 'Interaction'. As the term 'Interactive Architecture' indicates, those models "include contributions from the worlds of architecture, industrial design, computer programming, engineering, and physical computing" (Fox & Kemp, 2009). By the new definition of architecture, the interdisciplinary approach became an exigency through fulfilling the expectations of the society.

Correspondingly, the evolvement of industry, technology and built environment in tandem with each other, various innovative tools such as Building Information Modeling and Internet of Things have come to reality. The US National Building Information Model Standard Project Committee has the following definition for BIM: "*Building Information Modeling (BIM)*⁷ is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition" (United States National BIM Standard Project

Comitee, 2016). And IoT⁸ stands for 'Internet of Things' theme that is defined as; "*the interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data*" by Oxford (Lexico Dictionary, 2019). This research focuses on the possibility of integrating two existing technologies to form a more advanced system and create more energy efficient & sustainable results in built environment.

Over and above, the new architectural design understanding could be defined as "Form + Function + **Interaction**"; which includes 'human-centered design', energy efficiency, self-sustainability, responsibility and responsiveness.

To sum up, as Alison and Peter Smithson⁹ believed that they could transform people's lives for the better through architecture (Smithson & Smithson, 1986), and the world is continuously on a transformation, the adaptation of design thinking behind architecture also has to be transformed, and it requires a new

⁷ Building Information Modeling

⁸ Internet of Things

⁹ English architects that together formed an architectural partnership, and are often associated with the New Brutalism (especially in architectural and urban theory)

approach. This new approach is responsible, holistic, interdisciplinary and human-centered.¹⁰

Moreover, the urban phenomenon of 21st century is an integration of several disciplines such as architecture, social networks, technology, ethics and sustainability. Rising up the concept of smart cities¹¹ broaden up all of these concepts one-step further than the classical understanding and introduced new terminologies to the contemporary understanding. As a result of this evolution, a new definition of architecture and urbanism has arisen, which is a mutual adaptation of structures, infrastructures, systems, networks, interaction and holistic development.

Regarding to the state of art of the dissertation, the research is conducted by the project, under the title of '**Symbiotic Data Platform**'¹². Aligning with the '*new architectural design*' approach which is "*Form + Function + **Interaction***"; this thesis is concentrated on the globally accepted, most useful and productive methodology in Architecture-Engineering-

Construction industry, which is Building Information Modeling, while giving importance to the developments in Internet of Things, which is the enabling technology for data collection and interaction design. Main contribution of the research project is the creation of an interactive phase of BIM, which is designed for occupants' usage in the occupation phase of the building, without requiring any prior knowledge for operating the stated platform.

Symbiotic Data Platform is positioned to create a unique solution by the environmental and socio-economic concerns, by proposing a new possibility of blending two existing technologies in one platform. The Platform simply uses existing tools and creates a new decision making, by creating an interactive platform. This project is based upon the material information of the specific building, the energy usage and thermal comfort values, as well as the occupants' real-time data, behavior and desire. Visualizing and simulating the energy usage of the occupant of the building gives significant references for the projecting the energy saving as well as providing personalized and optimized thermal comfort.

¹⁰ See Sensibility & Sensitivity Chapter.

¹¹ Smart City is an urban development vision to integrate infrastructure technologies with information and communication technology (ICT) and Internet of things (IoT) systems to upgrade the urban structure in efficiency, productivity and sustainability.

¹² See Symbiotic Data Platform Chapter for the details of the project.



1.2. SCOPE AND ASSUMPTIONS

Research Brief:

The research is shaped with the context frame of the digital-design thinking of the new understanding of architectural design. Therefore, this research project focuses in-depth how the ideologies manifested in the 'state of the art' could be applied to practice. The project positions itself between the intersection of the integrity of art, design, engineering, science, and sociology.

Thus, for the foundation, the theoretical background of the research is constructed around the 'sensibility & sensitivity' context. **Sensibility** stands for the 'recipient' and 'responsive' technologies of digital era (Negroponte, 1995). Those concepts are the results of the digitalized world; such as sensor networks, IoT technologies, physical computing & responsive environments, Big Data, BIM data and so forth. Moreover, it also covers the outcomes and the consequences the last two industrial revolutions.

On the other hand, **Sensitivity** stands for the societies moral attitude towards this digitalized world. Contemporary concerns re-shaped the common cognition of the society. Citizens of the urban sprawl, experienced both the positive and negative parts of the digitalization. As a consequence, the global issues such

as climate crisis, pollution, population overgrowth and risk upon natural and energy resources. Regarding to those concerns, the perception of the fact and the reaction through common cognition is re-shaped by '*Collective Consciousness*'¹³.

By this new understanding and moral standpoint, people applied the prudent manners to their individual life and also, practitioners applied the sensitive approaches to academics and research & development. As a matter of fact, new technologies are designed with added values, such as sustainability, zero-waste, energy efficiency, optimized systems. For example, recently developed systems such as BIM and concepts such as Lean Construction are results of this new standpoint¹⁴. As a consequence of this theory, in this thesis; the '*Sensibility & Sensitivity*' concept is processed by the proposal of '*receptive-responsive tool*' which is 'Symbiotic Data Platform'.

Depending to the raising conscience upon energy efficiency, sustainability and socio-cultural issues; current technologies are revised with this point of view. With the scope of theoretical and technologic background review, it is found out that; even though Building Information Modeling systems target lean construction,

¹³ See Sensitivity Chapter.

¹⁴ See Sensitivity Chapter for definitions and further discussion.

sustainability, efficiency and many more, the research gap has been found.

The research gap is that; in current literature there are no existing study or system that integrates BIM + IoT and includes the interaction of the occupants to sustain thermal comfort through a receptive & responsive system. thermal comfort through a receptive and responsive system. Therefore, the research question arisen as following: "How to use the 'existing BIM data' and 'constantly produced real-time data' together; during the operational phase of the building, to upgrade the energy efficiency and enhance sustainability while addressing users' customized and optimized thermal comfort?"¹⁵

Research Project : 'Symbiotic Data Platform':

To develop such a project, "**thermal comfort**" has chosen as the principal concern to be investigated. For demonstrate Symbiotic Data Platform's applicability in practice, an online survey has been conducted. The survey results¹⁶ shows that the audience choose thermal comfort as the most important physical

condition in residential and public buildings. Also in the same survey, the audience responded question upon practices of energy efficiency. The feasibility and context validation predicates the quantitative values of the participants, and the profound literature review upon the related topics. Furthermore, by the author, thermal data is considered the simplest way to measure demonstrate the values, apply technologies and results.

The added value of the project is to be a customized + personalized thermal comfort control tool, meanwhile achieving optimal energy usage. The platform proposes an option for efficient operation phase for the buildings and a sustainable alternative for the built environment. Although the application is focused on thermal comfort in building scale, the same technology can be applied for other comfort dimensions and energy efficiency. Moreover, with a wider perspective, it can be applied at the city scale as already discussed in detail in the further research chapter of the thesis.

To clarify the metaphor of the title of the project, the definition of 'Symbiotic' is explained as following: *Symbiosis* (from Greek; συμβίωσις "living together", from σύν "together" and βίωσις "living") (Perseus, 1999), which translated means together and life, or life working together. It is the interaction between two

¹⁵ For detailed information upon Research Questions and Hypothesis, see related chapters.

¹⁶ For details, please see the Validation section under Symbiotic Data Platform Chapter. Also survey data is documented in the appendix of this thesis.



different biological organisms, by any type of a close and long-term proximity. It can be mutualistic, commensalistic, or parasitic. The mutualistic symbiosis is; also can be defined as 'mutualism'; which defines the relationships with benefits for both parties from the association.

Taking reference from this definition, the metaphorical denotation is done for the title of the project. The word 'symbiotic' stands for the mutual benefits for both parties, in the digital system of the platform. This relationship could be refined as various options, such as;

1. The 'transmitter' and the 'receiver' devices interactive relationship and the constant data exchange.
2. The collaboration of BIM data and the real-time data (IoT) as a context.
3. Human to Computer, Computer to Computer and Computer to Human interaction.
4. Thermal Comfort and Energy Efficiency bound.

Even if all the mutual relationships and the interactive data exchange is explained in further chapters more profoundly, hereby a brief introduction of the project is given in the following section 'Research Projects' Scope'.

Research Projects' Scope:

Principal objective of the project is to prove the possibility of using BIM data by the occupants to optimize comfort, as this issue has not been considered in BIM literature in detail yet. Research has been conducted through 'prototyping'¹⁷. The development of the 7 prototypes demonstrated the possibility to implement this technological innovation in practice. As a result of the research, the hypothesis is proven positively, in which, the implementation of real-time data into BIM, in occupation phase, to be used by the occupants of the specified building. BIM can be used as the existing database to be imported to other mediums; and moreover, it can be processed for enhancing the energy efficiency while maximizing the comfort of the occupant in daily basis.

Research Projects' Assumptions:

For applying the design-thinking to case studies and thereafter to the prototypes testing, the following assumptions are defined.

1. The reference of the definition 'optimization', 'optimized', 'optimizing' stands for the following:

¹⁷ See Prototypes Chapter.

Optimization is; “the action of making the best or most effective use of a situation or resource” (Lexico Dictionary, 2019) and on the other hand, mathematical optimization is often called as mathematical programming, which stands for; “is the selection of a best element (with regard to some criterion) from some set of available alternatives. Optimization problems of sorts arise in all quantitative disciplines from computer science and engineering to operations research and economics, and the development of solution methods has been of interest in mathematics for centuries” (Du, Pardalos, & Wu, 2008). This definitions are documented as assumptions, for eliminating any inconvenience while reading the research. In Symbiotic Data Platform, the word ‘optimization’ is used to refer the action made for ‘betterment’, ‘adjustment’ and ‘customization’ of thermal comfort by users preferences and desired conditions, while taking into account the material qualities (from BIM) and concerning the energy efficiency. No ‘mathematical optimization’ is done by the algorithm, since the project is not targeting a set of available alternatives, yet, it does a calculation within the available static (BIM) and real-time data (sensors). The optimization refers to the adjustments made by physical computing, to maximize the user thermal comfort on occupation of the building, meanwhile using the correct amount of energy, and to preclude excess consummation.

2. The Hardware:

The hardware of the platform is designed in two pieces, to operate as ‘receptive’ and ‘responsive’. The transmitter device is a ‘wearable object’, that collects and transmits the real-time data. On the other side, the receiver device is designed as a static piece that is connected with wires to the database and the operating system, where the existing material data and the real-time data is processed together for physical modifications.

The assumption upon the heating and cooling devices set up as being particular, electrical home appliances, that operate instantly.

3. Tests:

Tests done hypothetically by symbolic heater and cooler as two servo motors. The code and physical modification functioning are working correctly and operating without errors on the final version of the prototypes (Prototype VII).

Tests done with the condition of ‘future calibration’.

In current practice, the platform is operated by open-source softwares, such as Arduino IDE, OpenWeather and Blynk App¹⁸. In further research, Symbiotic Data Platform is planned to be developed as a particular mobile app.

¹⁸ For further explanation on the softwares, see Symbiotic Data Platform and Prototype VII Chapters.

LITERATURE REVIEW 2

2. LITERATURE REVIEW

The literature review consists five sections. First of all, as they are the main elements of the project, 'Building Information Modeling' and 'Internet Of Things' themes are defined and explained as the technical literature review. Afterwards, the BIM and IoT integration possibilities are revised within the previous research projects and existing literature. On this section, the period between 2002 to 2020 (January) is scanned regarding to the previous projects and publications that are related with the specific topic; by 3 main categories, which are *Tracking/ Monitoring, Sensor Integration / Real-Time Data Visualization, Energy Simulation* and *Facilities Management, Analysis*.

Corresponding to the technical literature review, the theoretical literature review is followed by reviewing some concepts such as *'The Fourth Industrial Revolution'*. And lastly, the two interconnected concepts and the main standpoints of the project that are Sensibility and Sensitivity is defined and explained by

aligning them with the *'new architectural design understanding'*, that was mentioned in the State of Art Chapter previously.

2.1. BUILDING INFORMATION MODELING

BIM; is the acronym for Building Information Modeling, and it is an intelligent model-based process that provides insight to help you plan, design, construct, and manage buildings and infrastructure. Recently, it's used by architects, designers, engineers, construction employees, stakeholders and companies. And more importantly, the workflow is proceeded at the same time, without having the same knowledge and technical language, that's to say, it is interoperable. The added value of this collective approach is to be 'interoperable', 'simple' and 'sustainable'.

Even though BIM existed as a concept since 1970's (Eastman, Tiecholz, Sacks, & Liston, 2008), in the whitepaper by Autodesk, on 2002, Building Information Modeling was introduced to market as following:

"Building information modeling is Autodesk's strategy for the application of information technology to the building industry. Building information modeling solutions have three characteristics:



1. They create and operate on digital databases for collaboration.
2. They manage change throughout those databases so that a change to any part of the database is coordinated in all other parts.
3. They capture and preserve information for reuse by additional industry-specific applications.” (Autodesk, 2002).

Moreover, The US National BIM Standard defines BIM in three dimensions;

1. **Building Information Model (a product):**
is a structured dataset describing a building;
2. **Building Information Modeling (a process):**
is the act of creating a Building Information Model;
3. **Building Information Management (a system):**
comprises the business work and communication structure that increase quality and efficiency” (United States National BIM Standard Project Comitee, 2016).

As it is a recent technology, it has great potentials. BIM's motto is **'Model as you Build'**. While the designer or engineer is modeling, the building is not only visualized, but also constructed by exact details virtually. It is a tool not only for modeling, but also for analyzing, estimating, calculating and operating. It includes all the phases of a construction. “Building

Information Modeling (BIM) is one of the most promising recent developments in the architecture, engineering, and construction (AEC) industry. With BIM technology, an accurate virtual model of a building is digitally constructed. This model, known as a Building Information Model, can be used for planning, design, construction, and operation of the facility. It helps architects, engineers, and constructors visualize what is to be built in a simulated environment to identify any potential design, construction, or operational issues” (Azhar, 2011).

BIM has been defined as a game-changing Information Communication Technology (ICT) (Isikdag, 2007). “Coordination among different organizations is enhanced and errors and clashes are detected early in design phase that result in speeding up the construction process, reducing costs, minimizing the likelihood of legal disputes and shortening the construction period” (Talebi, 2014). The technology of BIM, is a documentation method, and an application methodology, which is the current optimum process for AEC industry. As a result, in the same whitepaper by Autodesk summarize the benefits and the added value of BIM solutions as following; “Building information modeling solutions create and operate on digital databases for collaboration, manage change throughout those databases so that a change to any part of the database is coordinated in all other parts, and capture and preserve

information for reuse by additional industry-specific applications”
(Autodesk, 2002).

For the practitioners, applying BIM solutions on their design schedule, results as higher quality work, greater speed and productivity, and lower costs for building industry professionals in the design, construction, and operation of buildings. On the other hand, pointing out the factor that the buildings, which have a correct BIM representation, is very low in current practice at many countries. Although some of the new buildings have the models, and in the future the BIM system will be a regulation in construction industry in every country, still the application of the proposed system for existing structures could be a very costly and long process. Yet, for new and cooperate design offices, applying BIM methodology on their design and modeling methodology is a win-win situation due to the massive amount of well organized data structures, as well as the upcoming BIM regularization process.

Even though, sometimes it might be mistaken and defined as a Computer-Aided Design (CAD) tool, Building Information Modeling could be considered as a CAD Model, yet it is much more than that. *“BIM is more than just 3D CAD, it is a process and a way of working supported by digital technologies to improve building/infrastructure efficiency throughout the life*

cycle of an asset” (Hardi & Pittard, 2015). The added value of BIM is the **‘Information’** embedded into the 3D model. BIM is not a visualization software, yet, it has effective and attractive 3D models, as well as documentation as a result of the process. Even though it gives satisfactory results on modeling and visualization, BIM is a documentation tool and a communication method. So, The “I” of BIM is the most important factor of it.

Multiple computer-aided design (CAD) tools work as BIM authoring tools to generate BIM files in different formats containing various types of building information. The main softwares of BIM are, Revit from Autodesk (Autodesk, 2019), ArchiCAD from Graphisoft (Graphisoft, 2019), and a plug-in tool for Rhino which is called RhinoBIM - VisualArq, from McNeel (McNeel, 2019), (Asuni, 2019). The common point of all those softwares, is that, they are operated by the intelligent elements. The modeling is done by *constructing a digital twin of the real project*. The main point of the BIM is the accuracy and the correspondence to the reality. While modeling, data embedded elements are imported and a 3D model is visualized. All element and data is editable, they can be modified according to the needs and correspondence to the real material that will be used in the building. Moreover, as the model is developed by intelligent elements, those softwares can run energy analysis and many other calculations for energy efficiency, thermal and



daylight estimations. *“A computable Revit design model is a great fit for the analyses needed for sustainable design — even during schematic design. As soon as the layout of a building’s walls, windows, roofs, floors, and interior partitions (elements that define a building’s thermal zones) are established, a Revit model is ready for whole building analyses.”* (Moakher & Pimplikar, 2012). Also it is a useful tool for managing the operational phases of the project. *“In order to effectively cut down the project lifecycle costs and construction waste, there is a need to control, monitor and verify the design from early stages and set rigorous plans for maintaining the building during its future operation”* (Oskouie, Gerber, Becerik Gerber, & Alves, 2012).

Interoperability and Industry Foundation Classes:

Industry Foundation Class (IFC) is a standardized, digital description of the built asset industry. It is an open, international standard (ISO 16739-1:2018) and promotes vendor-neutral, or agnostic, and usable capabilities across a wide range of hardware devices, software platforms, and interfaces for many different use cases (buildingSMART, 2019).

One of the key aspects of BIM, which is interoperability requires a fluid workflow between professions, offices, parties and also between various softwares. Even though BIM is a methodology to follow, the designer uses a specific software. Working with files of different formats and need to exchange information quickly and accurately, regarding to the burden of BIM. To face this type of problems on exchanging the information between softwares, the transfer of information (geometric and non-geometric) is carried out with the help of a common extension, called IFC (Industry Foundation Classes) (e-Zigurat, 2019). The Industry Foundation Classes is fundamental for BIM practice, and mostly when it comes to openBIM, which aims to allow the compatibility of flows. *“Hundreds of software applications for use by many different stakeholders in the process can send and receive IFC data. Since 1997, IFC has been tried and tested through many iterations, gaining worldwide trust as a means to deliver projects from all over the world”* (buildingSMART, 2018). There is an alternative, also proposed by buildingSMART, when the flow does not support the IFC, is the BIM Collaboration Format (BCF), which is much more limited and does not cover all the uses of the IFC, but can result very useful in the compatibility phase and for revisions (e-Zigurat, 2019).

SYMBIOTIC DATA PLATFORM

resilibility & resiliency

The Global BIM Adoption Process:



Figure 1: Global BIM Adoption Map, Visualization by Author, Reference from (Paul, 2018)



Reference taken from: (Paul, 2018), explains the current global BIM adoption roadmap. *“BIM adoption results in many different types of opportunities and challenges compared to traditional ways of working in the industry and many studies have been made to reveal them”* (Talebi, 2014). Many countries are already using BIM as the principle methodology in AEC industry and in legal processes in construction. *“However, BIM standardization efforts and policy initiatives that ultimately influence the adoption varies significantly from country to country”* (Edirisinghe & London, 2015).

For instance, USA is one of the first countries that had the shift and regularized BIM as the mandatory methodology. This shift was done back in 2008 totally, including changing and adapting the education system to the new requirements. There are many other European countries that follow the footsteps of the change, yet most of the countries could not realized the total shift yet. On 2018, the research conducted by Paul, showed some of the current situations and forthcomings country by country.

As it is oblivious, even though it was declared, most of the countries could not complete their forthcomings and could not completely made the shift through BIM. Such as in Spain; BIM use is supposed to be mandatory in public construction projects from December 2018 and in infrastructure projects by July 2019.

On the other hand; *“Countries such as Singapore, the UK, the USA and Finland are leading in BIM policy regulations and adoption, while policy initiatives and adoption in countries such as Australia are still slow. Policy initiatives can range from exclusive mandatory requirements to more market driven laissez-faire approaches”* (Edirisinghe & London, 2015).

The economic benefits of BIM adoption is incontrovertible through productivity improvement, better visualizing and collaboration, and ease of communication. The adoption process might be rough and laboring, yet the outcomes are more sustainable and productive. BIM adoption creates new work positions and business fields. BIM is a new methodology to be used to achieve better results. *“In a digital environment where any information can be ascribed on the model, the simulated digital version of the building becomes testable in many aspects. Buildings are expected to perform against different tasks. By this way, performance becomes a prior criteria of design above many other aspects that a design is expected to satisfy”* (Tan & Paker Kahvecioglu, 2018). By using this technology and applying it as a methodology creates more efficient workflow, as well as the final artifact in the built environment is more efficient and sustainable relatively.

The BIM regularization and adaptation that is being realized worldwide during the last decade. Referring to this global BIM adaptation and regularization process, this technology is becoming a mandatory tool to be used in AEC industry. As a result of this regularization and adaptation, in the upcoming years, building models that are based on data will be the only legal documentation for the constructions.

BIM Further Potentials:

Regarding to the recent research on BIM; Becerik-Gerber and Kensek defined BIM as a modeling technology and associated set of processes to produce and communicate, while referring to (Eastman, Tiecholz, Sacks, & Liston, 2008) and added the properties of; analyze building models, and interfaces, methods, and applications that are pertinent to BIM technology, including but not limited to the following: sustainable practices, management and organizational issues around technology, and assisting technologies and methods (Becerik-Gerber & Kensek, 2010). In the same paper, they quoted; *“Both architecture and engineering professions are embracing new modes of interdisciplinary information sharing and focusing on two emerging and fast growing concepts: building information modeling (BIM) and integrated project delivery (IPD)”* (Becerik-Gerber & Kensek, 2010). The reason that BIM is proposing an

efficient and productive design and project delivery methodology regarding to the *‘interdisciplinary information sharing’*, also could be defined as *‘interoperability’*, which has a great potential to be developed further.

BIM is a communication method between architects, engineers, and other parties that are involved in a construction project. *“Through the digital design revolution the architect as ‘Building Information Modeling’ enabled professional has an ever improving set of interoperability opportunities through the protocols developed in partnership with all the principal stakeholders: designers, engineers, cost estimators, constructors, facility managers, and regulatory authorities”* (Burry, Karakiewicz, Holzer, White, Aschwanden, & Kvan, 2015). So, BIM also could be defined as a process and a workflow rather than a design and modeling tool. And what is more; this is a significant change of design understanding, on the way of organizational facts, as well as, taking the process as a holistic procedure for enhanced outcomes. Designing by BIM includes pre-design phases, design, construction, analysis, evaluation, operation & maintenance, and even the demolishing of the project. Adopting this process to the design mentality aligns with the contemporary necessities of 21st century and also to the *‘new architectural design understanding’*.



Applying the modes of notation and the logic of design creates a better communication environment between all the actors of the project. Regarding to the interoperability side of BIM, the data and the model is accessible by all the disciplines. With a single model, and all the information embedded to that model creates a collaborative working platform, while creating better data-transition. Using BIM as methodology creates a transparent data flow in relation to the cost calculations, facilities management, workflow follow-up and reliability of the project. Those benefits relatively increase the positive economic outcomes of the project. Likewise, BIM improves collaboration between information suppliers and users in the facility business. It also provide more accurate fundamental information to support decision making, while also providing a standard way of storing information so that it survives the test of time. At last but not the least, BIM builds a data collection and sustainment of information into the business processes (United States National BIM Standard Project Comitee, 2016). By using BIM methodology, the profit is tripled regarding to efficiency, scheduling, active workflow and accuracy of estimations.

Taking into account today's 'new' architecture vision¹⁹, architects, designers and engineers are having more responsibility and an advanced conscious on global future, environmental awareness, and sustainability concerns. BIM has a strong position on this ideological shift, on the way of presenting improved solutions for building industry, within the above mentioned concerns. *"BIM in green building, or "green BIM", is a process that can help architecture, engineering and construction firms to increase sustainability in the construction industry. It can allow architects and engineers to integrate and analyze environmental issues in their design over the life cycle of the building"* (Maltese, Tagliabue, Cecconi, Pasini, Manfren, & Ciribini, 2017).

Thanks to BIM softwares, the architectural models and construction details are documented digitally in databases. Initial idea of the 'Symbiotic Data Platform' comes from the excitement of that big data that is also open to access upon request. This practical shift in documentation technique allows the architects, engineers and designers to access the information of the built environment with real values, and allows the usage of those information for further changes in operation phase of the building. At last but not the least, BIM is an advantageous

¹⁹ See Introduction: State of Art Chapter.

process for AEC industry by creating an efficient and sustainable solution for the work flow by being interoperable between various disciplines, as well as being easy to use and also making the documentation internationally valid. Proposing the ultimate documentation software and gives the possibility to foresight the optimum material/ workforce/ economic savings. BIM has a great potential when its' data is combined to interactive tools, for more accurate documentation. For enhancing the potential use of BIM, 'real-time data' should be embedded to its technology.

As an additional point, there are other research areas upon BIM. In academy, urbanism and architecture faculties are specifically interested in the potentials of BIM, and many researchers are working on extending the limits of this method. For example, as long as there are BIM Models, the connection between them is a potential research line, such as a network of BIM in one complete structure of BIMs. For instance, City Information Model (CIM)²⁰ and Precinct Information Model (PIM)^{21 22} are current

researches done by the leading research groups upon BIM all over the world.^{23 24}

precincts. (Plume, RP2011: PIM - An Open Digital Information Standard throughout the Urban Development Lifecycle, 2017)

²² Jim Plume is Senior Research Fellow in Smart Cities program in UNSW Sydney University. Jim's areas of special interest and expertise: information modelling as applied in the professional design disciplines associated with the built environment. An on-going focus of that work is in the development of the Urban IT project, which is concerned with urban scale information models and the use of object database technologies to support design collaboration across all the built environment disciplines.

²³ The possible developments of BIM is discussed on the last chapter 'Further Research'.

²⁴ The potential developments of BIM in urban field might require a connection with IoT, that also is discussed in the last chapter, 'Further Research'.

²⁰ A City Information Model is a 3D digital city model, a framework of integrating BIM technology into GIS is demonstrated. A new concept of CIM is proposed with the goal of bringing great benefits to the urban construction and city management. (Xu, Ding, Luo, & Ma, 2014)

²¹ A Precinct Information Model (PIM) is a comprehensive 3D digital database model of a precinct that contains all the Information needed to support planning, design, development, construction, management, operation, use and retro-fitting of urban



2.2. INTERNET OF THINGS

Internet of Things is the inter-networking of physical devices, vehicles (also referred to as 'connected devices' and 'smart devices'), buildings, and other items—embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data.

In 2013 the Global Standards Initiative on Internet of Things defined the IoT as *"the infrastructure of the information society."* The IoT allows objects to be sensed or controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit in addition to reduced human intervention. When IoT is augmented with sensors and actuators, the technology becomes an instance of the more general class of cyber-physical systems, which also encompasses technologies such as smart grids, virtual power plants, smart homes, intelligent transportation and smart cities. Each thing is uniquely identifiable through its embedded computing system but is able to interoperate within the existing Internet infrastructure. An upgraded term for this global network is "Internet of Everything: loE". It clearly explains how IoT will evolve in our day, due to the

huge augmentation of the connectivity. The title of "Internet of Everything" as the name implies, connecting everything to the great network of 'everything'. Everything is not only including devices, computers, furniture, houses or roads. By the 'new' design understanding, this definition is involving also humans to the cycle. We are living in the day which all of us that live in the big cities, are well connected to the global network.

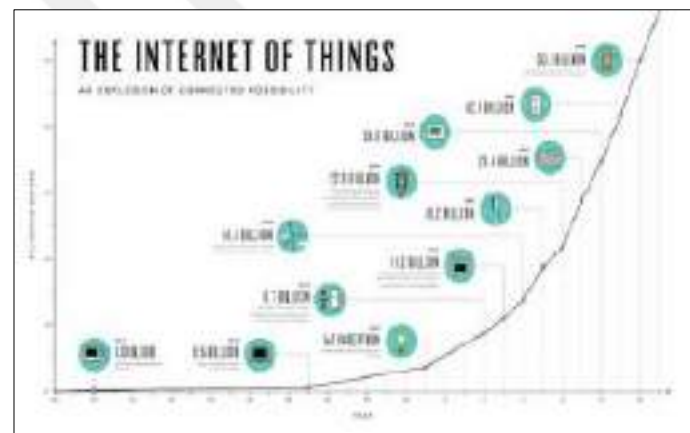


Figure 2: The Internet of Things Roadmap (Worrel, 2016)

The transformation of the daily life necessities lead the industry to develop new technologies. Digital era created the global network, which made the communication easier between people and also for things and devices to communicate with each other.

Through the Internet of Things; the embed intelligence is applied to every field of the industry including AEC. Currently on 2019, more than 25 billion devices are connected to network and producing real-time data (See Figure 2).

The Internet of Things is an emerging global Internet-based information architecture facilitating the exchange of goods and services. The IoT has the purpose of providing an IT-infrastructure facilitating the exchange of “things” in a secure and reliable manner, for example; its function is to overcome the gap between objects in the physical world and their representation in information systems. The IoT will serve to increase transparency and enhance the efficiency of global supply chain networks (Weber & Weber, 2010) and “The IoT is a very complex platform for the connection of things based on objects being tagged for their identification, but also sensors, actuating elements and other technologies.”, “From a technical point of view, the architecture of the IoT is based on data communication tools, primarily RFID-tagged items²⁵” (Weber & Weber, 2010). RFID technology is used to identify, track and locate entities. This technique has been used since the Second World War, and currently evolved to be used in civil applications. IoT is a network that connects the devices and other articles that

is being used, to each other. Basically, the system can collect data, analyze data, or even visualize the given data by complementary programs. By the help of sensors and RFID technique, the collected data is not only a value, but also a fact that might be used for further cases. Another example for IoT is the webpages, which are a great technology for human-to-machine interaction, but many use cases for the IoT are machine to machine. (Want, Schilit, & Jenson , 2015).

“Just as the Internet of things is connecting billions of devices worldwide, digitally integrated implants are creating a new interface with our physical anatomy. In addition to providing a machine-to-human interface, these implants may also enable machine-to-machine connection and analytics. Humans are becoming directly enmeshed with the network” (Ratti & Claudel, 2016). The network of the devices and other agents not only communicate with each other, also they can give some responses by the sensor technologies and motors (Asuni, 2019).

Adding up to the classical theories; mentioning a public utility is an organization that maintains the infrastructure for a public service (often also providing a service using that infrastructure) is quite interesting to understand the existence of connected devices as a new necessity. Public utilities are forms of public control and regulation ranging from local community-based

²⁵ Radio-Frequency Identification



groups to statewide government monopolies. Behind this definition, there is the simple utility problem of the built environment that is called the three utilities problem.

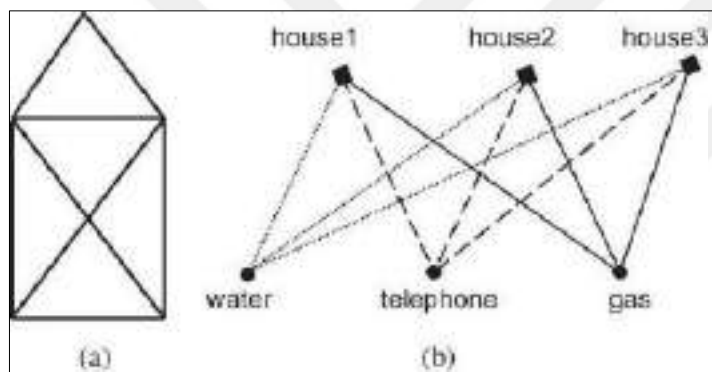


Figure 3: The Three Utilities Graphs also known as Thomsen Graph (Hilas & Politis, 2014)

The three utilities, was first mentioned at 1917 by Henry E. Dudeney. The classical mathematical puzzle is about the three cottages problem or sometimes water, gas and electricity can be stated as follows: “Suppose there are three cottages on a plane (or sphere) and each needs to be connected to the gas, water, and electricity companies. Without using a third dimension or sending any of the connections through another company or cottage, is there a way to make all nine connections without any of the lines crossing each other?”. The puzzle requires the impossible solution of connecting the lines from each house to each utility, without the lines ever crossing.

The reason why the solution of the puzzle is impossible, depends to the mathematical graph theory rules. There are at least two ways to use graph theory to prove that the utilities problem is impossible. As graph theory could be expanded to infinite numbers, the three utilities puzzle also could. Furthermore, adapting the theory of three utilities apart from the puzzle and thinking of 21st century infrastructures, the question gets broaden. This puzzle is as complicated as possible, and moreover, adding the 4th utility, which is Internet, complicates it even more. Apart from the gas, water and electrics, the emergent requisite of the new millennium is the connection and the communication services. The fourth concept rapidly ascended, and became one of the indispensable factors of built environment. Even though the utility itself is a cloud, the infrastructure is as great as the other three factors. The development of connected elements infrastructure is pretty challenging in the current urban forms.

Existing IoT Enabling Technologies

List reference by (Want, Schilit, & Jenson , 2015) and (Al-Fuqaha, Guizani, Mohammadi, Aledhari, & Ayyash, 2015).

Short-range wireless:

- * Bluetooth low energy (BLE) – Specification providing a low power variant to classic Bluetooth with a comparable communication range.
- * Light-Fidelity (Li-Fi) – Wireless communication technology similar to the Wi-Fi standard, but using visible light communication for increased bandwidth.
- * Near-field communication (NFC) – Communication protocols enabling two electronic devices to communicate within a 4 cm range.
- * QR codes and barcodes – Machine-readable optical tags that store information about the item to which they are attached.
- * Radio-frequency identification (RFID) – Technology using electromagnetic fields to read data stored in tags embedded in other items.
- * Thread – Network protocol based on the IEEE 802.15.4 standard, similar to ZigBee, providing IPv6 addressing.
- * Transport Layer Security (network protocol)|TLS – Network security protocol.
- * Wi-Fi – Widely used technology for local area networking based on the IEEE 802.11 standard, where devices may communicate through a shared access point.
- * Wi-Fi Direct – Variant of the Wi-Fi standard for peer-to-peer communication, eliminating the need for an access point.

* Z-Wave – Communication protocol providing short-range, low-latency data transfer at rates and power consumption lower than Wi-Fi. Used primarily for home automation.

* ZigBee – Communication protocols for personal area networking based on the IEEE 802.15.4 standard, providing low power consumption, low data rate, low cost, and high throughput.

Medium-range wireless:

* HaLow – Variant of the Wi-Fi standard providing extended range for low-power communication at a lower data rate.

* LTE-Advanced – High-speed communication specification for mobile networks. Provides enhancements to the LTE standard with extended coverage, higher throughput, and lower latency.

Long-range wireless:

* Low-power wide-area networking (LPWAN) – Wireless networks designed to allow long-range communication at a low data rate, reducing power and cost for transmission.

* Very small aperture terminal (VSAT) – Satellite communication technology using small dish antennas for narrowband and broadband data.



Wired:

- * Ethernet – General purpose networking standard using twisted pair and fiber optic links in conjunction with hubs or switches.
- * Multimedia over Coax Alliance (MoCA) – Specification enabling whole-home distribution of high definition video and content over existing coaxial cabling.
- * Power-line communication (PLC) – Communication technology using electrical wiring to carry power and data. Specifications such as HomePlug utilize PLC for networking IoT devices.

Physical Computing And Sensor Systems:

Sensors are important for tagging, tracking, locating, and monitoring things, and for enabling things to be aware of the environment around them. Sensors, as a key enabler of the Internet of Things (IoT), are produced by a variety of manufacturers, using many different protocols and formats (Fairgrieve, 2011).

Internet of Things can be applied to physical systems by the single board microcontroller system 'Arduino'. Arduino is an open-source electronics platform based on easy-to-use hardware and software which provides hardware and software for personal IoT projects. Arduino boards are able to read inputs

- light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language (based on wiring), and the Arduino Software (IDE), based on Processing (Arduino Foundation, 2017). Arduino platform is inexpensive, open-source and easy to use. Also as another facility, it is compatible with Windows, Microsoft and Linux Operating Systems. The devices and sensors are recently eligible through online purchase. Arduino allows the user create anything that could be imagined.

By their own self-description; *"Arduino is an open-source computer hardware and software company, project and user community that designs and manufactures microcontroller-based kits for building digital devices and interactive objects that can sense and control objects in the physical world"* (Arduino, 2015). Basically, it gives the possibility to the devices to sense, take, control, proceed and use the data. With the controlled data, the response is applied as a modification into the physical world. Teachers and students use it to build low cost scientific instruments, to prove chemistry and physics principles, or to get started with programming and robotics. Designers and architects build interactive prototypes, musicians and artists use it for

sensitivity & specificity

Makers, of course, use it to build many of the projects exhibited at the Maker Faire, for example. Arduino is a key tool to learn new things. Anyone - children, hobbyists, artists, programmers - can start tinkering just following the step by step instructions of a kit, or sharing ideas online with other members of the Arduino community (Arduino Foundation, 2017) . Arduino has various types of boards, shields and sensors to create specific projects. While doing the project. these are two stages. as connecting the



Figure 4: Arduino Board Types with Categories' (Arduino Foundation, 2017)



IoT in Built Environment:

“A collaborative data system approach to a building centric IoT is really the key to success for building owners and operators who want to be able to get meaningful data out of their building systems in a way that can be analyzed and is actionable” (Haines, 2016). Integrating sensor systems to built environment enables the building to become smarter and act as an interactive machine. The collected data could be used for further practices, in example, relating to building automation and control and in particular energy and sustainability management.

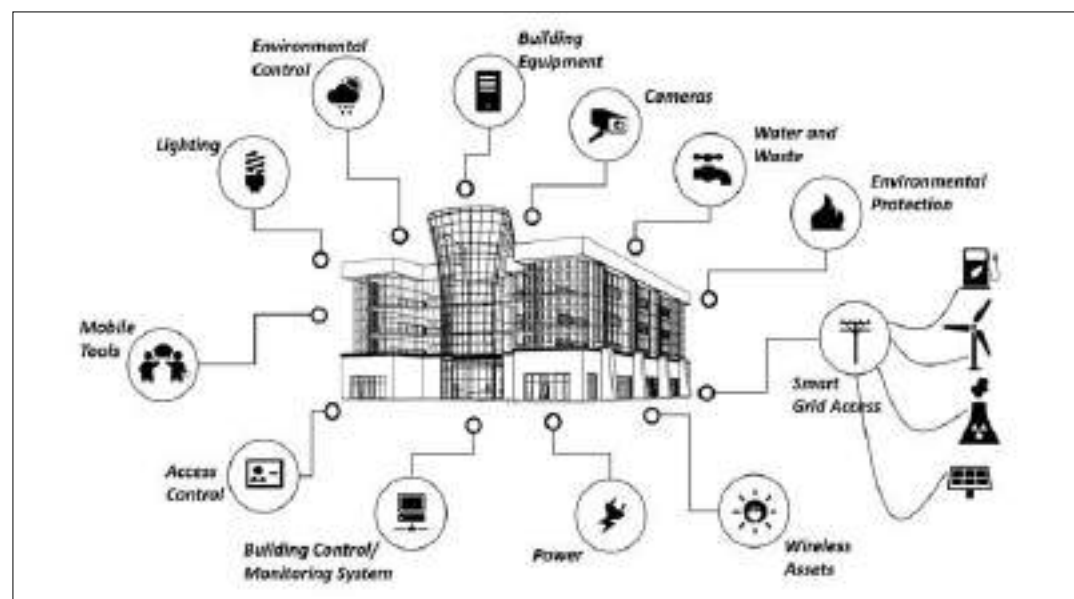


Figure 5: Buildings and IoT (Haines, 2016)

One of the relevant data collection method, is the information that is achieved real-time from the embedded sensors to the built environment. *“Sensing devices have become ubiquitous in certain building types. These devices both can monitor the building environment and track the movement of objects and people within the building. Through the effective collection of data a building informational model maybe maintained but a buildings operational model may also be created”* (Ozturk, Arayici, & Coates, 2012). There are various forms of remote sensors, that circulates the data wirelessly or wired. Those embedded networks of data flow, creates the database for the further use of the collected data, that might serve for energy efficiency, optimization or creation of responsive environments and interaction with the user. Embedded sensors and connected smart devices in the built environment creates a new layer in the space. By this new layer, the physical space has a new feature, and it is upgraded from being a static space to an interactive environment. Smart user of 21st century determines the necessity of intelligent environments and connectivity in every field. Architecture is one of them. To do so; Fox and Kemp wrote about this interactive environment as following: *“Through a computational platform, architectural spaces jointly engage into the context of everyday matters as an ideology of human-computer interaction. This generates architectural spaces, which embed computation into the physical world within a smart*

environment encompassing autonomous configurations and communication strategies. Correspondingly, the environment can be comprehended as an emergent space of re-configurable organization of systems, reacting continually within a direct engagement and interaction where users become participants within a behavioral framework based on unpretentious principles of contextual parameters and complex symbiotic relationships of communication through people-to-people, people-to- building; and building-to- building” (Fox & Kemp, 2009).

Responsive Environments:

Responsiveness is defined by Oxford Dictionary as following: *“The quality of reacting quickly and positively”* (Lexico Dictionary, 2019) and responsiveness theme is illustrated in the book (Bentley, Alcock, Murrain, McGlynn, & Smith, 1985), by the accompanying terms such as, permeability, legibility, variety, robustness, visual appropriateness, richness and personalization.

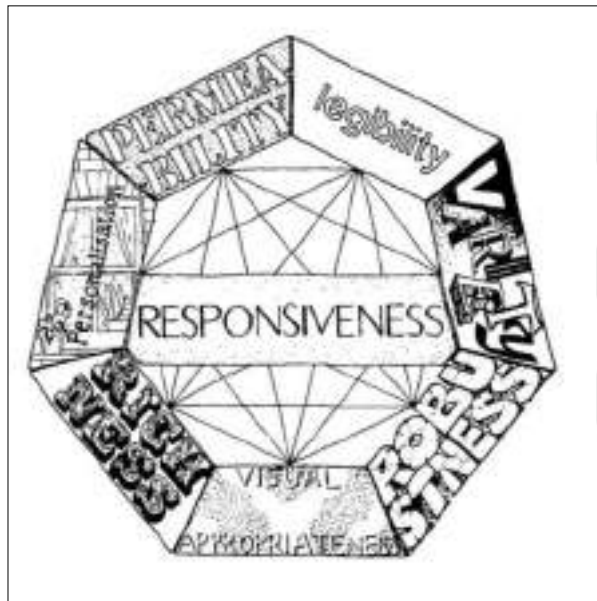


Figure 6: 'Responsiveness' by (Bentley, Alcock, Murrain, McGlynn, & Smith, 1985)

Those terms are explained as following:

1. *Permeability: designing the overall layout of routes and development blocks.*
2. *Variety: locating uses on the site.*
3. *Legibility: designing the massing of the buildings, and the enclosure of public space.*
4. *Robustness: designing the spatial and constructional arrangement of individual buildings and outdoor places.*
5. *Visual appropriateness: designing the external image.*
6. *Richness: developing the design for sensory choice.*

7. *Personalization: making the design encourage people to put their own mark on the places where they live and work* (Bentley, Alcock, Murrain, McGlynn, & Smith, 1985).

Taking the reference from Bentley et.al. definition on 'responsiveness', in current practice, the approach is converted to digital means. All the 7 pillars of responsiveness is being applied to the new architecture, by digital mediums, devices and softwares.

The term "**Responsive Architecture**" was introduced by Nicholas Negroponte²⁶, who first conceived of it during the late 1960s when spatial design problems were being explored by applying cybernetics to architecture. Negroponte proposes that responsive architecture is the natural product of the integration of computing power into built spaces and structures, and that better performing, more rational buildings are the result. Negroponte also extends this mixture to include the concepts of recognition, intention, contextual variation, and meaning into computing and its successful (ubiquitous) integration into architecture.

²⁶ Nicholas Negroponte is the founder and Chairman of MIT Media Lab, and also founded the One Laptop per Child Association.

The common definition of Responsive Architecture, as described by many authors, is a class of architecture or building that demonstrates an ability to alter its form, to continually reflect the environmental conditions that surround it. *“A responsive environment is also a space that invites certain emotions, actions and state of mind. Firstly, because it should somehow create an atmosphere within the environment that, on its own, contributes to the creation of a sort of user moods”* (Alves Lino, Salem, & Rauterberg, 2010).

Additionally, by the rapid change of technologies in the current era, also defined as digital era, the built environment is also being adapted to the new generation style of making things. *“A wave of new industrial processes is transforming building design and construction. The next generation of architecture will be able to sense, change and transform itself. The tools and materials discussed here make this kind of responsive architecture possible”* (Beesley, Hirose, & Ruxton, 2006).

To enable the responsive environments, the technology to be used is Physical Computing within IoT. *“Physical computing involves the creation of hardware devices that can sense and act in the real world. Physical computing techniques underpin a wide range of contemporary technology trends such as the Internet of Things, the quantified self and smart homes. There*

are many applications of physical computing, for example in creative arts, museums, ubiquitous and embedded computing, scientific sensing, robotics, engineering control systems and robotics” (University of London, 2019). Physical Computing creates a bridge between computer science and built environment by the artifacts produced.

Moreover, regarding to the new concepts in the field, ‘digitalism’²⁷ is a term that is coined also by Nicholas Negroponte, and he defined the ‘digital revolution’²⁸ as following:

“Computers are not moral; they cannot resolve complex issues like the rights to life and to death. But the digital revolution, nevertheless, does give much cause for optimism. Like a force of nature, the digital age cannot be denied or stopped. It has four very powerful qualities that will result in its ultimate triumph: decentralizing, globalizing, harmonizing, and empowering.” and *“Digital technology can be a natural force drawing people into greater world harmony... Being digital is different. We are not waiting on any invention. It is here. It is now. It is almost genetic*

²⁷ Digitalism (also known as digitality) is used to mean the condition of living in a digital culture, derived from Nicholas Negroponte's book Being Digital in analogy with modernity and post-modernity.

²⁸ The Digital Revolution is the change from mechanical and analogue electronic technology to digital electronics which began anywhere from the late 1950s to the late 1970s with the adoption and proliferation of digital computers and digital record keeping that continues to the present day.



in its nature, in that each generation will become more digital than the preceding one” (Negroponte, 1995).

The application of digitalism on architecture is liberating the possibilities of the built environment. *“Computers, the new digital media, liberate the duality of concepts of space in human civilization. The construction and simulation powers of digital media trigger all kinds of unlimited imagination. The new space of this kind may be called digital space or virtual space. This new space is between mental and physical spaces because it provides designers with not only unlimited imaginability of mental space but also live-inside perception of physical space. A new concept of space of mankind is thus generated” (Liu, 2003).* Referring to Negroponte’s point on 1995 upon digitalism, the theories evolved to be perceived as a new architectural understanding. The intelligence is related with the digitalism of the urban fabric, and making it ‘limitless upon imagination’, ‘efficient’, ‘sensible’ and ‘responsive’.

Furthermore, the term ‘digitalism’ and ‘digital revolution’; which switches the definition of architecture from being a space than being a sensible element of life, were also coined by Negroponte.

Upon the responsive architecture context, Grunkranz²⁹ stated;

“In fact, at this level of responsiveness, it is not just me who has a relation to the techno-environment but its technology also to me, caused by the design of it. This technology-human relation is a hermeneutic one. An interpretation of our world based on the possibilities of machine intelligence. If a user phrases the desire for warm space and low energy costs without static criteria, the responsive architecture has to interpret the user’s wants and needs within its technical abilities and compare it to the user’s behavior and appreciation of spatial qualities” (Grunkranz, 2009).

Responsive Architecture allows the built element to measure and sense the actual movements or other input of the user and the general atmosphere of the space and reacts according to the design. The mediums of these systems are generally sensors, control systems, actuators and the main computer, as well as Internet of Things. Via IoT systems, the term is currently developing and evolving. By the help of sensors, the applications and designs evolved to be interactive. Since therefore, Responsive Architecture creates Ambient Intelligence, meanwhile procuring an interactive environment and conceives ‘user experience’. ‘Ambient Intelligence’ is coined into literature

²⁹ He is a PhD Architect

at 2009, as; *“an emerging discipline that brings intelligence to our everyday environments and makes those environments sensitive to us.”* (Cook, Augusto, & Jakkula, 2009).

Additionally, ‘User Experience’ is a term that was coined back to 1990’s, and it has been developed since then. Hence, so far, a regular definition was hard to be concreted. ‘*There is little agreement on a unified notion or view on what exactly defines user experience.*’ commented by; (Law, Roto, Vermeeren, Kort, & Hassenz, 2008). According to Oxford dictionary, user experience is defined as; *“the overall experience of a person using a product such as a website or computer application, especially in terms of how easy or pleasing it is to use”* (Lexico Dictionary, 2019). This definition could be applied to architecture and built environment, regarding to the new understanding of architecture that requires interaction and responsiveness. Initially, user experience was a term just that was being used just for digital mediums, therefore, user experience mainly was interpreted as a result of user interface design, many researchers believe that positive user experience comes from the value and meaning of the product concept itself (Roto, Rantavuo, & Väänänen-Vainio-Mattila, 2009).

Together with the responsive architecture theme, Schnädelbach ³⁰ coined ‘Adaptive Architecture’ which is *“concerned with buildings that adapt to people, their surroundings and objects”* (Schnädelbach, 2016). Also, defined as, *“A framework which changes its structure, behavior or resources according to request. It is a multi-disciplinary approach concerned with buildings that are totally driven by internal data and also building those are designed to adapt to their environments, their inhabitants and objects. Because of its multi-disciplinary nature, developments across Architecture, Computer Science, the Social Sciences, Urban Planning and the Arts can appear disjointed”* (Kawalkar, 2015).

The **Figure 7** is a graphic that by Schnädelbach, which explains the Adaptive Architecture Feedback Loop: Personal data acquired from inhabitants actuates architectural elements, which changes the environment, in turn feeding back on inhabitants.

³⁰ He is a PhD Architect

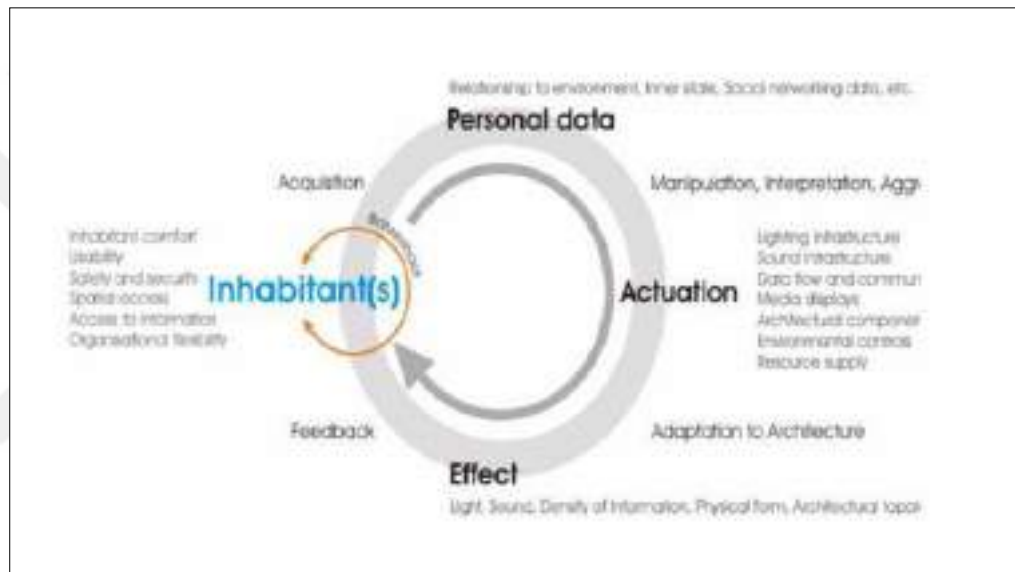


Figure 7: Adaptive Architecture (Schnädelbach, 2016)

Buildings have gained the feature of being responsive and interactive by the advanced uses of sensor systems and enabling machines and devices. The application of Responsive Architecture and Adaptive Architecture are managed by Intelligent Kinetic Systems. *"Intelligent kinetic systems arise from the isomorphic convergence of three key elements: structural engineering, sensor technology and adaptable architecture. At the intersection of these areas exists an unexplored architecture tuned to address today's dynamic, flexible and constantly changing needs"* (Fox & Yeh, 1999). I

Intelligent kinetic systems arise from the isomorphic convergence of three key elements: structural engineering, sensor technology and adaptable architecture. At the intersection of these areas exists an unexplored architecture tuned to address today's dynamic, flexible and constantly changing needs. In developing a general concept for the application smart environments to kinetic systems in architecture, we introduce a new approach to architectural design, where objects are conventionally static, use is often singular, and responsive adaptability is typically unexplored (Fox & Yeh, 1999). Consequently, by using the emergent terms and concepts such as intelligent kinetic systems, new terminology arises. 'Interactive Architecture' is one of them. While

Responsive Architecture could be defined as the built environment that acts according to environmental factors or movement, Interactive Architecture also covers up the same field and adds another detail, that is user interaction and user experience, with more inclusion and engagement. The concept refers to the design of the space featuring sensors, processors and effectors, embedded as a core part of its nature and functioning. Interactive Architecture includes building automation but goes beyond it by encompassing further forms of interaction and responses which might cover up physical modification, or, may include artistic purposes such as e-motive and designed artifacts; thus entering the field of interactive art.

2.3. BIM AND IOT INTEGRATION POSSIBILITIES

Previously, in literature, researchers and companies developed several solutions for integrating Real Time Data on a BIM Model. The concept of BIM has existed since the 1970s according to various references. However the concept have arisen at 70's, the term 'building model', as well as the term BIM is used today, was first used in papers in the mid-1980s: in a 1985 paper by Simon Ruffle.

However, back to 70's, the specific definition of 'Building Information Modeling' was not clear enough and there was no software to realize the term. The definitions and the theories were introduces to literature as concepts. Even the acronym "BIM" did not exist in the beginning and not as frequently used until 2000s. In the following 30 years, engineers, programmers, architects and designers developed solutions. Right after at 2002, Autodesk released a white paper entitled "Building Information Modeling" (Autodesk, 2002) which defines and explains the 'Building Information Modeling' system. In that period, simultaneously, other software companies were also developing similar solutions. Facilitating exchange and interoperability of information in digital format had previously been offered under differing terminology by Graphisoft as "Virtual Building", Bentley Systems as "Integrated Project Models", and by Autodesk or Vectorworks as "Building Information Modeling".

Apart from the current developments and the research conducted upon BIM, the field of Internet of Things are also rapidly evolving. By the Third and the Fourth Industrial Revolutions³¹, sensor networks and digital technologies became eligible and accessible. Additionally, the importance of data have

³¹ See Sensibility section.



been accepted, and also taken as a strong socio-economic and also political power source. Consequently, research and development on data mining, sensor networks, real-time data collection, physical computing, embedded sensor systems and many more became trending topics in academic and private research fields.

Nowadays, interdisciplinary studies are leading the research and development field. Almost every research areas are interconnected to each other. To achieve significant results, contemporary research is being conducted by applying multi-disciplinary methods, and using knowledge from many related fields. Correspondingly, the emergent research upon BIM and IoT is one of the current hot-topics in architecture, construction, design, mechanical engineering and computer science areas. To be more specific for this research project, the question is; if the interaction between the digital model and the real time data is possible? Regarding to this question, Manuel Castells raised his theory on 2002 commented upon the blended technologies with physical space: *"They consist of territories which are distant, which are linked to different geographic hinterlands. But they are electronically connected; their function and their meaning come from their connections. Thus, they do not exist separately. In that sense, they are not purely electronic networks. The electronic networks link up the specific places, and it is this*

hybrid space that is the space of flows. The space of places organizes experience and activity around the confines of locality. ... Rather, they are transformed in the interface between electronic communication and physical interaction. They are transformed by the combination in practice of cities, networks, and places but without fully integrating them" (Castells, 2002).

As it is explained extremely clear by Castells, the concepts of the digital world, physical reality and the user is totally connected to each other. Moreover, further integrations and advancing the technological possibilities are yet to come. Besides the physical world, the cloud is like the secondary layer that surrounds all the elements that is active in our lives. There are various connections that are present and being used today. What this research aims to contribute is to find the possible potentials and connection between of the existing technologies. With respect to Castells theory and introduction, physical space and digital world is interconnected. Taking into account that BIM is a visual representation of the physical reality, with embedded data, could be an accurate representation that is proving Castells theoretical research.

Additionally, from theory to practice; a paper by Becerik-Gerber and Kensek previously on 2010 by a survey, documented the interest on BIM, per profession and per department. According

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to the survey, per profession, the maximum interest was from architects, followed by consultants, contractors, technology providers, engineers and developers. On the other hand, per department, out of 79 student participants, the highest interest was from construction management department, followed by civil engineering, building science, architecture, mechanical engineering, business administration, policy planning and development structural engineering electrical engineering aerospace engineering systems engineering departments (Becerik-Gerber & Kensek, 2010). This study shows the interdisciplinary and interoperability of BIM, and its potential to be developed further within many other disciplines collaboratively (See Figure 8).

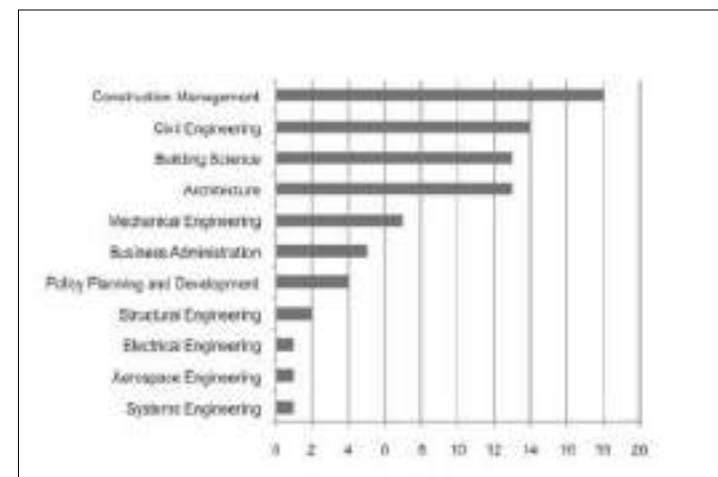
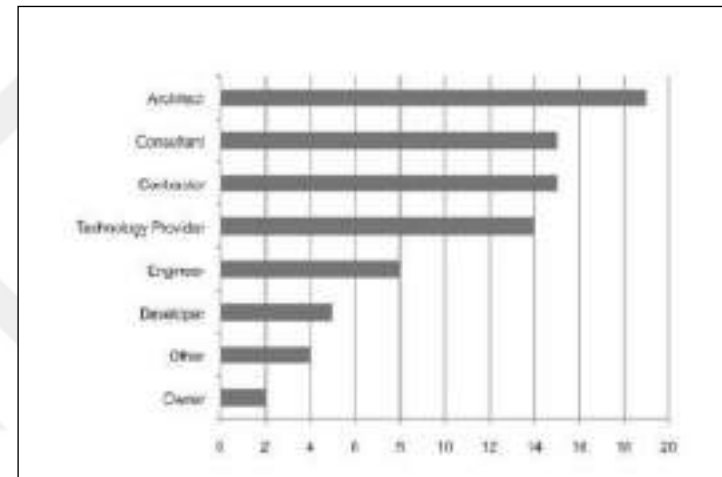


Figure 8:: Survey Results (Becerik-Gerber & Kensek, 2010)



Literature Review on BIM and IoT Integration:

Eventually, arising from the potentials of the two existing technologies (BIM and IoT), many researchers around the world dedicated time to this very specific connection possibility between them. Moreover, the integration of those concepts does not have any limit, therefore interdisciplinary research projects are specifically interested on investigating on this field. As a matter of fact, in current practice and R&D³² of academic practice, the real-time data is being investigated, meanwhile many fields are specifically interested in developing their upcoming research by the help of big data and information technologies.

Specifically, the research upon integration of the two technologies is surveyed to understand the interest and validate the importance of the topic. Apart from the general literature review done by scanning scholar engines, online and actual libraries, the literature review upon the specific topic '**BIM and IoT (Real-Time Information) Integrated Research**' breakdown is done via 'Google Scholar' online search engine due to the wide range of covered sources. Not only journal articles but also white-papers, conference proceedings, online documentations

and ongoing project reports are also examined within this review. The aim of the literature review on this specific topic is to identify the gap in the literature for this research project. Searching by the '**Building Information Modeling**' and '**Internet of Things**', '**Real-Time**' keywords, all the related papers are documented. This graph only shows the research that has a integration of BIM and IoT in the specific project or, theoretical review.

After the profound review, those articles are classified by 3 categories by each of their content;

1. *Tracking/ Monitoring,*
2. *Sensor Integration / Real-Time Data Visualization, Energy Simulation,*
3. *Facilities Management, Analysis.*

The first graph (Figure 9) shows the overview of the documented and reviewed articles, and subsequently, the detailed list that has the articles distribution per year with full title and authors names, can be found.

The graph of the literature review is summarizing the related research upon the integration of BIM and real-time data; during

³² Research & Development

the time period between 2002-2019 to show the increase and distribution of research on the specific topic, and 2020 only January month, to show the intensity of interest on the field.

Starting from 2005, as it was eligible from Google Scholar; the interest started by facilities management and construction management departments, followed by sensor integration, visualization-simulation and energy analysis themed research upon BIM. Thereafter 2013, tracking-monitoring, way-finding and emergency management studies have been studied in the scope of integrating BIM with real-time.

From 2014 and onwards, interdisciplinary research gain an increase and researchers from various departments were working on the same project with the same objective, by collaborating and sharing their knowledge.

BIM AND REAL-TIME INFORMATION INTEGRATED RESEARCH LITERATURE REVIEW



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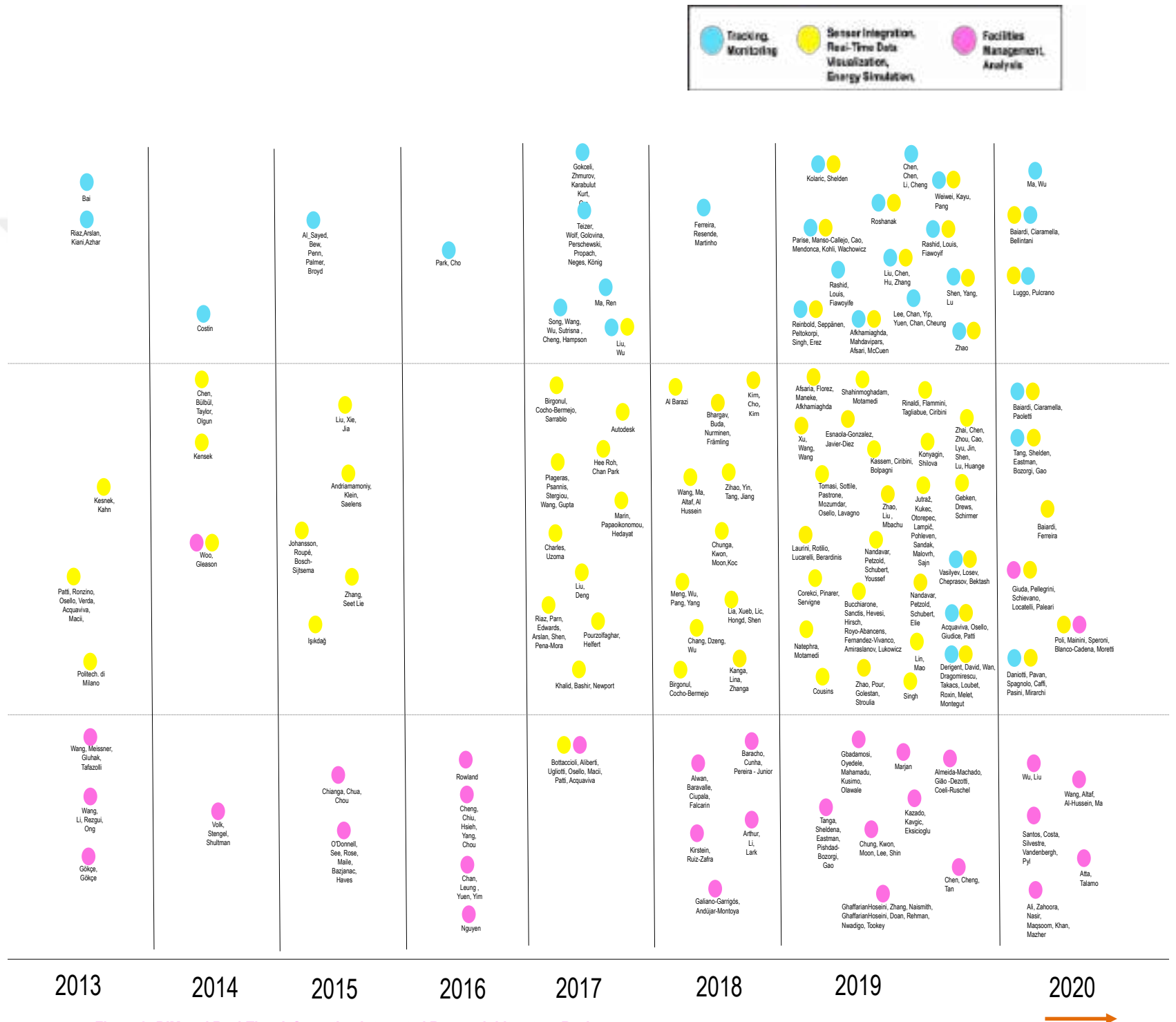


Figure 9: BIM and Real-Time Information Integrated Research Literature Review



2002-2020 BIM & Real-Time Integrated Research Literature Review Chart Interpretation:

Even though BIM was a concept that was coined much earlier than that, at 2002 by the white paper published by Autodesk, the term became the hot topic for the AEC Industry because of proposing revolutionary changes for design and management of construction.

The research upon the BIM and IoT integration have gained popularity by 2013 around the world, with the direct connection of the developments in related technologies, as well as the emergence of the Fourth Industrial Revolution. Then by 2017 the research have made the peak, when the importance of blending those existing technologies', and their interrelation possibility seen as the next big thing. The increase of interest and intensity of the research, especially after 2017 is significant. By the Fourth Industrial Revolution, the accessibility of the devices and eligibility of knowledge for the application of sensor & real-time technologies is the biggest catalyzer of the peak.

Regarding to the peak, another important factor was the *Arduino Platforms'* creation on 2005 and its' public release on 2007. Arduino Platform is one of the most easy to use and accessible tools for the IoT research, personal and academic projects and it has been used for developing the research

projects even without specific knowledge on computer science, computer engineering nor programming. The Arduino became a tool also for non-experts, as well as academic researchers since it is user friendly and efficient. The lighter-weight and economically affordable, less expensive versions were distributed in the open-source community by 2010. It became easier to access and shop the kits by online shopping and international shipping. It was estimated in mid-2011 that over 300,000 official Arduino's had been commercially produced, and in 2013 that 700,000 official boards were in users' hands (Adafruit, 2011). Thanks to Arduino and similar open-source tools, remarkable research with very high budgets are currently being developed by leading software companies, as well as technical universities all around the world.

The distribution of research in the specific topic is mostly done by Civil Engineering, Architecture and Computer Science departments of academy. Building Information Modeling is investigated by the engineers for facilitating efficiency for management of the projects, so that, real-time information is being intended to be introduced to the softwares by related faculties' researchers. For projects' follow up in real time, and linking the real information to the digital twin; from site to the computer is being developed by the research on the integration of the two technologies.

Regarding to the timeline of the literature research, the academy started to publish upon the theme by 2005. After 2005, by the Third Industrial Revolution and BIM regularization and adoption processes worldwide; by engineering and architecture faculties, BIM have started to gain attention and real-time information became prominent. Following the increasing interest on the field, on 2007, Isikdag published some papers upon the integration possibilities of BIM and real-time data. (Isikdag, 2007). On his articles, he discussed the promising open gap on literature that should be fulfilled with the upcoming research. After 2010, it can be observed that the research interest increased, most probably in relation with the Arduino platforms' release.

Later on, an elaborate research and case-study conducted by Attar, has significant results of proving the integration possibilities of BIM and real-time, by sensor integration, energy simulation and performance analysis within an occupant centric approach, which makes it a key paper for this research (Attar, Hailemariam, Breslav, Khan, & Kurtenbach, 2011).

Meanwhile, the real-time information is intended to be embedded into the digital twin of the building for tracking, monitoring and visualization of existing data in real-time conditions, energy efficiency, comfort optimization and sustainability have been studied mostly. On the other hand,

sensor integration and using BIM data for developing real-time projects are also on demand. Moreover, many research have been done upon sustainability, energy efficiency, post-occupancy evaluation, emergency maintenance, facility management is being conducted in academy, through interdisciplinary projects.

The case of architectural design and architectural engineering departments, the specific research is done in a more experimental and sophisticated manner. Such as, another key paper for this dissertation conducted by Karen Kensek³³. On that paper, they introduced real-time data with Revit software, for controlling architectural features, in relation with environmental factors. Similar researches were done previously, by using other softwares such as Rhino-Grasshopper, yet, this research is different and the first one by integration of Building Information Modeling with IoT. Also the case studies that are based on Rhino + Grasshopper – Firefly base, and development on Revit + Dynamo are documented on another article. The research is concluded as; *“the process was reversed to demonstrate that not only could data could be sent from sensors to change the 3d*

³³ Karen M. Kensek is on the faculty of the USC School of Architecture at the University of Southern California. She is a leading figure in architectural computing, focusing on analytical building information modeling and building science. She is a past president of the Association of Computer Aided Design in Architecture (ACADIA). She has been teaching for over 20 years in the transforming field of computer applications.



model, but changes to parameters of a 3d model could effect a physical model through the use of actuators. It is intended that these virtual/physical prototypes could be used as the basis for testing intelligent façade systems before constructing full size mock-ups” (Kensek & Kahn, 2013).

As another key paper, the research by Wang et.al, states that the BIM technologies ntegrated with sensor networks open up a new horizon with promising capabilities to monitor building operation & maintenance, and therefore preventing energy waste during the life-cycle of the building. The result of the project is summarized as: *“By knowing the building status at any given time and location, which is largely unseen to most users, it is possible to change occupant behavior, improve building safety, avoid unnecessary energy consumption and facilitate better working environments” (Wang, Gluhak, Meissner, & Tafazolli, 2013).*

In the paper by Johansson et.al., the research highlights the complexity and challenges involved in visualizing large and detailed Building Information Models (BIM) in real-time. *“The contribution of the paper is twofold: (a) an in-depth analysis of four commonly used BIM viewers in terms of real-time rendering performance and (b) the development and validation of a prototype BIM viewer specifically designed to allow real-time*

visualization of large and complex building models” (Johansson, Roupé, & Bosch-Sijtsema, 2015).

The research and the related conference paper by Rowland on 2016, explores how gamification can provide the platform for integrating BIM together with the emergent IoT. The goal of the research is to foster the creation of a testable and persistent virtual building via gaming technology that combines both BIM and IoT (Rowland, 2016).

Lately, the research projects gain move advanced level by addressing socio-economic and environmental concerns also, such as smart energy management. As such, a project by Bottaccioli et.al. investigated an opportunity that emerged of mixing two information categories to either create better models and to detect unwanted or inefficient energy behaviors. The project analyze and visualize energy behaviors in buildings, by integrating heterogeneous data such as BIM, IoT, GIS and meteorological services. By this integration; real-time visualization of energy consumption is achieved and building performance evaluation and simulation is generated. *“The presented experimental results showed that our solution simulates with a good accuracy the heating performance of the case-study building” (Bottaccioli, et al., 2017).*

Another key paper and a real case study conducted by Kim et.al, investigates the way to collect real time building data using IoT and BIM. In the operation and maintenance phase in building life cycle, the building status data such as temperature, humidity, air quality, energy consumption, etc. must be corrected to manage building effectively. The conclusion of the real-case study is with current technology and software applications, the proposed framework of real time building data correction using BIM and IoT is limited, and further research is needed. (Kim, Cho, & Kim, 2018).

Lastly, Bhargav et.al, from Aalto ASIA (Adaptive System of Intelligent Agents) team at Computer Science department at Aalto University, conducted a real case study project by the European Union's Horizon 2020 research foundation, that successfully integrated building information with real-time visualization, by sensor installation, via a web-based system. The research is resulted as, *"A large proportion of IoT devices are deployed in the built environment providing an opportunity to develop interfaces that allow user interaction through open, intuitive interfaces."* and *"It is possible to engage wide range of stakeholders with IoT devices by integrating them with building*

information data" (Bhargav, Buda, Nurminen, & Främling, 2018).

Consequently, by the key papers and all other research upon the specific topic, it is obvious that the eligibility of the technology and hardware, and accessibility of knowledge to process the data, leads the interest of researchers to investigate upon the further possibilities of the existing technologies and their mergence. Both technologies are hot topics on AEC industry on current day, while the interdisciplinary studies are on demand for augmenting the worthwhile outcomes. It would be difficult to classify the topic by a single discipline, since it requires knowledge from many fields of interest. Especially, after 2017 - 2018, the rapid increase of the research that combines BIM and IoT is obvious which is nearly doubled up. The detailed list of the previous graph upon BIM and Real-Time integrated research can be found onward. Also the of coupling between various disciplines in same research with common interests can be observed from the following list.



2002	Autodesk	Building Information Modeling
2005	O'Sullivan Keane	Specification of an IFC Based Intelligent Graphical User Interface to Support Building Energy Simulation
2008	Rueppel, Stuebbe	BIM-Based Indoor-Emergency-Navigation-System for Complex Buildings
2009	Moon Kim, Choi	A BIM Based Data Model for an Integrated Building Energy Information Management in the Design and Operational Stages
2010	Thusen,Kirkegaard,Jensen	Evaluation of BIM and Ecotect for Conceptual Architectural Design Analysis
	Hajian, Becerik - Gerber	Scan to BIM: Factors Affecting Operational and Computational Errors and Productivity Loss
2011	Attar, Hailemariam, Breslav, Khan, Kurtenbach	Sensor-enabled Cubicles for Occupant-centric Capture of Building Performance Data
	Alahmad, Nader, Brumbaugh, Cho, Ci	The "BIM's 4D+" Dimension: Real Time Energy Monitoring
2012	Öztrürk, Arayıcı, Coates	Post Occupancy Evaluation (POE) in Residential Buildings Utilizing BIM and Sensing Devices: Salford Energy House Example
2013	Bai	RFID Sensor-Driven Structural Condition Monitoring in Integrated Building Information Modeling Environment
	Riaz,Arslan, Kiani,Azhar	CoS-MoS: A BIM and wireless sensor based integrated solution for worker safety in confined spaces
	Wang, Meissner, Gluhak, Tafazoli	Integration of BIM and live sensing information to monitor building energy performance

2011	Attar, Hailemariam, Breslav, Khan, Kurtenbach	Sensor-enabled Cubicles for Occupant-centric Capture of Building Performance Data
	Alahmad, Nader, Brumbaugh, Cho, Ci	The "BIM's 4D+" Dimension: Real Time Energy Monitoring
2012	Öztrürk, Arayıcı, Coates	Post Occupancy Evaluation (POE) in Residential Buildings Utilizing BIM and Sensing Devices: Salford Energy House Example
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	Riaz,Arslan, Kiani,Azhar	CoS-MoS: A BIM and wireless sensor based integrated solution for worker safety in confined spaces
	Wang, Meissner, Gluhak, Tafazoli	Integration of BIM and live sensing information to monitor building energy performance
2015	Al_Sayed, Bew, Penn, Palmer , Broyd	Modelling dependency networks to inform data structures in BIM and smart cities
	Zhang, Seet Lie	Building Information Modelling for Smart Built Environments BIM and IoT: A Synopsis from GIS Perspective
	Işıkdağ	Sensor Service Architectures for BIM Environments Enhanced Building Information Models The Future of Building Information Modelling: BIM 2.0
	Liu, Xie, Jia	WebVis BIM: Real Time Web3D Visualization of Big BIM Data
	Andriamamoniy, Klein, Saelens	Sensor Handling In Building Information Models. Development Of A Method And Application On A Case Study
	Johansson, Roupé, Bosch-Sijtsema	Real-Time Visualization of Building Information Models (BIM)
	O'Donnell, See, Rose, Maile, Bazjanac, Haves	SIMMODEL: A Domain Data Model for Whole Building Energy Simulation
	Chianga, Chua, Chou	BIM-enabled power consumption data management platform for rendering and analysis of energy usage patterns

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2.4. SENSIBILITY

Sensibility according to Oxford Dictionary, is; *“The quality of being able to appreciate and respond to complex emotional or aesthetic influences”* (Lexico Dictionary, 2019). Moreover, another definition of the same word has a more accurate and generic description made by Merriam-Webster dictionary;

“1. ability to receive sensations : Sensitiveness; tactile sensibility.

2. peculiar susceptibility to a pleasurable or painful impression (as from praise or a slight) —often used in plural.

3. awareness of and responsiveness toward something (such as emotion in another)” (Merriam-Webster Dictionary, 2019).

In this dissertation, the first complementary concept is ‘Sensibility’, that stands for the ‘Sensible’ information and its exchange. Referring to the all existing and real-time data that could be collected, is considered sensible information in this research. Data collection and documentation were being done manually by the employees of the companies whom were registering data input. To analyze, compare and monitor the data by the developments and eligibility of computers, the digital technologies have been accelerated and facilitated better management tools for data control. Within the digital eras’ technologic development explosion and the eligibility of Internet connection, the user, who is the original data generator, became

who inputs the data to the network. This can be explained as an example of use of social media, smart phones and Wi-Fi individual use, and so on. And, as the final step reached, recently, the machines itself are capturing data by sensors and recipients, and proceeding this input to the network, open source systems and to the greater setup.

Initially, raising the discussion upon the concept of the *information flows*; on 1996 by Graham, Cornford and Martin, stated that: “As the latest wave of ‘information superhighway’ and Internet hype ebbs away, we should perhaps redirect our efforts towards closing the current gap between the ‘information rich’ and the ‘information poor’ rather than speculating about future divides.” (Graham, Cornford, & Marvin, 1996).

Over and above, Castells introduces the term “*space of flows*”, which is; ‘a new spatial form characteristic of social practices that dominate and shape the society. *“The space of flows is the material organization of time-sharing social practices, that work through flows. By flows, I understand purposeful, repetitive, programmable sequences of exchange and interaction between physically disjointed positions held by social actors”* (Castells, 2010) ‘Space of flows’ point out that the physical space is a whole with the cloud of communication.

Along with information flows theories, the existing data have gained attention by 1990's. The term has been in use since the 1990s, with some giving credit to John Mashey for popularizing the term 'Big Data'. Big Data is a computation term that is defined as; *"Extremely large data sets that may be analyzed computationally to reveal patterns, trends, and associations, especially relating to human behavior and interactions"* (Lexico Dictionary, 2019).

Thereby, by 2000's, regarding to this massive growth and development on information technologies, new concepts and definitions have been emerged. Consequently, all those devices connected to Internet and to each other by IoT, caused an enormous scale of data flow. Within the developments of digital era and with the arising of the networked society, the cloud of information, that was previously named as 'Big Data', which became prominent in everyday life. The Wired Society (Martin, 1978) or Network Society (Van Dijk, 2012) (Van Dijk, 1999) (Castells, 2010) of today is living in the physical space with an additional digital dimension. These correlations are producing a new element every second and all add up in the Big Data.

The Third Industrial Revolution:

Throughout the history, generations have developed several industrial revolutions, within their necessities. Building upon the first and the second industrial revolutions, Jeremy Rifkin have coined the term "Third Industrial Revolution" on 2011, by blending the digital revolution with energy efficiency and the economic changes based on the new developments.

Regarding to the connection of industry and communication technologies; Jeremy Rifkin³⁴, who is the writer of the legendary book, 'Third Industrial Revolution' was taking the reference of the emergence of the new communication systems and software as the beginning as a revolution of the new century. In the book, it's mentioned; *"A great communications revolution occurred in the 1990's. Second generation electrical forms of communication—personal computers, the internet, the World Wide Web, and wireless communication technologies—*

³⁴ Jeremy Rifkin is an American economic and social theorist, writer, public speaker, political advisor, and activist. Rifkin is the author of many books about the impact of scientific and technological changes on the economy, the workforce, society, and the environment. Moreover; is the author of The New York Times best selling book, The Third Industrial Revolution. He is an adviser to the European Union and to heads of state around the world. He is a senior lecturer at the Wharton School's Executive Education Program at the University of Pennsylvania and the president of the Foundation on Economic Trends in Washington, D.C.



connected the central nervous system of more than a billion people on Earth at the speed of light. And, although the new software and communication revolutions have begun to increase productivity in every industry, their true potential is yet to be fully realized” (Rifkin, 2011). He described the transformation as ‘fundamental economic change occurs when new communication technologies converge with new energy regimes, mainly, renewable electricity’ and named it as the ‘Third Industrial Revolution’.

Rifkin, specified the 5 pillars of the new revolution as following:

“The five pillars of the Third Industrial Revolution are (1) shifting to renewable energy; (2) transforming the building stock of every continent into micro-power plants to collect renewable energies on-site; (3) deploying hydrogen and other storage technologies in every building and throughout the infrastructure to store intermittent energies; (4) using Internet technology to transform the power grid of every continent into an energy internet that acts just like the Internet (when millions of buildings are generating a small amount of renewable energy locally, on-site, they can sell surplus green electricity back to the grid and share it with their continental neighbors); and (5) transitioning the transport fleet to electric plug-in and fuel cell vehicles that

can buy and sell green electricity on a smart, continental, interactive power grid” (Rifkin, 2011).

The Fourth Industrial Revolution:

Building upon the Third Industrial Revolution, recently, at 2018, we are experiencing the “Fourth Industrial Revolution” which the term is coined by Klaus Schwab³⁵. However; the first and the second industrial revolutions lasted between 50 -100 years and within a century span; the time between the third industrial revolution and the fourth industrial revolution was extremely short when it’s compared to the previous ones. The main reason behind the shortening of the time between the last two industrial revolutions is mainly the basis of building upon the great development of the previous industrial revolutions as well as the digital transformation and the globalization. *“Digital technologies that have computer hardware, software and networks at their core are not new, but in a break with the third industrial revolution, they are becoming more sophisticated and integrated and are, as a result, transforming societies and the global*

³⁵ Klaus Martin Schwab is a German engineer and economist best known as the founder and executive chairman of the World Economic Forum. He was professor of business policy at the University of Geneva from 1972 to 2002. From 1993-1995, Schwab was a member of the UN High-Level Advisory Board on Sustainable Development. From 1996-1998, he was Vice-Chairman of the UN Committee for Development Planning.

economy” (Schwab, 2017). Moreover, in the book, the revolution is defined as following:

“The fourth industrial revolution, however, is not only about smart and connected machines and systems. Its scope is much wider. Occurring simultaneously are waves of further breakthroughs in areas ranging from gene sequencing to nanotechnology, from renewables to quantum computing. It is the fusion of these technologies and their interaction across the physical, digital and biological domains that make the fourth industrial revolution fundamentally different from previous revolutions” (Schwab, 2017).

By the recent developments in technology and engineering, which determine the Fourth Industrial Revolution, catalyzed the access to information and data eligibility. As a result of the introduction of new and advanced sensors, elicits more complex possibilities of data flows.

The Industrial age, is an age of atoms, gave us the concept of mass production, with the economies that come from manufacturing with uniform and repetitious methods in any one given space and time. The information age, is the age of computers, showed us the same economies of scale, but with less regard for space and time. Moreover, ‘digital living’ that is defined by Negroponte, will include less and less dependence

upon being in specific place at specific time, and the transmission of place itself will start to become possible. Even though the society of the information age does not require a specific place to exist, it is inevitable that they transform the environment that they belong to a more digitalized, automatized, virtual, efficient and productive.

Sensibility in Today's World:

Following up the new industrial revolution the digital developments and systems & networks, the connection technologies and theories had a great enhancement since, Internet, social media and smart devices sprawled all the moments of our lives. In tandem with the personal usage of these devices, since 1999, companies and scientists were working on a greater network to step up to the new era.

British entrepreneur Kevin Ashton first coined the term ‘Internet of Things: IoT’ in 1999 while working at the Auto-ID Labs (Wood, 2015). He first used it to describe how internet-connected devices would change our lives forever, and moreover, how the world is stepping up to a new phenomena. From Cisco Internet Business Solutions Group (IBSG), Dave Evans writes about the forthcoming about IoT in 2011 and CISCO made public the



statement, *“There will be 25 billion devices connected to the Internet by 2015 and 50 billion by 2020”* (Evans, 2011).

“The concept of embedded intelligence in buildings is not new; rather what makes it currently possible are cheap digital sensors, computer power to handle big streams of data, and the development of software specifically developed for on-going operations and maintenance of buildings” (Kensek, Integration of Environmental Sensors with BIM: case studies using Arduino, Dynamo, and the Revit API., 2014). Since the technologies of sensing and data collection became eligible and accessible thanks to the third and fourth industrial revolutions, the design research that corresponds to digital data collection also augmented. Additionally, in relation with the emergent ‘Fourth Industrial Revolution’; by the eligibility of accurate data collection, the research quality also shows significant increase.

The connectivity and globalization of new generation, requires a better organization in management. The massive amount of data, (Big Data), became one of the most valuable terms globally. Data evolved to be power rather than being just information. The last decade of the world, society mainly depends to the connection, the network and the digitalization for their everyday necessities. The more items we own, the more computerized our lives, such that, the era govern us to ease our

life by digitalism in many disciplines such as art, architecture and urban means. 2000’s new generation babies are born to the world that everyone is connected to each other, one way or another. Especially in the urban space, having a mobile phone is more or less not a choice nor luxury anymore; it is a regulation to adapt and survive in digital era.

As Mitchell wrote,

“The artificial nervous system developed the capacity to perceive and quickly respond to conditions and events in the physical world, while digital processes had increasingly immediate and significant consequences in the physical world. Old metaphors of a distinct ‘cyberspace’ and transcendent ‘virtual worlds’” (Mitchell, 2007).

Apart from the importance of the connectivity, the main matter is the ‘sensing’ case. The items are connected by the Internet network to each other, furthermore, these connected items are also able to take the data by themselves and share it with the cloud. What is fascinating that, the Internet of Things is sensible, responsive and convenient. The new understanding of architecture and urbanism is guiding the user to expect more reaction from the space. The cognition of new era is highly susceptible, and the architecture and urban formations are responsive via information and real-time data. As taking data as

an inseparable layer of physical world, Castells³⁶ mentioned, “...space is constantly being remodeled and reconstructed by the transformation of the communication, transportation and telecommunications systems” (Castells, 2002).

With the emergent association of those networks with the new understanding of architectural design, requires re-shaping the physical spaces within the new needs of the modern society. Physical space is not an interior, yet it involves all the built environment. The theories upon information flows and network society is context aliased also in urban scales. Information layer is an invisible existence, metaphorically, like a veil, surrounding and being augmented in due course. Such as, along with the previous mention by Castells, when Kittler was writing upon technology and network society, he mentioned: “*What strikes the eye of the passerby as a growth or entropy is technology, that is, information ... Regardless of whether these networks transmit information (telephone, radio, television) or energy (water supply, electricity, highway), they all represent forms of information. (If only because every modern energy flow requires a parallel control network.)*” (Kittler, 1996).

³⁶ Manuel Castells Oliván is a Spanish sociologist especially associated with research on the information society, communication, urban forms and globalization. The 2000–2014 research survey of the Social Sciences Citation Index ranks him as the world's fifth most-cited social science scholar, and the foremost-cited communication scholar.

As Batty³⁷ put further, “*Cities ... are about ‘connecting people’. The various processes that bring people together to produce and exchange goods and ideas that take place in cities define a multitude of networks that enable populations to deliver materials and information to support such endeavors. Physical and social networks tend to mutually reinforce one another as they develop*” (Batty, 2011).

Today, due to the digitalization³⁸ and the evolution of the world, “*society, of course, only exists at the interface of individuals and identities mediated by institutions. This interface and this mediation are at the source of the network-state*” (Castells, 2002). Regarding to this; 3 main networks can be stated as;

1. Digital Network,
2. Social Network,
3. Physical Reality.

³⁷ Michael Batty is a British urban planner, geographer and spatial data scientist, and a Bartlett Professor of Planning in The Bartlett at University College London . He has been Director and Chairman of the Centre for Advanced Spatial Analysis, set up when he was appointed to UCL in 1995. His research and the work of CASA is focused on computer models of city systems.

³⁸ Digitalization is the integration of digital technologies into everyday life by the digitization of everything that can be assisted and developed by computers and computerized systems.



However these two networks are generating an infinite chain between each other. And moreover, adding up the physical reality on top of it, the whole cycle is defined and ruled by the main source, which is the 'user'. So that, the main and most important element of all these theories is eventually 'us' who is the human, the user. To see and understand this fact is the added value of the recent époque. These three terms are encapsulated the contemporary life and by some authorities it is highly criticized, but on the other hand, it is true that this was a choice that the society took and this decision shaped the reality of our era. According to my point of view, the importance is to take the reality to our side and make profit out of it. This can be possible by understanding the system and how this great cycle goes round and round. The networks are producing data, and this data is collected under the big title Big Data.

"With a trillion sensors embedded in the environment—all connected by computing systems, software, and services—it will be possible to hear the heartbeat of the Earth, impacting human interaction with the globe as profoundly as the Internet has revolutionized communication." Said Peter Hartwell, the senior researcher of HP Labs (Wood, 2015). As many items are connected, as more data is in the cloud. Our sphere is getting round and round by more connectivity.. Even not only the items and people are getting connected, but also the spaces and

events are. *"In the space of flows, separate locations are linked up electronically in an interactive network that connects people and activities in different geographical contexts"* (Castells, 2002). Consequently, this is creating the Big Data.

The built environment is incorporating more day by day with the digitalism to achieve a more connected society and a better network. Mitchell's concept of *"E-topia"*; is a new urban form in which we constantly interact, either deliberately or automatically, with online information systems, which increasingly will be in the wireless mode (Mitchell, 1995). E-topia is introduced to literature in 1995, when the digital era started to arise. It was one of the best forthcoming on the evolution of social structure of the millennium. 20 years afterwards, Mitchell's concepts have evolved and recently became the key aspect of future foresight that how smart cities will evolve. Over and above, 'E-topia' is obviously a milestone on my research upon blending BIM with IoT for 'Symbiotic Data Platform'.

Another point of view is introduced due to the relation between society and digital network by Castells as; *"The interaction between the revolution in information technology, the process of globalization, and the emergence of networking as the predominant social form of organization constitutes a new social structure: the network society"* (Castells, 1996); (Castells, 2002);

(Castells, 2010). The network society is the new form of community in the contemporary world. Society cannot be taken individually, apart from the surrounding factors that make the society act as itself. Digitalism in architecture and the Internet Web is the greatest form that included to the communities new network.

Within all those emergent alterations of architecture and urbanism, new terms such as, 'communications revolution', 'information age', 'information superhighway', 'cyberspace' or 'virtual community' (Graham & Marvin, 1996) arisen for the future of cities. In the mega cities context, there is an immersive amount of data production, and an information flow between agents every second. Is it possible to define or calculate how big is the data being produced in one second? How the network is integrated and how many layers that do this city have? As a matter of fact; day-by-day, minute-by-minute this data is growing as well as the human population grows and the cities emerge. This phenomena is called the 'emergent cities or territories' of the future. It is a combined fact of human and digital networks of the mega cities. *"Cities need to be described by a variety of datasets due to the complexity and diversity of the urban environment. These datasets may come from various aspects such as population, crime, business, employment, and transport information etc. and use many different data types. And the*

volume of the data is huge" (Hamilton, Wang, Tanyer, Zhang , Arayıcı, & Song, 2005). We are surrounded by the data and information that we produce every second. The challenge is to extract the necessary data to progress beneficiary information for the specific issues. Big data is a great source that is 'sensible', and if it is controlled and interpreted with 'sensitivity' it will be more powerful within time, in the future.

A further subject of sensibility is the analysis and mining of the gathered data. 'Data Mining' discipline deals with the extraction of knowledge and the raw data in big data network. To simplify, by using data mining, it is possible to make some clustering, generalization and characterization of data. The term 'Data Mining' is introduced in literature in 1989 at a workshop, by Fayyad.³⁹

In his book; Piatetsky-Shapiro⁴⁰ defined 'knowledge discovery', also known as 'data mining' as following:

"We analyze knowledge discovery and define it as the nontrivial extraction of implicit, previously unknown, and

³⁹ Usama M. Fayyad is data scientist and co-founder of KDD conferences and ACM SIGKDD association for Knowledge Discovery and Data Mining. He is a speaker on Business Analytics, Data Mining, Data Science, and Big Data.

⁴⁰ Gregory Piatetsky-Shapiro is Senior Member of Technical Staff and Principal Investigator of the Knowledge Discovery Project at GTE Laboratories.



potentially useful information from data. Problems in dealing with large, noisy databases, the use of domain knowledge, the role of the user in the discovery process, discovery methods, and the form and uses of discovered knowledge” (Piatetsky-Shapiro, 1991).

Moreover, there is a term; which is considering symbiotic relation of the big data producers. *“Symbiotic data mining is an evolutionary approach to how organizations analyze, interpret, and create new knowledge from large pools of data. Symbiotic data miners are trained business and technical professionals skilled in applying complex data-mining techniques and business intelligence tools to challenges in a dynamic business environment” (Athappilly & Rea, 2006).* ‘Gathering data’, ‘data collection’, ‘data capturing’ or in other words ‘sensibility’ without a ‘sensitive’ approach is not satisfactory.

The main source of the physical space such as a building or a city; is the human (the user). As mentioned above, the developments are made by humans to upgrade the life of humans. Data is produced by human activities, every second. Information flow - communication are crucial on contemporary world, regarding to the economic, social and cultural aspects. Data is the main product of the process of everyday life. It is inevitable to underestimate the importance and power of data for

the authorities; in the future. As being the end-user, people are the producer of data as well as the main target of all these concepts as payback. To conclude, for the desired model of the new architecture context and future cities ideology, all the sensible attempts have to be delicate, and approached sensitively.⁴¹

⁴¹ Sensitivity concept is explained in the following chapter; ‘Sensitivity.’

2.5. SENSITIVITY

Sensitivity according to Oxford Dictionary, is; “*The quality or condition of being sensitive*” (Lexico Dictionary, 2019). In this dissertation, the second complementary concept is ‘Sensitivity’, that stands for; the delicate attempt of receiving, processing, analyzing, using and benefiting the digital era’s fruits. The data is critical and powerful. Sensitivity is an approach to be taken regarding to handle the great amount of information that is produced by humans, and the interactive environments.

Sensitivity stands for the societies moral attitude towards this digitalized world. Similarly as it happened throughout the history, today also the contemporary issues are re-shaping the common cognition of the society. Citizens of the urban sprawl, experienced both the positive and negative parts of the digitalization. As a consequence, the global issues such as climate crisis, pollution, population overgrowth and risk upon natural and energy resources. Regarding to those concerns, the perception of the fact and the reaction through common cognition is re-shaped by ‘*Collective Consciousness*’.⁴²

Collective Consciousness is a term coined by sociologist Émile Durkheim on 1893. It defines the is the set of shared beliefs, ideas, and moral attitudes which operate as a unifying force within society (Durkheim, 1997). “*Collective consciousness (sometimes collective conscience or conscious) is a fundamental sociological concept that refers to the set of shared beliefs, ideas, attitudes, and knowledge that are common to a social group or society. The collective consciousness informs our sense of belonging and identity, and our behavior*” (Cole, 2019).

In contemporary day, *the architectural design understanding* get its’ share from *collective consciousness*, by having the shift of beliefs, from mass production, to sustainable, self-sufficient, efficient and optimized design-thinking. Today, in relation with the global issues, society has a more prudent standpoint for upcoming generations. Now, designing with collective values are required for distinctive projects. This moral attitude and responsible manner is defined as ‘*Sensitivity*’ in this dissertation.

With the tremendous increase in connectivity and digital technologies, data and information flow are growing with the direct proportion as population growth. As Manuel Castells have mentioned, “*We are about to cross a critical threshold: half of the population of this planet will soon be living in cities*” (Castells,

⁴² See Sensitivity Chapter.



2002). Apparently, cities are the most attractive matter of fact for the humans. Actually, cities act as population magnets. As a consequence, the emergence of the mega-cities, the growth of metropolitans, and the building of world capitals are attracted the millennium generation to enter the web of digital world. Everything in today's urban life is producing data, and we all live in a relationship of the data produced by the surrounding environment. As the world rounds everyday, user produces data and that data is defining the life. Imagine how is the cloud getting denser every second, even with the 'Messenger' chatting - messages that have been send. Here, in this point arises the importance of Big Data control, and the importance and the greatness of the cloud.

The society is the main aspect of a sensitive urban form. Besides the structure and infrastructure, the sensitivity shapes the livable values of a place. A smart city not necessarily has to be a sensible one with data collection and analysis features, but a sensitive city is absolutely a smart city in advance. Presence of sensitivity in an urban system by both social and digital manners could be an ultimate model for the futuristic vision. Urban fabric cannot be considered only as the buildings and infrastructures, the sociality is also a layer of its structure, as much important as the material complements. So that, the development has to be planned and analyzed according to the

societies' morals. Sensitivity of the city, and urban development can be considered as the urban ethics that will guide the future developments. It is the collective value and a change maker. To be more concrete, 'sensitivity' is the concept that complements the data importance of the digital era. If the data cannot be organized, examined and proceed sensitively; *-moreover ethically* - this data can be the most dangerous and also the most impractical factor of failure of the era. *"The world's most valuable resource is no longer oil, but data"* (The Economist, 2017) and it gives an enormous power to the authorities that dominates the big data.

Regarding to the connection of big data and urban infrastructures, sociologist Jennifer Gabrys has written about *the "new wave of smart-city projects that deploy sensor- based ubiquitous computing across urban infrastructures and mobile devices"* (Gabrys, 2014). On that research, she was pointing out the positive impacts of those systems on sustainability and efficiency, yet on the other hand, the adverse effects, such as potential dangers of open-data that might be monitored or managed. In the same research, to state the connection of data and society, she refers to philosopher Michel Foucault who previously wrote about the mechanisms of power and control exercised by the state, and how its manifestations in the structures of buildings and the city can be understood as a *'bio-*

political machine'. "Gabrys argues that smart-city design processes should focus on the performance of urban environments as demonstrated through the behavior of people within them rather than collecting data on citizens and populations. The sensitive subject of monitoring human activity should be approached with the necessary safeguards to ensure privacy and data protection of individuals and allow for open-endedness towards behavioral patterns and demographics" (Van Ameijde, 2019).

'Sensitive' Concepts Applied To Architecture & Construction Industry:

To be more specific regarding to the particular research topic, apart from the importance of data and the existence of it, one another important aspect of this research is to approach the content with morals and harmonious with ethics within the scope of the content in AEC Industry. 'Sensitivity' is not only a concept for morals, but also, about the critical understanding of global values and natural resources. Our planet is facing a climate change and a crucial energy risk in the current century. *"The global energy system is in danger of falling short of the hopes and expectations placed upon it"*, stated by the International Energy Agency (IEA) in The World Energy Outlook 2014 Report (International Energy Agency, 2014).

As it is introduced in the 'State of Art' Chapter of this dissertation; *'the new architectural design understanding'* is a holistic approach that covers up various aspects, from structure, function and aesthetic to being environmentally responsible and conscious. Thereby, the new generation designer is more conscious upon the social, economic and environmental global facts. The new generation designer have already raised the awareness for global concerns, and took action with a sensitive approach. The new generation designer is not only an expert on



form and function, but also it is the change-maker. With reference to the emergent concerns, 'Global Warming', 'Climate Change - Climate Crisis' and the environmental impacts of the built environment are some of the leading topics. Relatively, those concerns are 'sensitive' and must be taken care of with a well-developed knowledge as well as a delicate approach, on the way of sustainability and global future.

Hence, the majority of the world's energy sources are concentrated in few geographical locations, and the human population is growing as well as the waste and the energy demand grows. Small villages of 100 years ago became major cities and big cities became mega-cities that constantly attract more immigration, while growing new industries, and day-by-day constructing new man-made masterpieces in the built environment. As a consequence of this growth and this development, cities need more and more energy sources, in direct relation with the populations' consummation. On the other hand; every day, growing cities and forming mega-cities with massive populations is neither a disaster nor a negative issue, if handled sensitively and responsibly. As a positive consequence of this growth, the global energy production, distribution and use is becoming more efficient as a result of countless routine actions, such as households replacing light bulbs with more efficient ones or using internet-enabled devices, motorists

upgrading to more fuel-efficient vehicles, businesses replacing old boilers and municipalities insulating public buildings. Backed by a reinvigorated policy focus on energy efficiency and driven by relatively high-energy prices, these actions are helping to lower the growth in global energy demand. Energy efficiency offers an effective way to reduce the need for additional capital expenditure on energy supply, tackle environmental concerns and sustain economic growth (International Energy Agency, 2014).

Without energy efficiency and cost development of new energy technologies, the global energy system & economy would be even more under stress. However, by the new proposals upon better efficiency and developing the new generations' conscience upon sustainability will make a huge difference. As a consequence; the changes in global trends, the shift through becoming more conscious users, and the collaboration of academic research and industry; will develop new tools and platforms regarding to the concerns.

Lean Construction as a Sensitive Approach:

Another milestone on the sensitivity concept of this research is the 'Lean Construction' theme. Lauri Koskela coined the term "Lean Construction", at early 1990's. Lean Construction is a

“way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value.” This approach tries to manage and improve construction processes with minimum cost and maximum value by considering customer needs (Koskela, Howell, Ballard, & Tommelein, 2002) In the article that Koskela was searching for transition from the conversion model to alternative models, he described the paradigm shift under the title of Lean Construction, and explained the term as following: “In Lean Project Definition, representatives of every stage in the life cycle of the facility are involved, including members of the production team that is to design and build it. Alignment of values, concepts, and criteria allows transition to the Lean Design phase, in which a similar conversation occurs, this time dedicated to developing and aligning product and process design at the level of functional systems. During this phase, the project team stays alert for opportunities to increase value. Consequently, the project may revert to Project Definition. Further, design decisions are systematically deferred to allow more time for developing and exploring alternatives” (Koskela, Howell, Ballard, & Tommelein, 2002).

Regarding to the definition and practice of Lean Construction and the Lean Project Definition, the research project ‘Symbiotic Data Platform’, represents the design thinking of the Lean

Design principles, on the way of aiming the optimum energy saving and sustainability outcomes for environment during the lifecycle of the building. Even though the initial theory of Lean Construction is dedicated to the construction phase of a building, the outcomes are projected through the operation phase of it. So that, further thinking over this lean design theory leads the project into reality by creating a tool that grounds the base on being lean and as sustainable as possible. At the end of the day, it is all about innovation. Thinking beyond the Lean Construction is to create the Lean Lifecycle for the built environment.

The sensitive touch in architectural and construction technology galvanized the developments on modeling and analysis software and platforms. Building Information Modeling introduced to the literature and industry regarding to the great need of complex and detailed information models during the design stage.

Constructions mission actually starts after the construction finishes and the occupation starts. This stage is called ‘operation’, and the main user is the ‘occupant’ on this stage. The buildings that are not used after construction by any reason are doomed to demolish. Yet, the normal scenario after construction is the operation and maintenance. Consequently, the life cycle of the building covers the stages from the first days



of the construction – planning, the operation stages and until the demolition.

The Buildings' Life Cycle is explained by O'Sullivan & Keane as following; *"The Building Life Cycle, which is being referred to in the directive, defines the entire life of a building from design, through conception, occupancy and on to eventual demolition. This creates a need for long-term energy efficient designs to be present in all buildings. The concept of a Building Information Model (BIM) describes an integrated data model that stores all of the information relevant to a building throughout the building life cycle. The BIM is a central data model where all information can be accessed by a variety of tools dealing with the entire building definition. This will remove the need for a new building model to be developed for each tool. In order to fully realize the acceptance of BIM's a universal standard had to be created"* (O'Sullivan & Keane, 2005).

Thereby, the 'Life Cycle Assessment' is a concept that relates the environmental and energy efficiency aspects within BIM methodology. According to United States Environmental Energy Protection Agency (USEPA); 'Life Cycle Assessment' (LCA) is a can be used to evaluate the potential environmental impacts of a product, material, process, or activity. An LCA is a comprehensive method for assessing a range of environmental

impacts across the full life cycle of a product system, from materials acquisition to manufacturing, use, and final disposition. LCA study results help to promote the responsible design and redesign of products and processes, leading to reduced overall environmental impacts and the reduced use and release of more toxic materials. LCA studies identify key materials and processes within the products' life cycles that are likely to pose the greatest impacts, including occupational and public toxicity impacts. These assessments allow businesses to make product improvements through environmentally sound process, material, and design choices (Energy Protection Agency, 2017). Building Information Modeling is a tool that is designed for assessing the project delivery in optimal results. On this way, LCA is applied while the decision-making process of the project. So far LCA is a decision-making method for the design phases, and it is a tool for the designer, planner and engineers. This assessment gives a foresight of the life span of the project, and it is also a 'cradle – to-grave' approach, among all other approaches. This methodology has direct relation with the 'Lean Construction' theme of Lauri Koskela, and it is crucial on AEC industry. BIM is a suitable tool to apply the LCA. Relatively, BIM is defined by B. Succar as; *"a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle"* (Succar, 2009). Main concern of LCA is

reducing the costs of material and energy usage, and delivering the project as sustainable as possible. *“The raising concerns for climate resilient buildings are expected to reinforce the requirements for novel decision-making paradigms in building structures that will augment the traditional engineering performance indexes (cost, safety and buildability) with sustainable components (energy use, resources depletion, emissions and waste)”* (Eleftheriadis, Mumovic, & Greening, 2017).

“The operational stage of an LCA is linked to the energy emissions during the occupation phase of a building and usually covers a significant proportion of its total life cycle emissions. It includes all the impacts associated with the building’s systems such as heating, cooling, lighting, ventilation, equipment use, etc...” (Eleftheriadis, Mumovic, & Greening, 2017). In case, the project that is designed and built by BIM methodology, might be sustainable in various fields, such as economy, energy consumption, material analysis, distribution, cost-benefit, work force, time; the operation phase is not modeled, or reflected to the BIM File as information input. Eventually, LCA is a method that is made to address various fields and achieve a better project delivery. LCA includes the operational phase of the building and it is also considered in BIM process while planning. Since LCA objective is to set better policies and reach better

energy efficiency, a continuous analysis and evaluation should be implemented to the process. Because of BIM is used for plan, design and construction, when it comes to the operation phase, the BIM methodology loses the substantiality. When the building is occupied, the model is not needed in current practice. Even though there are many public buildings (such as, schools, commercial buildings, airports. etc....) using BIM during their FM, there is a lack of usage of existing BIM data and model in residential buildings. The occupant cannot access the model, or the information of the building; thereby, they cannot get involved to the ‘real-time’ sustainable use of the building, which corresponds to the living cycle. **After the construction is completed and the occupation starts, regarding to the users behavior, thermal comfort level and real-time thermal data of the location should be additional variables for the re-assessment.** By ‘Symbiotic Data Platforms’ hypothesis formulation, LCA is considered as an assessment method, yet it should be upgraded by those additional factors that are mentioned before.

To conclude; by *Sensibility and Sensitivity* concepts; the foundation terms of Symbiotic Data Platform is determined, and moreover, the technical and theoretical literature review is aligned by the general terms defined as the state of art, concerning the *‘new architectural design understanding.’*

3 RESEARCH QUESTIONS

3. RESEARCH QUESTIONS

The research question is: “How to use the ‘existing BIM data’ and ‘constantly produced real-time data’ together; during the operational phase of the building, to upgrade the energy efficiency and enhance sustainability while addressing users’ customized and optimized thermal comfort?”

The predetermined ‘*Sensibility & Sensitivity*’ concepts specify and align with the research question, on the way of giving importance to the research field by the ‘*new architectural design understanding*’⁴³. The contemporary practices of AEC industry are interdisciplinary and multi-dimensional when it comes to focus on existing problems with innovative approach. The contemporary research approach has a more socio-economic and environmentally responsible manner, which is previously defined as ‘*sensitivity*’. Due to suggesting innovative solutions, taking benefit of the existing technologies with a new standpoint is substantial on the way of creating added values. Initially, the problem definition for the research question arisen from the fact

that the occupant of the building is not using the existing BIM Model and its benefits of the embedded data in the current technology. However; facilities of the architecture, computer science, and technology fields are already capable to assist the upcoming proposal on this field.

To consolidate the research, complimentary research questions are proposed, such as searching new possibilities on how to upgrade BIM methodology to be interactive, the possibility of using existing BIM data during the occupation phase of the building, and lastly, researching on the potential of enhancing energy efficiency & comfort optimization together by taking benefit of BIM. As a matter of fact, Building Information Modeling can be considered as one of the most efficient, productive and promising design tools of today, and on the other hand, interactive design is the most possible generative & innovative solution for tomorrows’ world. Taking this starting point as a question leads this research to search the open gap⁴⁴ that, BIM is ending in the operation phase, also known as the maintenance of the built environment & building; meaning, BIM needs to be upgraded to an interactive level that suits today’s

⁴³ See ‘State of Art’ Chapter.

⁴⁴ The open gap of BIM will be enhanced in the hypothesis section of the proposal.



‘new architectural design understanding’ and should address a better qualified development plan for the technology.

Reaching to a *‘responsive’* stage of the smart systems is the basis and the main aim of this research proposal. By investigating the responsiveness in BIM, it would be possible to achieve the interactive level; the network of the ‘things⁴⁵’ would be giving us the possibility to approach nearly all the information that we need to have on the way of reaching more efficient, and better quality of smart systems, in real-time. The more data input provides more answers, just like having a data sheet helps to complete the missing points of the other document. And the network of the objects are connecting the elements that we are using everyday in our daily life hold a great potential to research upon between the interaction of objects and people. At last but not the least, due to the fact that, aiming for a responsive system for a city, starting from the smallest scale is the first step to be taken if it is addressed to get a digital urban infrastructure in the new era. The future is lying in between the unseen, invisible cloud of data according to the state of affairs. Eventually, it is impossible to underestimate the emphasis of the network of

world-wide-web, neither the open source data⁴⁶. By open source, we are more connected, educated and culturally developed. It is liberalization and a social upgrading. Today, thanks to the existing technologies and The Fourth Industrial Revolution; this technology became a part of daily life, and most of the devices, objects and furniture that we use in our everyday life can be tagged with sensors and introduced online. They can sense the data, analyze and visualize. Individual systems help the user to sustain the environment, nevertheless, there are missing links that still exists. IoT concept is the biggest enabler of open-source reform and open data exchange. What is progressive in this research is to propose a term ‘interactivity for BIM’, that will be operated by the occupants without requiring any prior knowledge; hasn’t been applied to the existing theories. Inasmuch as there is a great development of the technologies and projects that are ongoing, that this project contributes and aligns it with the requirements of the contemporary needs. Combining the potential benefits of the agents, such as; IoT, sensor systems, modeling technologies, information models, open-source data, the cloud, visual programming, and taking the benefit from the potential of existing data; to achieve a platform that will be sending feedback

⁴⁵ Reference taken from the context ‘Internet of Things’

⁴⁶ Open Source is a decentralized development model that encourages open collaboration via internet.

to the user, taking the produced data from the user and the socio-cultural, environmental and economic outcomes.

Also the following supportive questions, which are discussed in the last chapter, 'Further Research' ⁴⁷. Those research questions are targeting the urban scale applications of the proposed model. The main topic for the further research is *"Converting Smart Cities to Responsive Cities"*.

To develop this term, the following question emerged; as *the occupants of the buildings are the citizens of the cities; "How the proposed platform (Symbiotic Data Platform) that blends BIM and IoT to each other, could be further developed to be operated as a city infrastructure, to address various other concerns in relation with the sustainable urban development?"* Moreover, within the scope of the further research ideas, the following question is covered around the 'Responsive Cities' framework; *"How could a digital infrastructure for the smart cities would upgrade the city excellence of the cities and could create a transaction of mutual benefits between citizens, to result as a transition between smart cities though responsive cities?"*

⁴⁷ See 'Further Research' chapter.

4
HYPOTHESIS

4. HYPOTHESIS

By the 'Symbiotic Data Platform'⁴⁸ proposal, it could be possible to introduce the reflection of the captured data thanks to the Internet of Things to the Building Information Modeling system of the built environment or vice versa. So that, this research ensues a new platform that overlaps two mediums in one platform.

As it is coined in BIM Handbook (Eastman, Tiecholz, Sacks, & Liston, 2008) that, BIM enables the designer and the engineers 'virtually' to construct the building. Within this new way of working, the AEC industry had an advance technique to analyze, document and manage the project. Currently, in Europe, all the countries have the BIM adaptation procedure and BIM regulation in order to construct and register a building in legal means. Regarding to the fact that by mid 2000s, the AEC Industry will apply the total shift on design thinking, and will adapt to BIM. As a consequence, the documentation of the built environment will be available for further use. By the global BIM adoption process,

it is foreseen that all the municipalities will have the documentation, as BIM Models, and those data will be available upon request by practitioners when needed. For legal construction requirements, the BIM file will be the mandatory documentation for registration and premises. As a consequence, BIM models holds giant amount information in digital means, but those data won't be used actively when the life starts inside of the buildings. 'Symbiotic Data Platform' aims to fill this open gap by creating a link between existing material and construction information and real-time data, during the 6th stage: the operation phase of BIM, in which the user is the occupant, and the occupant is actively using the facilities of the building.

Technically, the platform aims to create a 'real-time information model', which also could be a network of 'real-time information models'. And as a result, the new tool for smart homes, which will upgrade the smart home to a responsive home. Additionally, as continuation of the project, the project might be developed further as an urban infrastructure that will propose an innovative solution to the intelligent cities phenomena. As it was mentioned above, the open gap of BIM is that, the process of the platform is designed until the operation phase, also known as the maintenance of the built environment & building; which is only processed by the designer or the engineer.

⁴⁸ See Chapter 6: Symbiotic Data Platform



The gap is, coming along with the following question:

'Since BIM is a platform that holds nearly all the data of the building, why it does not interact with the occupant of the buildings' real-time and personalized input; for better comfort level and user comfort optimization, as well as addressing energy efficiency?'

The hypothesis of this research project in relation to the open-gap, is as following:

"BIM is the digital twin of the real building, so it holds all the information of it. Occupants are the end users of the building, whom use the building actively, and they must have access to the existing information of their built environment in the digital era. The Network Society (Castells, 2010) require smarter systems from the built environment. With current technology, existing softwares, devices and tools are capable of capture, process, analyze, blend and interact with the big data and real-time information together. So, the existing information and real-time data could be used for further benefit of the occupants, such as comfort optimization and/or energy efficiency."

Recently, there are concepts being used and developed everyday such as 'smart homes', 'smart phones', 'smart cities', which are being operated by the 'modern-day user'. Nevertheless, the actions that the users realize just could be used as it should be, in the existing technologies. The produced data is challenging to be used as an incubation medium or as a decision – making gear. Therefore, 'Symbiotic Data Platform' proposes all the means in this platform act as equal nodes of the system. The **'Dual-Development Cycle'**⁴⁹, which means, using the users data to upgrade the communities life qualities, and as return, the upgraded life will empower the individuals in various ways, such as social, environmental and economic fields. Furthermore, the platform would be an interactive tool that will act as a 'receptive & responsive' agent, so that; the user will be the main server of this system. The tool is desired to stand as a medium in the decision making process in the smart systems of built environment as well as, an interaction medium between the citizen and the smart cities. As a result, apart from creating a new link between the user and smart features, using the digital facilities to constitute citizen participation to address sustainable urban development is most likely possible with the proposed platform.

⁴⁹ Dual-Development is explained in Symbiotic Data Platform chapter with a separate section.

4.1. BLENDING BIM WITH IOT

Regarding to the research and readings done upon BIM and IoT interaction, the detailed analysis on specific topic is documented previously on the 2002-2020 BIM & Real-Time Integrated Research Literature Review Graph⁵⁰. On that graph and the interpretation done regarding to the results, its' found out that, there is a gap in the field (open gap), which is the future use of the embedded technologies on the softwares, and interactive use to develop within BIM. There is a specific group of researchers that are interested on discovering the possibility to combine existing technologies for further developments in both academic and private projects, yet; the projects are still not concluded as a specific software that create access for direct use of combined technologies. The combination is still being developed across the world in many institutions.

Even so, BIM is the sustainable plan for architecture, construction, energy efficiency and economy, there is the conflict reveals on the last phase of the proposed BIM systems. The sustainability of the use, is addressed until the building is

constructed and maintained, however, there is a big deficiency existing literature⁵¹ **upon how to continue using the existing information during the operational phases, such as creating an interaction between the user (occupant) and the existing BIM data's in the real-time.** This might be possible by a receptive and responsive platform. Yet, *"By setting up real-time connection between live sensor data and the comprehensive BIM, building operators can literally see where the energy problems are with the help of building models. However, combining these different kinds of information, which are usually created in different formats on different platforms, is a big challenge"* (Wang, Gluhak, Meissner, & Tafazolli, 2013).

To point out the importance of data produced in our daily life, to look at the closest example would be enough. In example, many residential and commercial buildings have already installed sensors and data capturing equipment to monitor building conditions and energy efficiency. *"By knowing the building status at any given time and location, which is largely unseen to most users, it is possible to change occupant behavior, improve building safety, avoid unnecessary energy consumption and*

⁵⁰ See Literature Review Chapter.

⁵¹ The open gap in literature.



facilitate better working environments” (Wang, Gluhak, Meissner, & Tafazolli, 2013).

Sensing the physical conditions is the first step to be taken in order to introduce sustainable solutions. To install and capture existing data is an easy and fairly cheap process when considering the solutions and benefits that could be proposed. Apart from the sensor systems, the challenge in this research is to convert the input that is collected by the sensor, and monitor this data in a real-time information model, which could be developed upon BIM.

Blending BIM with IoT, upgrades the current BIM network to a dynamic level. This approach could be considered a real-time projection on the existing model as another data layer. *“Therefore, a big challenge for the utilization of BIM during a facility’s lifecycle stands to make it “dynamic”. A “dynamic” BIM contains real time building information such as data from various kinds of sensors, so the model can reflect the existing conditions.”* (Chen, Bulbul, Taylor, & Olgun, 2014). The importance of blending BIM and IoT is, to be interdisciplinary and to achieve compatibility by serving the ‘responsiveness’ approach. There are two different possibilities to follow this compatibility. One is directly taking BIM as the building scale and proposing network between the smallest built elements, and

the second possibility is to follow CIM, which corresponds to City Information Modeling that is introduced to the literature by Jorge Gil⁵² (Gil, 2013), that takes city as the scale, and analyze and model city via an urban scale infrastructure by this approach. Relevantly; ‘The Project Dasher’ project by Autodesk (see Figure 10) is a good example of how BIM and IoT could be implemented to the current softwares, with real-time energy performance monitoring purpose. *“Project Dasher is an Autodesk research project using a BIM-based platform to provide building owners with greater insight into real-time building performance throughout the life-cycle of the building”* (Autodesk, Complex Systems Research, 2019).

“In this context, we need a more integrative approach to maintain the complex balance between our energy-saving measures and occupant comfort. Using BIM as an ideal platform for managing complex building information, Project Dasher aims to go beyond existing building dashboards to represent a comprehensive framework for monitoring building performance” (Autodesk, Complex Systems Research, 2019). Hence, *Project Dasher* is a visualization tool interacting with BIM software. The

⁵² Jorge Gil Jorge’s research focuses on the sustainability and accessibility of urban design and of public transport networks. He develops multi-modal transport and land use network models built on open GIS platforms.

SYMBIOTIC DATA PLATFORM

symbiosis & sensitivity

collected data is screened and presented in the 3D model for better understanding of the space with the concerned factors, as well as for a pertaining to the building performance and overall operational requirements. Even though it is an important contribution and an invaluable project that covers the topic 'blending BIM with IoT', *Project Dasher* is not a tool that would be used by the occupants. It is a design tool for the end-user of the design cycle, it would be used by practitioners of BIM.

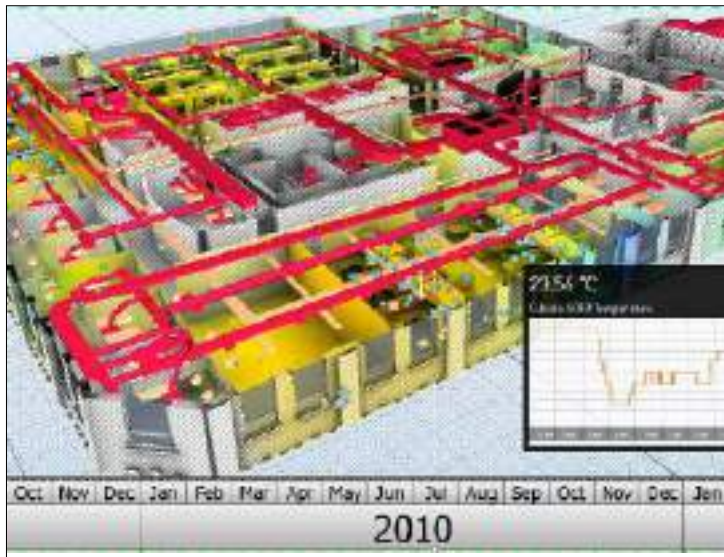


Figure 10: 'Project Dasher' (Autodesk, Complex Systems Research, 2019)

Apart from the biggest project that focuses on the interaction between BIM and real-time information '*Project Dasher*', there are uncountable research going on across the world regarding to research and develop this very specific connection. "*Connecting real-time data streams from the rapidly expanding set of IoT sensor networks to the high-fidelity BIM models provides numerous applications. However, BIM and IoT integration research are still in nascent stages, there is a need to understand the current situation of BIM and IoT device integration*" (Tang, Shelden, Eastman, Pishdad-Bozorgi, & Gao, 2019). The overview of the BIM – IoT devices integration for Smart Built Environment context covers up a wider field that includes cloud computing, interoperability issues, SOA, web services for BIM and IoT, standards for information integration and management, hybrid approach, semantic web technologies, new query languages, new data schemas, BIM tools' API and relational database, facility management, construction logistics and management, health & safety management and construction operation & monitoring (See Figure 11).

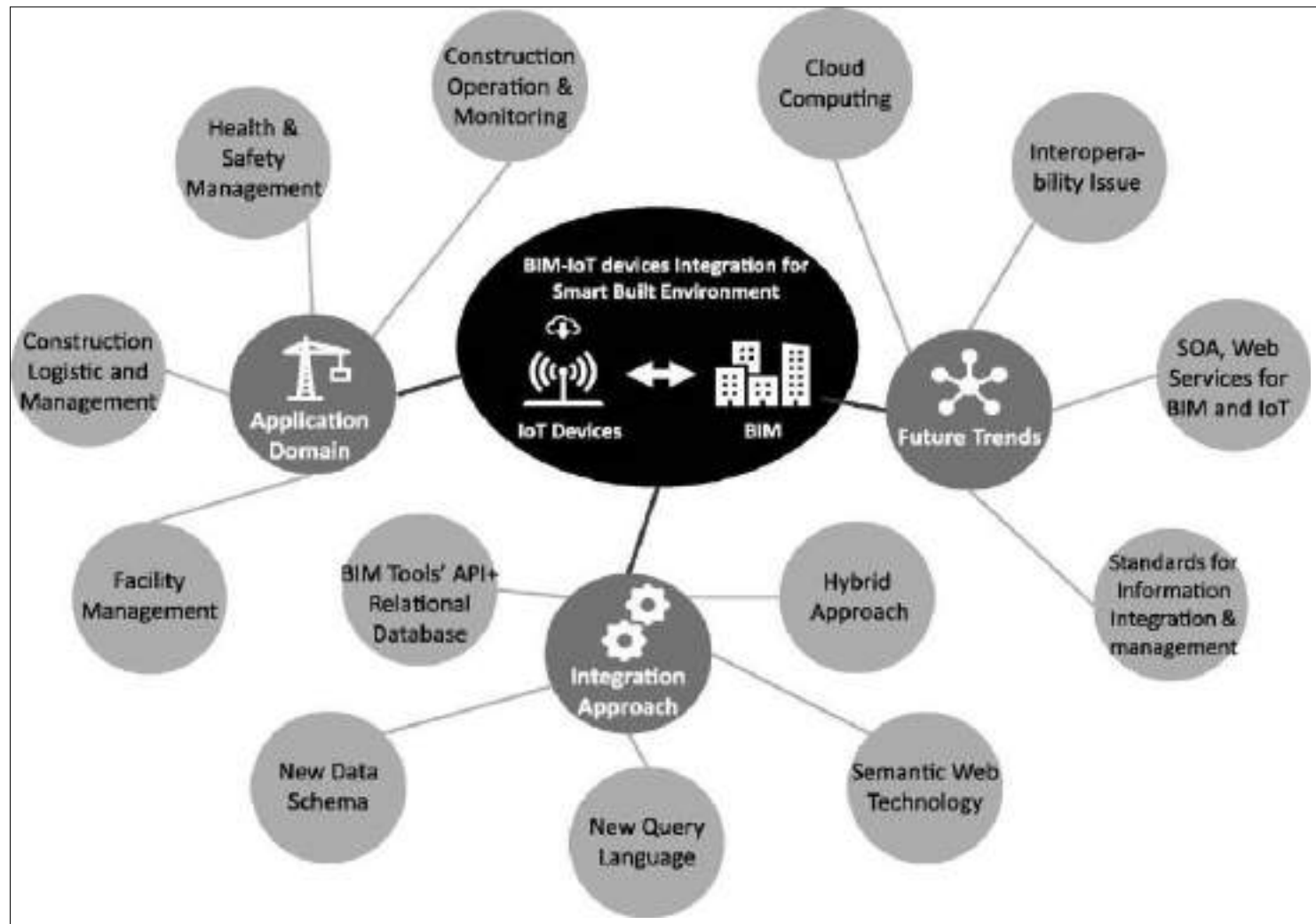


Figure 11: 'BIM – IoT devices integration for Smart Built Environment'
Diagram (Tang, Shelden, Eastman, Pishdad-Bozorgi, & Gao, 2019)

4.2. 7TH STAGE INTERACTION

The hypothesis is formulated by taking the references from the previous literature on the field, and also by reviewing the research projects. Regarding to the references, this research focuses on the possibility of developing a further stage for Building Information Modeling. This new stage is meant to empower the occupants by providing energy efficiency, productivity, sustainability and optimizing thermal comfort. The new stage creates this possibility by implementing Internet of Things to BIM; and taking benefit of the existing information from the BIM Model.

7th Stage of BIM: Interaction is a new stage, which is built upon the concepts of Post-Occupancy Evaluation (POE), Building Energy Modeling (BEM) and Building Thermal Comfort Optimization.

Post - Occupancy Evaluation:

Post Occupancy Evaluation (POE) is an evaluation and an analysis method for the user satisfaction and the function of the building. POEs can supplement Life Cycle Analysis, by complementing the determinations based on energy use and

quantifying the types and amounts of construction materials, increasingly used to compare the impact of buildings. *“Post-Occupancy Evaluation is a platform for the systematic study of buildings once occupied, so that lessons may be learned that will improve their current conditions and guide the design of future buildings. Various aspects of the occupied buildings’ functioning and performance can be assessed in a POE, both chemophysical (indoor environment quality (IEQ), indoor air quality (IAQ) and thermal performance) as well as more subjective and interactional (space use, user satisfaction, etc.)”* (Meir, Garb, Jiao , & Ci, 2009). POE has qualitative and quantitative toolkits coming from 3 resources; that are ‘occupant feedback & satisfaction questionnaires’, ‘bills and metrics’, and ‘measurements, monitoring and readings’. Those tools and methods provide subjective and objective feedback. Planning and practice of the building could be analyzed throughout the building’s life cycle from the initial design to occupation. The benefits from POE can be in the short, medium and long term:

- “1. Short-term benefits include obtaining users’ feedback on problems in buildings and the identification of solutions;*
- 2. Medium-term benefits include feed-forward of the positive and negative lessons learned into the next building cycle;*



3. Long-term benefits aim at the creation of databases and the update, upgrade and generation of planning and design protocols and paradigms” (Preiser & Vischer, 2005).

In his book; Stewart Brand⁵³ quoted about the importance of the occupant factor as; *“Many buildings that win awards are not popular with their users. All buildings are predictions, all predictions are wrong”* (Brand, 1994). Eventually, the estimations cannot predict a reality. In real time, the human factor is included to the network and the reaction could be different than the designed or expected facts. *“When we consider the predictions we used to create and maintain buildings there are those based on errors of judgment which are unavoidable and those mistakes which are avoidable”* (Ozturk, Arayici, & Coates, 2012). Traditionally, Post Occupancy Evaluation (POE) is conducted against the prescribed performance specification and mainly relies on two activities; the effective collection of real world data and the formulation of this data into models that allow trends and deviations to be observed. However, it is required to gain efficiencies by identifying potentially easier and more economical methods and

tools for the collection of data such as wireless sensors (Ozturk, Arayici, & Coates, 2012).

‘Energy in Buildings and Communities Program (EBC)’ developed the Annex 66 concerning the definition and simulation of occupant behavior in buildings. It is a collaborative research worldwide, and has several subtasks for defining and evaluating the occupant behavior and comfort optimization in built environment. Occupant behavior is complex, stochastic and multi-disciplinary (see Figure 12). This document explains the user effect on operational phase of the building. Energy related occupant behavior in buildings, is a very important aspect for building design optimization, energy efficiency, performance analysis and evaluation, and building energy simulation concerning the affect on occupants’ comfort and developing a better conscience of built environment.

Annex 66 is a guide for Symbiotic Data Platforms’ design methodology as well as creating a theoretical background for the research. Quantitative description and simulation of human behavior in residential buildings article, by (Peng, 2012), explains the relationship of user and the building in energy efficiency concerns by the following diagram:

⁵³ Stewart Brand is an American writer, best known as editor of the Whole Earth Catalog. He founded a number of organizations, including The WELL, the Global Business Network, and the Long Now Foundation. He is the author of several books, most recently Whole Earth Discipline: An Ecopragmatist Manifesto.

SYMBIOTIC DATA PLATFORM

symbiosis & sensitivity

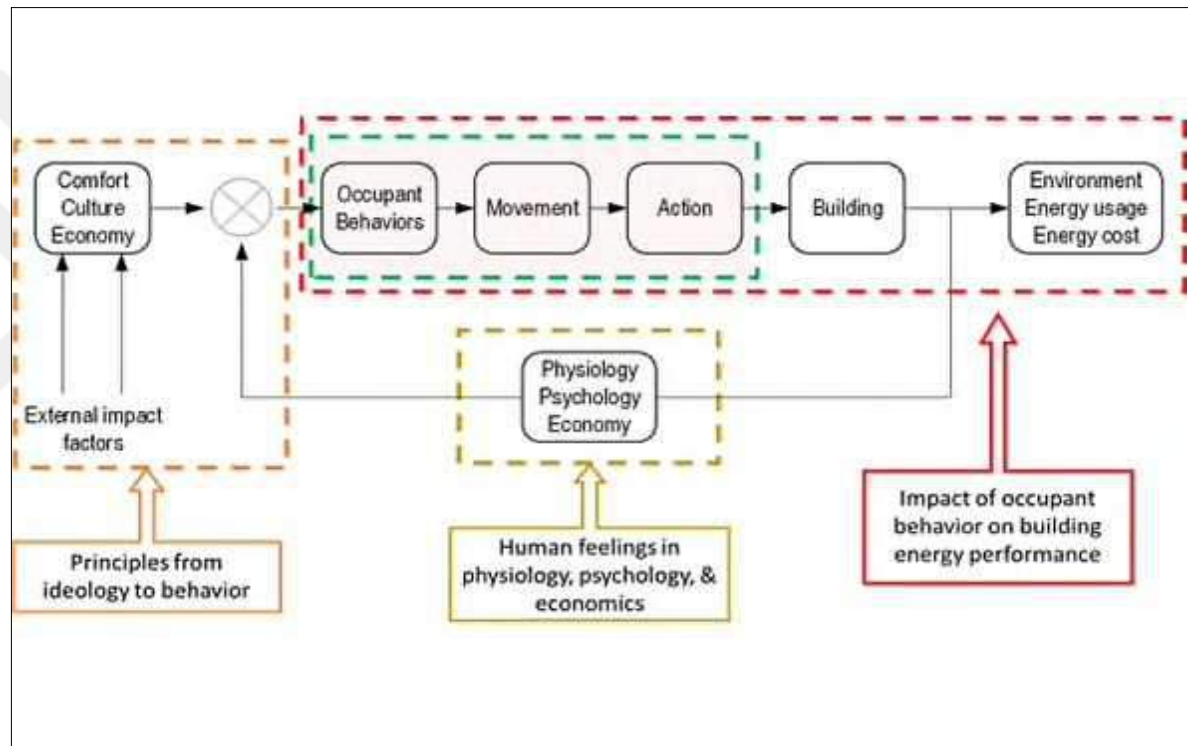


Figure 12: Relationship between humans and buildings (Peng, 2012)

Evaluation of a building's success in supplying a healthy and usable environment by its occupants and users as well as professionally produced appraisals are a necessary component of Life Cycle Analysis (Gale, 2005) and this is where the POE comes into account. "Currently the primary motivation for POE tends to be on user satisfaction" (Ozturk, Arayici, & Coates, 2012). The outcomes of POE are addressing the well being of the residents. Not only evaluating the satisfaction & comfort of

the occupant; but also; by this evaluation, creating better solutions and modification of existing situation is a goal of this process. Developing and maintaining buildings at lower costs, depends to the quality of design, yet; the user input and behavior are important regarding to how buildings in use deviate from the expectations of their design.

Autodesk group explain the Building Control Systems (BCS) in relation with POE and mention the sustainability concept by users' comfort optimization as following;



“A sustainable building is not a fixed ideal, but a moving target that must be reassessed on an ongoing basis in order to respond to the ever-changing patterns of its occupants and its context. While building performance tools have traditionally focused on the simulation and evaluation of a specific design, we are witnessing a growing need for tools that can help us to continuously evaluate and verify building performance. Today, most buildings are equipped with sophisticated Building Control Systems (BCS) that collect data from thousands of end-points. These systems help building operation managers maintain buildings by minimizing long-term operational cost ensuring occupants’ comfort” (Autodesk, Complex Systems Research, 2019).

However, a key challenge is to develop enhanced methods of organizing, studying and communicating data, to achieve better results. By proposing the 7th Stage to BIM methodology, creates a connection between the Operation Phase of BIM and the Post-Occupancy. Interaction Stage provides an intense evaluation to the built artifact, while taking reference from the BIM data, applied materials information, and blends this information with the users habits and energy usage information. This creates the connection between POE with current BIM practices, in real-occupational life span.

Building Energy Modeling (BEM):

As it was stated by IEA-EBC in Annex 66; *“Having deep understanding of occupant behavior and being able to model and quantify its impact on use of building technologies and energy performance of buildings is crucial to design and operation of low energy buildings. Existing studies on occupant behavior, mainly from the perspective of sociology, lack in-depth quantitative analysis”* (IEA-EBC, 2016). Quantitative analysis for research upon energy-efficiency in relation with occupant behavior is crucial and essential.

Building Energy Modeling is based on the Building Information Modeling foundations. *“A major benefit for application of BIM is storing and organizing the energy-related building information. For example, real-time energy monitoring systems generate information with regards to the home energy consumption, temperature, and occupancy where such information need to be stored in an organized way under proper thermal zone, equipment, and building components”* (Kamel & Memari, 2019). Buildings are major consumers of energy, especially for mechanical heating and cooling of the built environment (Energy Efficient Strategies, 2008) and also, they are the major source of energy consumption, accounting for 40% of primary energy consumption in most countries (International Energy Agency,

2019). Energy efficiency in buildings became a concept that is significantly important and a mainstream requirement for global sustainability.

“Energy simulation models act as a data source for simulated performance metric generation. A theoretical level of building performance will be displayed against which actual building operation can be compared” (O'Donnell, Morrissey, Keane, & Bazjanac, 2004). Building Energy Modeling (BEM) is an additional facility of BIM, which provides energy simulations. There are various BEM tools capable of importing these BIM files to perform energy simulation. Interfaces such as OpenStudio, DesignBuilder, BEopt, or eQuest do not perform the simulation inherently, and there is the need for integration of energy simulation engines such as EnergyPlus or DOE2, which perform the analysis based on different mathematical tools and thermodynamic equations.

Performance could be analyzed within the context of physical conditions, material adequacy, environmental surrounding, local climate such as sunlight, vegetation, temperature, and also for the cultural adaptation to all those. *“The architectural design, and therefore the design process as well, could incorporate complex properties of a building's performance within its environment through detailed simulations and real-world data*

gathered through sensors, measurement, and mapping processes” (Van Ameijde, 2019). Energy Modeling is taking reference from those factors, and has a great potential to increase the building quality as well as the spatial design in relation with the occupant comfort.

In this research project, including energy modeling leads sustainability through reduction in energy consumption; which is one the motivations of Symbiotic Data Platform.

Building Thermal Comfort Optimization and Energy Use:

Buildings account for about 40% of the global energy consumption and contribute over 30% of the CO2 emissions. A large proportion of this energy is used for thermal comfort in buildings. The intensification of energy consumption in HVAC systems is the largest energy end use both in the residential and non-residential sector, comprising heating, ventilation and air conditioning (Pérez-Lombard, Ortiz, & Pout, 2008).

Comfort optimization in general terms defined by Slater, in his book 'Human Comfort' as, *“a pleasant state of physiological, psychological and physical harmony between a human being and its environment”* (Slater, 1985).



Comfort optimization could be applied to various aspects of the buildings such as energy consumption, referring to thermal comfort, visual comfort, occupant satisfaction, and energy efficiency. The evaluation of building performance relevant to the optimized conditions ensures a better outcome in every field. As a matter of fact, comfort optimization could be planned and applied during the design phases, regarding to the energy analysis and estimations. *“The majority of these buildings were designed with a variety of energy saving characteristics regarding the local climatic conditions”* (Meir, Garb, Jiao, & Ci, 2009). For instance, using double-skin facade, calculation of the thermal mass, application of natural ventilation and passive heating or cooling devices would be the sustainability principles of comfort optimization. During the occupational phases, by the real conditions, an enhanced optimization that is important aspects for comfort and energy efficiency; could be done by physical measurement and monitoring, and occupants’ feedback. On this research, regarding to the comfort optimization and energy efficiency; focusing on occupants’ thermal comfort is chosen since it is easy to measure, gives accurate results and technologically applicable.

Thermal comfort is; *‘the state of mind which expresses satisfaction with the thermal environment’* (Taffe, 1997) and the standard of the generalized optimal temperature for a healthy

adult for indoor temperature around 20 or 22°C (68 to 72°F) (The American Heritage Dictionary, 2019). Thermal Comfort of the user is the most dominant parameter of energy consumption in the built environment. Thermal comfort research gained importance in AEC industry on the late 1960’s (Fanger, 1970). *“During the late 19th century, ‘thermal comfort’ was introduced as an environmental factor that is part of overall indoor comfort. In addition to poor air quality, poorly ventilated rooms can also result in unwanted thermal effects (both through temperature and humidity)”* (Bluyssen, 2013).

Regarding to the users action; there are two adaptive principles for thermal comfort optimization, as, physiological and behavioral; *“Physiological adaptation (in terms of acclimatization) is not likely to play a major role in affecting occupants’ thermal comfort for the moderate range of thermal conditions prevailing in the built environment. Psychological adaption refers to the effects of cognitive, social and cultural variables, and describes how and to what the extent habits and expectations might change people’s perceptions of the thermal environment”* (Yang, Yan, & Lam, 2014) and, *“Behavioral adaptation is by far the most dominant factor in offering people the opportunity to adjust the body’s heat balance to maintain thermal comfort, such as changing the activity and clothing levels & opening/closing windows and switching on fans. A*

consequence of adaptive principle is that occupants try and hopefully become adjusted to their immediate thermal environment” (Yang, Yan, & Lam, 2014).

Apart from the users’ personal adaptations, in architectural design field, the challenge and the goal is optimizing the thermal conditions by design and mechanical implications. To do so, energy analysis tools help the designer for the decision-making. Also, for further optimization in occupation; using sensor systems to capture thermal information and other methodologies to collect users feedback is essential.

The conceptual model in the **Figure 13** explains the loss of homeostasis (discomfort and distress) that triggers the occupant to search a more neutral state of thermal comfort. This search performed by modifying their environment by manipulation of the thermal state by interaction with appliances, through behaviors. When homeostasis is fulfilled, health and wellbeing are also achieved. Consequently, the modification and the interaction with the environment results in energy use. Eventually, thermal comfort and energy use has direct relation. This energy use depends on the users consumption, wellbeing and socio-cultural aspects such as habits.

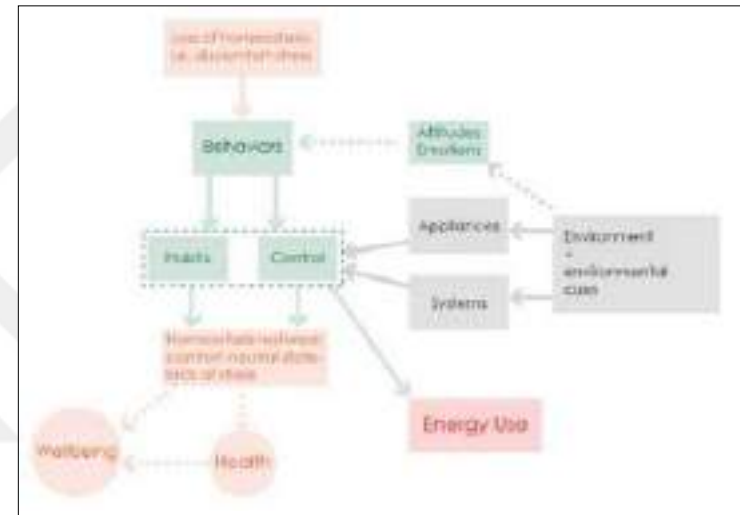


Figure 13: The Homeostasis Conceptual Model (Ortiz, Kurvers, & Bluysen, 2017)

Proposing 7th Stage to BIM - Interaction:

BIM Methodology has been defined universally within 6 analysis and application stages as:

1. Design
2. Visualization
3. Simulation
4. Documentation
5. Building
6. Operation



The stage that this research specifically focused is the 6th and the last phase, which is '**Operation**'. All the professions and interested stakeholders can contribute with all these phases as it was mentioned before. Yet, the end user of the building, which is the occupant, is not completely included to the plan by using the existing information model. Most importantly, in the operation phase, the biggest role belongs to the occupants. By proposing a new stage with inclusion of the occupant to BIM methodology, the intention is to widen up the potential of the power of existing data for further use, and introduce a new phase during the operation of the building.

The transition from traditional engineering and design approaches that is previously defined as '*new architecture understanding*', leads the industry to further capacity building. Holistic '*performance-based*' & '*performance-driven*' approaches are required to fulfill the requirements of an efficient built environment. Those approaches require good knowledge of optimization algorithms and integrated software applications such as BIM (Shi, 2010). Although BIM is a great methodology when it comes to communication, facilities management and interoperability, and it is the most efficient process of AEC industry; '*performance*' is assessed only the planning of the project and analyzed during the construction process. In continuation, during the occupation the '*performance and energy*

efficiency' are not considered as factors to be assessed by BIM after construction; by a dynamic & real-time possibility.

Even though BIM implicates the Life Cycle Assessment of operational stage, and has a great potential to be developed, the operational stage is not implying the use of BIM data, and the occupant of the building is not taking the benefit of the existing model and information that is embedded to the model day-by-day.

Occupation of the building means a massive energy usage. Operation stage is when the occupant actively involves to all the facilities of the building. To maintain the services as well as the activities, energy is needed. The energy use of buildings covers a great proportion of the costs during the life span of the building. The operational emissions compared to the construction phases. For instance; a research shows that during the operation phase, the emissions could raise until 85%, while during the embodied phase could be 15%; that means a great difference around 60% raise. This fact has to be considered as a reference since there are other examples such as; in high performing low-energy buildings the embodied emissions could reach up to 45% during the operation stage (Anderson, Wulfhorst, & Lang, 2015).

Moreover, the operational stage must include the user as an active factor. *"The operational impacts accumulate over time and they can be significantly influenced by the occupants' pattern of energy use and systems' efficiencies"* (Ibn-Mohammed, Greenough, Taylor, Ozawa-Meida, & Acquaye, 2013). Yet, in current practice BIM is not projecting the active user activity in the model, nor has an additional refined tool for further energy analysis for the occupational phase. Even though there are many research projects going on, as software or as a tool, the real-time analysis, visualization or real-time pattern projections of occupants' habits are not present in recent technology of BIM. Performing real-time optimization and decision-making within BIM is one of the industry's future challenges (Attia, Hamdy, O'Brien, & Carlucci, 2013). Consequently; the facts listed previously, there is an *'open-gap'* with an interesting research line. As BIM has the potential to be developed in multi-dimensions. By existing concepts, such as Post-Occupancy Evaluation and Building Energy Modeling (BEM), it is observed that the pre-construction energy and comfort evaluation of life cycle might not give accurate assessment for the optimal thermal comfort and energy efficiency in reality.

It is clearly seen that the operational phase is not quite enough to define the upcoming process that will be running through.

Introduction of an emergent phase that can correspond the context of the 'Symbiotic Data Platform' is the **7th Stage: Interaction**. Even though there are research projects that includes real time data to BIM methodologies, for facilities management or location tracking, all of the projects focus on the design and construction. An Interactive BIM, should be used by designers as well as the occupants. The massive existing data could be used during the occupation phase of the building by the residents of it.

7th stage Interaction, corresponds to the 7th dimension of BIM. Similarly to the 6 stages of BIM Methodology, there is another globally accepted concept of 'dimensions of BIM' (See Figure 14).

The 7 dimensions are;

- 3D. Shape (Model)
- 4D. Time
- 5D. Cost
- 6D. Sustainability
- 7D. Performance.



Figure 14: 7D – 7 Dimensions of BIM (Opinion Writers, 2018)

Those dimensions address each concern specifically as a construction should cover. On this research, the focus is on 6th and 7th dimension. as the project deals with the occupational phase, and the performance of the building. On 6D, BIM performs energy consumption analyses and proceeds estimations. During this phase, the sustainability concerns are covered by the optimization of energy efficiency which results in more complete and accurate energy estimates earlier in the design process. It also allows for measurement and verification during building occupation, and improved processes for gathering lessons learned in high performance facilities. The Life-Cycle BIM strategies are included in 7D as well. Interaction in BIM by 'Symbiotic Data Platform' project, defines the blending



of BIM methodology with Internet of Things technology on occupation phase of the building. This phase represents the inclusion of the occupants real-time data for the assessment during the operation and maintenance phases of the building.⁵⁴

In this phase, BIM is used to achieve the existing data of the living environment. This data is used in the interactive platform which relates the material data with the real time data, and also by the human-computer interaction that generates the user input. This phase also could be defined as **'Real Time Information Modeling'** or **'BIM in Responsive Architecture'**.

The aim is to develop a new branch that includes both BIM with intelligent environments and responsive structures to have a contemporary, conscious & environmentally responsible approach on architecture, engineering and design.

⁵⁴ The '7th stage: Interaction' is explained in Symbiotic Data Platform chapter and applied in the development of the Prototypes.

5

METHODOLOGY

5. METHODOLOGY

5.1. DESIGN SCIENCE RESEARCH METHODOLOGY

Design Science Research Methodology is an interdisciplinary research method. According to Van Aken, the objective of this methodology is to create and collect knowledge upon engineering based, interdisciplinary professions, while questioning design solutions of a conjectural problem (Van Aken, 2005). Additionally, Hevner et.al. states that the main purpose of Design Science Research is to achieve a knowledge collection and process it through a problem domain by defining and application of a designed artifact. *“Two paradigms characterize much of the research in the Information Systems discipline: behavioral science and design science. The behavioral- science paradigm seeks to develop and verify theories that explain or predict human or organizational behavior. The design-science paradigm seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts”* (Henver, March, Park, & Ram, 2004). This methodology conducts the research project to a

more advanced level from the traditional techniques upon ‘architectural-design-computing’ fields since the fluency of it is interdisciplinary and depending to experimentation and knowledge construction.

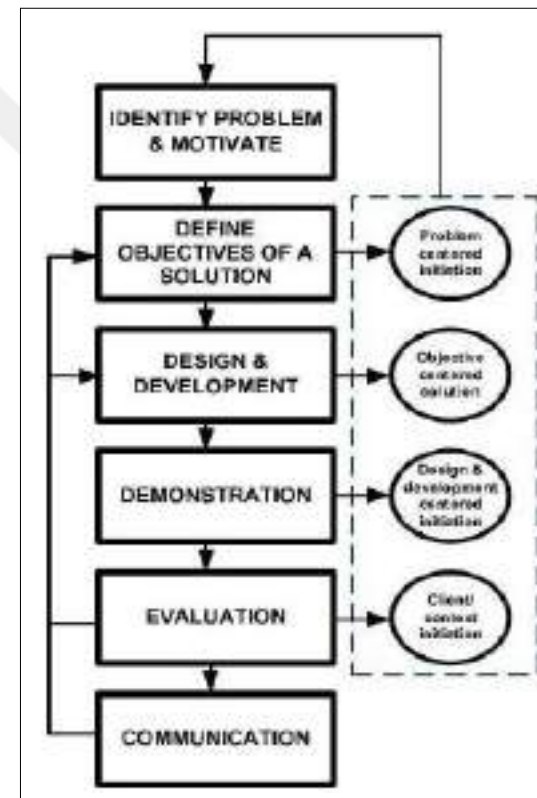


Figure 15: Design Science Research Methodology Process Steps Graph (Peppers, et al., 2006)



Design Science Research Methodology (Figure 15) ; have the following correlative steps that are operated as a cycle (Peffer, et al., 2006), such as; 1. Problem identification and motivation, 2. Objectives of a solution, 3. Design and development, 4. Demonstration, 4. Evaluation, 5. Communication.

Consequently, Design Science Research Methodology in current practice blends various standpoints for a single problem, to achieve versatile solutions. *“The artifacts created in the design science research process include, but are not limited to, algorithms, human/computer interfaces, and system design methodologies or languages”* (Vaishnavi & Kuechler, 2015). While the problem identification requires a complex solution; the design science completes the rest of the design process by facilitating the theoretical and technical requirements. Throughout this process, the creation of the knowledge would be transformed to a more advanced level, and the self - evaluation would point out the next steps of the design evolution, also by the linkage of prototyping and proof of the proposed hypothesis by a real-artifact and its testing which the design science references. The innovative artifacts as a result of this processes reflects the open-ended possibilities of interdisciplinary practices.

At last but not the least, *“Design Science is a methodology based information technology research, yet nowadays it is applicable to various other fields such as architectural research since contemporary research have been evolved to be interdisciplinary and more complex”* (Simon, 1996). This methodology paradigm coined to the literature at 1990's and initially started to be used in engineering industry. Nowadays, this methodology is applicable in various fields, and it evolved to be an interdisciplinary way of researching.

Design Science Research focuses on the development process of the project itself, rather than concentration on the end-result. The gained knowledge is the outcome of the project, regarding to this methodology. Correspondingly; *“The creation of new knowledge through design of novel or innovative artifacts (things or processes) and the analysis of the artifact's use and/or performance with reflection and abstraction. The artifacts created in the design science research process include, but are not limited to, algorithms, human/computer interfaces, and system design methodologies or languages”* (Vaishnavi & Kuechler, 2015). The outcome of this research methodology requires the end-result to be aligned with the digital era's contents.

SYMBIOTIC DATA PLATFORM

resilibility & sensitivity

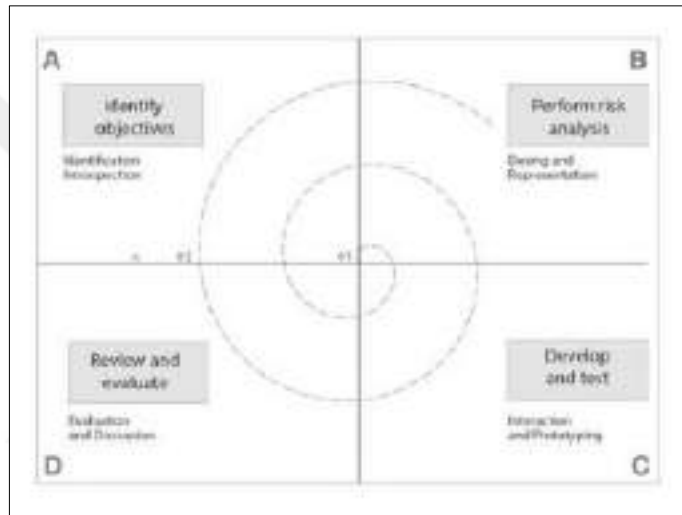


Figure 16: Design Science Research Methodology Graph. Graph by Zeynep Birgonul and Oriol Carrasco.

5.2. DESIGN THINKING

Taking the reference from Design Science Research Methodology, this second phase 'design thinking' is the realization part of the project. It also could be defined as, the shift through practice from theory. As a matter of fact that, design phase required many research on literature review, Building Information Modeling and its' softwares, physical computing, sensor systems, data based modeling tools, visual programming and classic programming, and many more... It is an interdisciplinary challenge. Design Phase is based on the classical design thinking methodology: a non-linear process by Dam & Siang (Dam & Siang, 2019), which is explained by a graphic on Figure 17.

The design process of 'Symbiotic Data Platform' takes the reference from the non-linear process of design thinking methodology. Inspiration from the literature review, research on existing technologies, understanding the realized projects, thinking upon new ways to create more productive and efficient projects with various points of view is the initial stage of this process. Right after the general idea and hypothesis is formulated, the Ideation stage follows the conceptual project, by realization and testing of several prototypes. Documentation of



every creation and idea, both success and failure is extremely important for this research project.

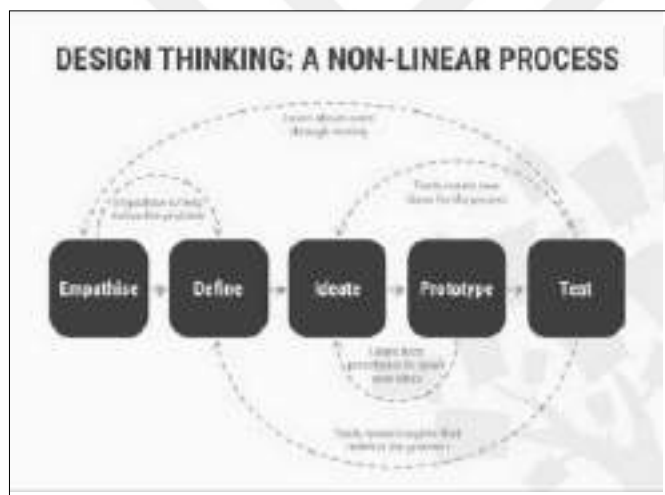


Figure 17: Design Thinking: A non-linear Process (Dam & Siang, 2019)

On this phase, the definition of the roadmap of the research is defined. Relevantly; a variety of concerns upon the initial research questions are investigated. Finding a way to connect BIM and IoT, had to be analyzed and realized by physical entities. Some of the cases are listed down, such as, 'electricity consumption', 'thermal comfort' and 'water usage'. Out of this list, the most accurate concern to be investigated and calculated has decided as the 'thermal comfort'. By the sensors technology and by being easy to sense and reflect according to the user

interaction with the physical space, the thermal values are the most suitable for this research. In the first stage of design thinking, the selected concept is analyzed by the current technology and the applicability is tested. As a result, the prototypes design is completed. On the second stage, the reflection of the results is visualized, documented and discussed and interpreted. As the final part, the final design of the prototype and in association with this design, the interface of the platform is designed. Operation rules are defined, and the last interpretation regarding to the outcomes is done. See Figure 18 for the diagram of the 'design-thinking diagram'.

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symbiosis & sensitivity

CONCEPTUAL ROADMAP

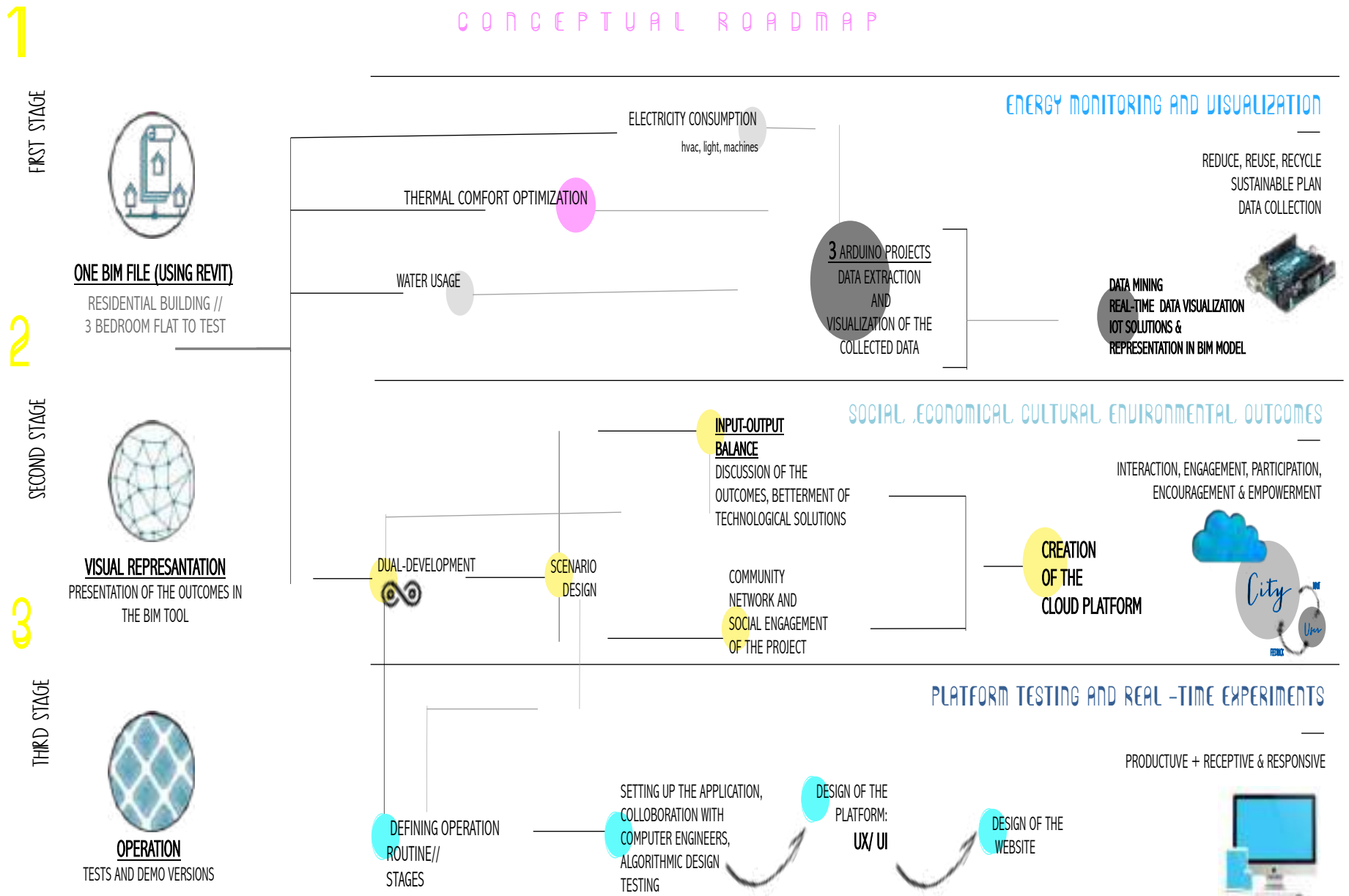


Figure 18: 'Symbiotic Data Platform' Roadmap



5.3. METHODOLOGY APPLICATION TO THE RESEARCH

Analysis Phase

In the very early phases of the research, to create the basis for the research project, a very intensive and complex analysis had to be made. While researching and learning upon the main concepts of the project, which are BIM and IoT, those concepts had to be analyzed and digested deeply to discover their possibilities. The complementary literature and objectives were also examined in this phase. Regarding to the design-thinking diagram, this phase corresponds to the first stage where also the problem definition was made. The literature review upon BIM and IoT was made and interpreted through the 'sensibility and sensitivity' concept to explain the approach that is going to be intended. The intended relation could be explained as, the sensibility concept is the theoretical explanation of the theories behind BIM data and IoT, along with sensitivity concept that could search for some connection between the technologies and the upgrading of the smart built environments and future built environment and city systems.

Research Questions And Hypothesis Formulation

Referring to the analysis done previously, in this phase, research questions were defined and the hypothesis was formulated and the research questions are defined. Also the research objectives and the added value were discussed. In addition, the possible limitations and foresights were thought and defined in this chapter. Following the research and the decision making process on theories, the literature review was revised again.

Synthesis Phase

After defining what to examine and how to study it, the synthesis of all the literature review and theoretical background came together in this phase. On this phase, finding possible ways to approach the research topic is discussed. By improving personal skills as a researcher, developed better possibilities and capabilities for the following phases of the research. For example, Revit courses, Arduino courses, programming courses and other online seminar, conferences and lectures could be classified in this phase of the research. Additionally, networking and interviewing various researchers and practitioners on the field was worthwhile for the sake of the evolution of the project, and more importantly the prototypes. Synthesis phase was not a stage to start and finish; yet, it was more a continuous learning process throughout the whole research project.

Implementation Phase: PROTOTYPING // TESTING

In this phase the intention is to implement the design – (proposal of the ‘Symbiotic Data Platform’) to one prototype. This part had three application topics, first of them is the application of the theoretical background to the conceptual setting, which had the operation system architecture, the network, the technological and infrastructural necessities, cost and benefit analysis. Second of them was the software part, and third of them is the small sensor and device - hardware part. Documentation and visualization of those phases during the design, implementation and testing were fundamental on prototyping. Each and every trial was photographed, documented, and the schematics, graphs and flowcharts were visualized. Also, all the libraries and codes were saved in separate files for each prototype.

Case Study

To validate the hypothesis, the prototyping had to be tested with some models and cases. Blending BIM data with IoT real-time data over various techniques are done in this phase. Data extraction and analysis is done in this phase, as well as, defining the thermal calculations origin formulas. To decide the most suitable calculation is decided. By the development of the case studies testing, some modifications were done on the algorithm (code). Every test is evaluated the benefits and deficiencies with a critical approach, so that the following prototype could be

developed further. This phase was conducted within the sequence of prototyping phase concurrently.

Reflection Phase

This is the last and the most probably one of the most fruitful part of the dissertation, as being the inference of all the work that had been done. In this part, the main focus was on the results of the design, the possible limitations during the application and also the outcomes. Eventually, after all the inferences, the further research proposals implied as an additional chapter in the end of the thesis.

Limitations and Foresight

Being aware of the possible deficiencies, and having a critical approach on the research project is crucially important to realize a successful work. Both the Project / Prototype chapter and the Further Research chapter had the auto-criticism phase to question the quality of the work, as well as to open new discussion fields.

Rethinking Phase Further Research

The Rethinking phase, or the Further Research chapter of the thesis focuses on the possibilities to develop the project in a more advanced and complex forms. Due to the fact that, ‘Symbiotic Data Platform’ is a promising and open-ended



project, and the prototypes are working well in the building scale, the possibility to widen up the scale could be a new research project. More literature review, theories and personal inference were added to this chapter. For deeper analysis, Barcelona is taken as the example city for further investigation due to the success of its' recent smart city applications and having various ongoing projects. In example, Smart city BCN project, there are two ongoing programs under the title or 'Superblocks' and 'City OS', which give references the literature review to focus on. Apart from the Smart City BCN, the second and more specific project, @22BCN, which has many technological and social impacts on the development of the city and the society. Moreover, the 'Smart Citizen' project is a good example to show the possibilities of user interaction, and data usage in urban structure by sensor kits. At last but not the least, the City Protocol is a good reference for thinking upon, also to understand the city structure.

The further research possibilities part might be classified as a part of the literature review. As the main concept for the further

research is to study upon 'Responsive Cities, the realized projects in Barcelona, as well as other smart city examples were documented to create a strong basis for the '**Livable Cities With Collective Values**' proposal. The main statement of the further research: 'livable cities with collective values' (further research) will be explained and deeply discussed in relation with city science. Researching and thinking on existing technologies, literature and concepts and moreover the possible problems and concepts were basically got shaped in this phase.

Conclusion And Closing

The last stage of the re-thinking phase is conclusion and closing. On this very last part, the project was summarized. The results are checked and the last tests are conducted. Project abstract is re-phrased, as well as the state-of-the-art is revised. The latest literature is examined and added to the literature review, to stay up-to-date. Lastly, the thesis format was re-checked, documentation of appendix, bibliography and lists and tables were organized.

SYMBIOTIC DATA
6
PLATFORM



6. SYMBIOTIC DATA PLATFORM

Definition Of Symbiotic:

According to American Heritage Dictionary of the English Language, the definition of 'Symbiotic' is as following;

1. Involving interaction between two different organisms living in close physical association.

2. Denoting a mutually beneficial relationship between different people or groups.

Example: "A symbiotic relationship benefits both parties"
(American Heritage Dictionary of the English Language, 2011).

Introduction:

Under the theory of 'Blending BIM with IoT', the main objective is to introduce to the literature the interactive possibilities of the interoperable system. This research aims to introduce a new approach on digital and responsive architecture & urbanism, which simply combines these two concepts under one title. BIM is considered as the future solution of the architecture and construction field and on the other hand, IoT is the key aspect for advanced architecture, and the forthcoming developments of the responsive techniques. By uniting these systems, the principal aim is not only regeneration our building to a smarter and more sustainable way, but also upgrading the end-users perception upon the 'collective values and sustain the socio-environmental qualities.

In Symbiotic Data Platform project, real-time data feedback is crucial since it is not just a monitoring tool, but also it is an interactive data platform that is operated by the end-user, who is the occupant of the building. To operate that platform, BIM is the basis and real-time data is the interactive input, that will be enabled by the IoT system. The Platform is a receptive-responsive tool for 'personalized' optimization of thermal comfort. The research focuses on; searching new possibilities of how to upgrade BIM methodology to be interactive, the possibility of

using existing BIM data during the occupation phase of the building, and lastly, researching on the potential of enhancing energy efficiency & comfort optimization together by taking benefit of BIM.

Likewise, pointing out the importance of BIM data in Symbiotic Data Platform, by focusing on the thermal comfort, using the prototype as a regular daily tool for private rooms of the residents could show a good feedback on both energy efficiency and their personalized comfort qualities.

As a similar design thinking in another project example, in E-Cabin research by University of Trieste states, *“The elements of the cabin (furnishings, materials, sounds, smells, temperature, humidity, ventilation, brightness, hygiene, etc.) are not enough to satisfy the holistic concept of comfort. It is necessary to consider also the passengers’ characteristics, their needs and their feelings in the cabin environment”* (Nolich, Spoladore, Carciotti, Buqi, & Sacco, 2019). This is the reason why Symbiotic Data Platform is designed based on the principle of blending BIM and IoT in one artifact by having a user-centered approach.

Main objective by proposing the ‘Symbiotic Data Platform’ is users’ optimized thermal comfort in real-time. Symbiotic Data Platform is not a design tool. Even though by visualizing and

analyzing the real-time data, it is not a ‘data visualization’ tool either. The platform is operated by the occupants of the building. The platform uses this real-time data capture for real-time physical modifications in occupants’ comfort optimization, by getting reference from the existing BIM document and material qualities by extracting the datasets from the BIM file. Simplifying and monitoring the existing data by the platform, will be the new solution for responsible users that enhances the productivity, energy efficiency and sustainability.

In their book *Adaptive Thermal Comfort: Principles and Practice*; Nicol, Humphreys & Roaf highlighted the importance of the relation between people and the built environment in thermal context. In conjunction with that importance, Symbiotic Data Platform positions itself to search a better inter-relation between the user and the built environment. They wrote;

“The relationship between people and environment is complex and active, bringing in time, climate, building form, social conditioning, economic and other factors as well as the immediate physical environment. This complexity implies that the indoor environment needs to take this variability into account. This means an indoor environment that changes with the season and the climate, that allows buildings to change, suggests how quickly they should do so and reflects the



willingness of occupants to vary their environment by returning some measure of control to them” (Nicol, Humphreys, & Roaf, 2012).

At last but not the least, expounding the thermal condition with the energy use, it is a fact that the consumption rate have been increased with an incontrovertible amount as the technology develops and requires much more energy than just a decade ago. Into the bargain, climate change effected the existing buildings regulations and local adaptations. The multi-functional and diverse societies live together and share the same indoor environment, which creates a variety of comfort desires. On the other hand, the new products and construction materials, with BIM, the AEC industry could provide better quality in construction and occupation stages. As a result, the indoor environment is influenced by regulators, end users, society norms and construction industry’ facilities. Currently, the built environment is a result of all those factors (See Figure 19).

Despite the fact that the negative and positive effects of environmental and social facts create complex problem identifications, Symbiotic Data Platform aims to attain an adequate and simple solution for the current climatic change, customizing and optimizing thermal comfort, and energy-efficiency in relation with each other by using current technology.

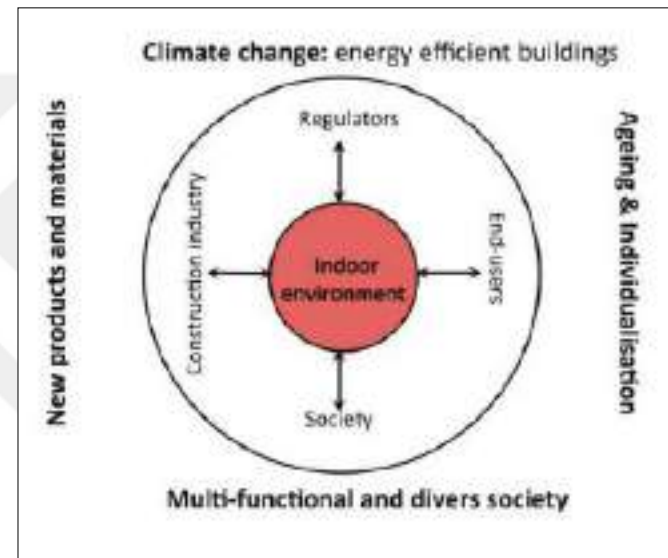


Figure 19: Drivers are different from 100 years ago (Bluyssen, 2013)

Hereby, ‘Symbiotic Data Platform’ is a receptive – responsive tool that creates an information cycle/network between the smart built environment and the smarter user. Introducing the ‘**Dual-Development**’⁵⁵ concept is a key outcome of the platform as well as being an added value. The interaction of the user with the sensor system activates the physical modification for comfort optimization, which conducts a continuous data exchange. This collaborative and productive information exchange corresponds

⁵⁵ See ‘Dual-Development’ Section in this chapter.

SYMBIOTIC DATA PLATFORM

sensibility & sensitivity

the sustainable data cycle between the user and the physical space.

The further research upon the final prototype of 'Symbiotic Data Platform'; would be upgrading this prototype as a collective interface that would connect the users data with each other via the online platform for mutual benefit. This collaborative platform would address the collective values of the society will be proposed by the end of the process. The single platform usage could be united by bigger scale, which creates a participatory network between the neighbors. Also, by uniting those BIM data and the real-time energy usage information, would result as a City Information Model / Network. This will upgrade the citizen participation in urban field. It is a promising project on the way of introducing a responsive city system by multi-ended outcomes.

The idea of '*Not only the homes, but can the city be responsive?*' conducts the further research of Symbiotic Data platform to be developed in the city scale. Regarding the future possibilities of this research that might be developed, would address a grater scale. The objective of the further research would be enhancing the intelligence in the society regarding urban values & empower the citizen with collective values. Additionally through the theoretical perspective, having

'sensibility and sensitivity' concept that will be concluded as '**Livable Cities with Collective Values**'⁵⁶ proposal would be the complementary literature part that will empower the main goal of the proposal.

To conclude, the purpose is to be able to gather data by 'real-time values' and precede this input to a greater system that can be responsive and critical. As Pablo Picasso said and inspired most of the designers, it is believed that; "*all we can imagine is real*", with the recent artistic, inspirational, intellectual and technologic possibilities. The specific interest of this project on progressive topics is to lead the society live, shape and share a much better qualified built environment.

Wearables:

Wearable technology addresses various fields such as; heath, entertainment, fashion & design, art, activity tracking and monitoring and many more. "*Wearable computing moves computation from desktop to the user*" (Starner, et al., 1997). Wearables are smart electronic devices with micro-controllers, which can be attached to clothes, used as an accessory, embedded as a body implant, or used and worn simply as a

⁵⁶ See Further Research Chapter.



device for its purpose. Wireless technologies such as Bluetooth and Wi-Fi communications are used to process the wearable devices.

Wearables' history started from 1995-1997, with Jennifer Healey and Rosalind Picard at the MIT Media Lab, when they designed, built, and demonstrated data collection and decision making from wearables. Those devices were a part of the research that monitored continuous physiological data from the wearer. By 1990s' to 2000s', many significant research and development projects have been realized. In July 2014 a smart technology footwear was introduced in Hyderabad, India. The shoe insoles are connected to a smartphone application that uses Google Maps, and vibrate to tell users when and where to turn to reach their destination. Nowadays, smart wearable computers are a part of daily life; such as Apple Watch are collecting and processing real-time data and managing daily tasks. Wearable tech assists the user with the microcontroller thanks to the proximity in between, and also manages a continuous real-time data-flow. It gives a closer association with the user, which as a matter of fact creates efficient and accurate workflow. Many research on wearable technologies and wearable computers concluded as the quality of life is enhanced through using the devices.

Wearables are computer augmented technologies that gives access to personalized and accurate results for the required results in physical reality. Regarding the close interaction of the user and the data collection and transmission device, Starner et.al. wrote the following; *"Finally, wearable computing augmented realities are truly personal. The user grows to expect his interface to be accessible continually and unchanging, unless specified otherwise. Such a persistent and consistent interface encourages trust. With experience, the user personalizes his system to ensure fluid use in everyday contexts. As a result, the user's personal system becomes a mediator for other computers and interfaces, providing a familiar, dependable interface and set of tools complementing the abilities the infrastructure provides (more processor power, additional sensing, etc.)"* (Starner, et al., 1997).

Smart clothes and textiles, wearable micro-controllers & sensors, smart jewelry and embedded devices, healthcare activity tracking & monitoring mini computers are being used to address efficiency and productivity of the user. By the Fourth Industrial Revolution, their existence and availability have been catalyzed, and the benefits of the usage of wearable technologies are being understood by the community.

Due to the fact that closer association with the user results better quality data collection and efficient workflow, on Symbiotic Data Platform project, the main idea is shaped within the wearable data-collection and processing device that will be used by the occupants. In this research, those wearable devices are studied as Prototypes⁵⁷, by empirical trial-and-error learning method, that develops through the deficiencies and necessities for a better result. The objective of using wearable technologies in this project is to engage the user with their built environment and creating human-to-computer, computer-to human interaction, with the scope of the general objective of the project which is optimizing the thermal comfort with energy efficiency. To do so, Symbiotic Data Platform is developed by the following phases listed below.

Project Development Phases & Scope:

1. Problem Identification
2. Literature Research⁵⁸
3. Design Thinking
4. Decision Making and Definition of the Scope of the Project
5. Modeling and Data Collection (Case Studies)
6. Prototyping and Testing
7. Final Prototype⁵⁹
8. Representation and Simulation
9. Results and Analysis
10. Conclusion.

⁵⁷ See Prototypes and Final Prototype Chapters.

⁵⁸ See 'Literature Research' Chapter.

⁵⁹ See Final Prototype Chapter.



6.1. THE DIFFERENCE BETWEEN SYMBIOTIC DATA PLATFORM AND SMART HOMES

As mentioned previously, Symbiotic Data Platform's intentional goal is to create an interactive platform that works by automatic data capturing. By the platform, the concept of 'Smart Homes' would be put forward to a more advanced level by connecting the smart homes in an open-access network and having benefit of the captured data. It is intended not to be just only an upgraded smartly-digitally controlled home or building, it will be a platform that will interact with the user and analyze data for upgrading life quality and productivity. It is meant to be a receptive-responsive open platform.

What is a 'Smart Home'?

The official definition of Smart Homes, by Oxford, is as following: *"a home equipped with lighting, heating, and electronic devices that can be controlled remotely by smartphone or computer"* (Lexico Dictionary, 2019). Smart homes concept is being studied since the last decade. In the first instance, the concept is coined by MIT Media Lab. The pioneering work upon smart environments was the 'Smart Rooms' research by the MIT Media Lab (Pentland, 1996). *"A smart home is a home- like*

environment that possesses ambient intelligence and automatic control, which allow it to respond to the behavior of residents and provide them with various facilities" (De Silva, Morikawa, & Petra, 2012).

Currently, the concept already has been developed and it became eligible for many people. The application of smart homes depends to the human-machine, and machine-to-machine interactions. Application of sensor systems is the first attempt to convert a traditional home to a smart home. *"A key enabling technology is the Sensor Web, which envisages a network of sensors spatially distributed and embedded within the environment"* (Sheth, Henson, & Sahoo, 2008).

Smart homes can be analyzed by various categories, such as providing automatized services for wellbeing, surveillance for safety and energy efficiency. The first category that provides well being by automatized systems and data collection, includes residential and healthcare contexts. The second category is for camera and motion capture systems for burglary, fire, natural disasters, and accident protection and control and also for any kind of control when the residents are absent. The third and the last category applies sustainability and energy efficiency concerns, for water, gas, electricity, thermal HVAC systems trash disposal and light; to help the occupants to reduce the

energy consumption of the house by monitoring and controlling of the devices and rescheduling their operating time according to the energy demand and supply (De Silva, Morikawa, & Petra, 2012). Regarding the third and the last category of smart homes; *“Monitoring energy consumption in the home is also increasingly important, because energy consumption is rising at a higher rate than population growth, and households are responsible for over 40% of total energy use in most countries. Ambient intelligent homes facilitate smart energy management through nonintrusive load identification and estimation, as well as minimally intrusive load shedding and automation for energy efficiency”* (Paradiso, Dutta, Gellersen, & Schooler, 2011).

As it was mentioned above, the smart homes could have various sensor networks for different outcomes. In **Figure 20**, the 17 sensor categories (Cook, 2012) can be seen.

The smart home sensor categories listed by Cook is as following;

1. *Ambient Intelligent control*,
2. *Light sensor*,
3. *Windows and Door control*,
4. *HVAC control*,
5. *Lighting control*,

6. *Automatic pet feeder*,
7. *Motorized drapes*,
8. *Automatic watering*,
9. *Mailbox sensor*,
10. *Driveway sensor*,
11. *Security system*,
12. *Lawn moisture sensor*,
13. *Face recognition sensor*,
14. *Motion sensors*,
15. *Door sensors*,
16. *Ambient intelligent interface with car*,
17. *Ambient intelligent interface with smart phone*.

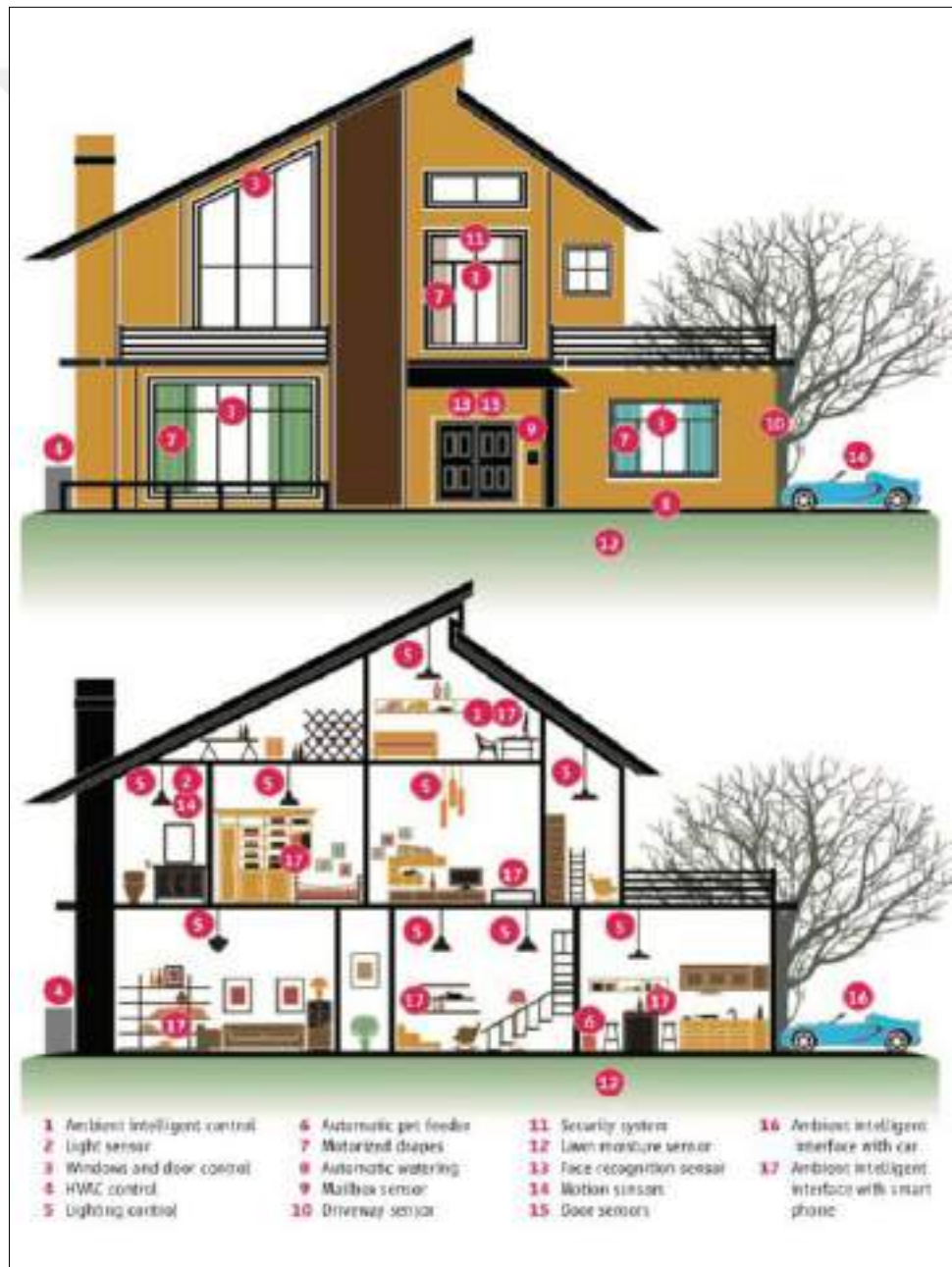


Figure 20: 'Smart Home' (Cook, *How Smart Is Your Home?*, 2012)

The list could be expanded by new sensor and interface technologies, while the homes are getting smarter by direct correlation with the civilizations intelligence increase. All the smart home sensor are introduced to the built environment for creating faster, more efficient, productive and easy solutions for everyday needs. Embedded sensors report in real-time to the host or they will keep the information in the memory for offline processing. In order to address complex situations, multiple agent- based intelligent tools have been developed. Moreover, smart homes are currently developing for providing better and more advanced results. However, with recent advances in electronics and computing, sensing technologies the sensor systems already became very satisfactory, yet; providing the ambient intelligence that is required to make decisions for smart behavior is still a challenging task. *'Human behavior at home is highly unstructured'* (De Silva, Morikawa, & Petra, 2012). Estimation of human behavior is currently a wide research area by many disciplines including phycology, computer science, architecture and many more... Consequently, automation and sensor systems still are not the optimal solution for managing everyday tasks, still holds a great potential to be enhanced, developed and advanced regarding to offer more satisfactory results for smarter homes.

The foresight on smart home technologies envision that day by day, the usage of computer integrated devices and the necessity of adaptation to those technologies will increase. Some anticipations state that the future home will be a robot more than a simple space to live in. Already, many software companies are developing specific softwares that targets this embedded interactive environments. Moreover, not for only private use, but also for the public benefit, the network of smart homes are being discussed as a future infrastructure.⁶⁰ Smart homes are getting smarter day by day, and the next step seems to be for this theme, is to be upgraded as putting forward the smartness to be sensitive and respondent. As much as real-time data processing gains prominence, developing responsive environments, for not only mechanically control the devices but also propose and perform 'responsible' solutions for environment, economic concerns and improved quality of life.

For Symbiotic Data Platform project, it is possible to say that all the three categories of smart homes could be applied to the platform. Yet, the most important outcome of the platform is a mixture of first and the third category, which are enhancing the well being of the occupant and reducing energy consumption. The platform is definitely smart, yet not only smart, but also

⁶⁰ See 'Responsive Cities' Chapter.



much more, such as being interactive and 'receptive & responsive'.

'Symbiotic Data Platform's Added Value for Smart Homes:

First of all, Symbiotic Data Platform takes the reference to be a smart home system. Smart homes are a good reference for a home automation system that addresses energy efficiency, monitoring, controlling. Even though the concept is a well structured and efficiently working system, it always can be put further and developed with more advanced concerns. *"Coming soon to your home? In an ambient intelligent home, sensors collect information about the environment and the residents. An "intelligent agent" uses this information to decide whether actions need to be taken to adjust, e.g., temperature or lighting"* (Cook, 2012). Smart homes in 21st century, is not only a machine control network embedded into living environment, but also a data collection platform, an analysis tool and at last but not the least, an intelligent mechanism for optimizing the life quality by automation.

Regarding to this theme, the 'ThinkHome' project (See Figure 21) is a good example on the upgrading of the smart home concept: *"The ThinkHome system is designed under two main premises: it shall ensure energy efficiency and comfort*

optimization. While a focus on energy is easily justified with sustainability and economic considerations, the reason to prominently feature comfort originates from the fact that comfort is a main decision criterion for homeowners to employ expensive building automation technology. Thus, ThinkHome aims at providing a comprehensive system and architecture for sustainable next-generation buildings" (Reinisch, Kofler, Iglesias, & Kastner, 2011). By this project, the energy efficiency in relation to the user comfort is proposed by the help of intelligent multi-agent systems. By this proposal, the user became prominent in the smart home systems, due to the upgrading of energy efficiency and cost reduction considerations. The ThinkHome project is a clear example of the difference between smart homes to interactive/responsive environments.

Without further explanation, taking the reference from the previous example; it would be easier to introduce 'Symbiotic Data Platform's function; by the following examples. For instance; lets think of a couple sleeping in the middle of the night, and one of them is sick with flu, and the other one that hates hot temperature. Imagine the BIM system that has all the reference of the construction materials thermal values, hot water pipes that goes around their building and also all the reference of the heating/cooling system. Can we connect that pre

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symbiosis & sensitivity

designed and updated model with the furniture that they use? Moreover, can they get involved to the connection? Is it possible, without the users' active input, the digital model and our furniture and devices can sense what they feel, or what they demand from the built system?

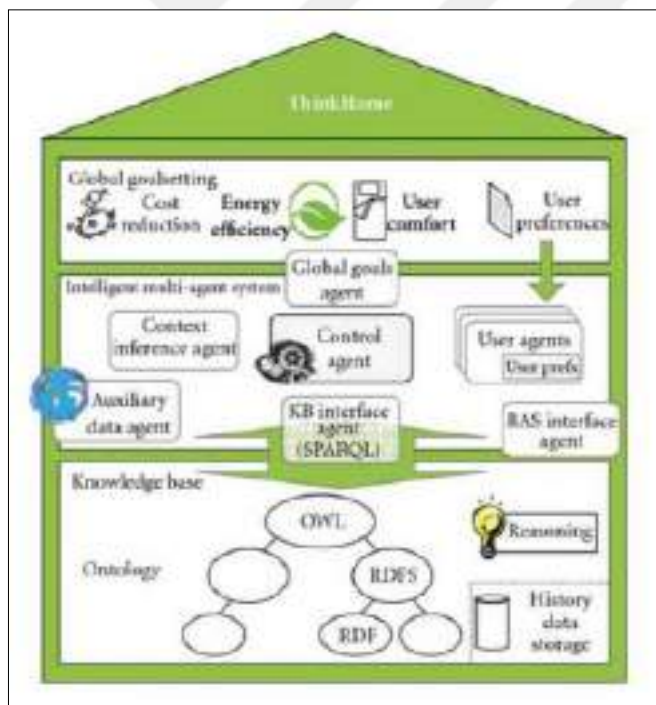


Figure 21: 'ThinkHome' an energy efficient smart home (Reinisch, Kofler, Iglesias, & Kastner, 2011) Design Thinking Diagram

To better explain Symbiotic Data Platforms concept, imagining an example above, and creating in our minds a house that senses our body temperature, 'individually'. Or, lets' imagine a

GPS system that senses that the user is arriving to home in 30 minutes and arranges the house temperature accurately to the users sensation in that recent moment, without any button pressed or any active input, only by sensing how you feel, and what you desire at that moment, with reference of ambient data.

Also, as another case; imagine a baby cradle that is sensing your baby's body temperature, age and metabolic needs, and simultaneously, the environmental factors such as room temperature, humidity, noise and all the other possible factors to involve in the comfort necessities. It would be efficient, if this furniture arranging for the baby, better than the user can do as humans, thanks to an algorithm and proven data, and the baby sleeps with the full joy and benefit of the night sleep? Sensing the baby's needs, and optimizing the comfort level, will prevent the baby to get sick or cold, so often. While arranging the comfort level to personalized optimal levels, this system can also ensure the best energy efficiency, regarding to the users desired energy usage. Even though these projects are present as interactive furniture thank to IoT, still a complete platform that can assist all the information processed in real time, does not exist.

Depends on how the user feel, what they want in that moment. By the help of smart phones, the body can be analyzed and the



smartphone can send the info to your smart home. Also this operating system is intelligent enough to understand if you change your idea to come home, by tracking your signal, without your data input. All is automatic, but not auto-controlled. The system understands the user and responding to what could be desired.

6.2. SYMBIOTIC DATA PLATFORM DESIGN

Design Thinking:

Initial design thinking of Symbiotic Data Platform is explained by a diagram (See Figure 23). In this diagram, two main disciplines, BIM and IoT is blended in the Big Data. By integration of existing data with real-time data, the 'Real-Time Information Modeling' emerges as a concept. This concept could be applied to building scale, or to city scale, by the possibility of the created data network and its' responsiveness.

The platform is a receptive-responsive agent, that collect the data for decision making, and as a result of the feedback, another input is generated. The continuous cycle is defined as

'Dual-Development'⁶¹. In the advanced scale, if the project will be developed further as a city infrastructure, various public themes could be addressed, such as, *energy efficiency & water management, mobility & parking, governance, economy, socio-cultural community networking, security & crime management, emergency situations and service quality management*. The data collection by the interactive prototype as wearable devices, and by the receptive-responsive interface; 'a network of data exchange' is the foresight of the project. As a result, the goal is addressing social, economic and functional aspects, on the way of sustainable urban development. Even though Symbiotic Data Platform is tested by optimizing thermal comfort, the same mentality could be applied to all sensible content. To conclude; the design thinking objective of the Platform is aimed to be an *'Interactive Infrastructure that works Interoperable by its' unique Interface - "4I"'*⁶²

⁶¹ 'Dual-Development' concept is explained in the following chapters.

⁶² The 4I Result is explained in the Conclusion section of this chapter.

SYMBIOTIC DATA PLATFORM

symbiōtcity & symbiōtcity

During the Design Thinking stage, naming the platform as 'Symbiotic Data Platform' and designing the logo by interpreting the continuous Celtic infinity symbol was a metaphor for the receptive-responsive network of the project. See Figure 22, for the final version of Symbiotic Data Platform's Logo.

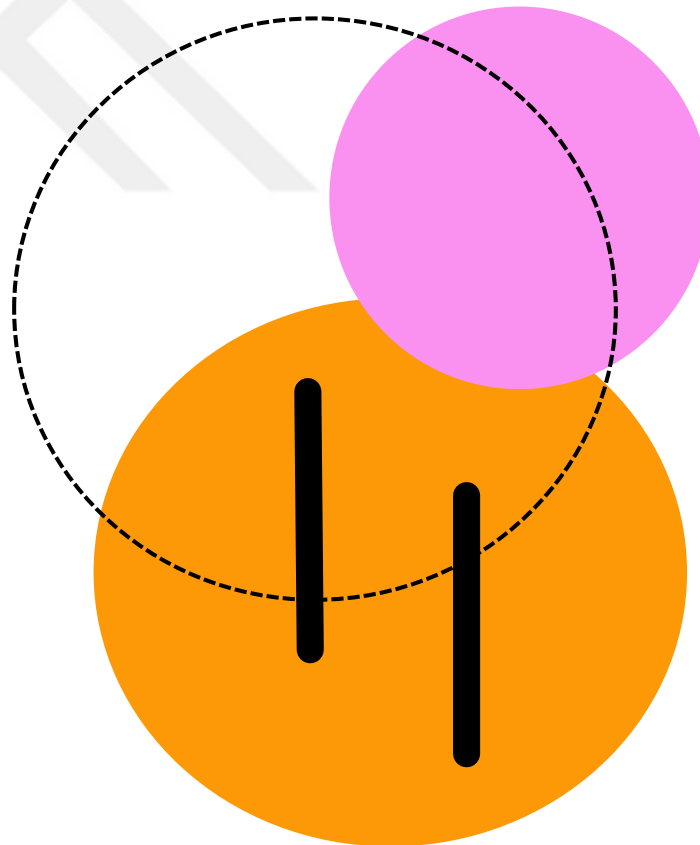


Figure 22: 'Symbiotic Data Platform' Logo, Conceptual



1. Two Main Disciplines



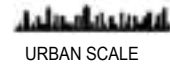
2. Database



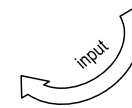
BIG DATA

**"REAL - TIME
INFORMATION
MODELLING"
// RTIM**

3. Dual - Development

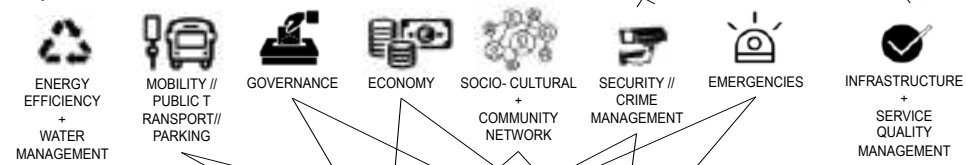


URBAN SCALE



USER

4. Themes



5. Goals



SOCIAL



ORGANIZATIONAL &
FUNCTIONAL

**SUSTAINABLE
URBAN
DEVELOPMENT**

6. Result



INFRASTRUCTURE



INTERFACE



INTERACTION



INTEROPERABILITY

Figure 23: 'Symbiotic Data Platform' Design Thinking Diagram

6.3. SURVEY AND CONTENT VALIDATION

For the validation of the research project, an online survey have been conducted. The survey was send via e-mail and social media platforms to the participants. The surveys objective is understanding the society norms on thermal comfort and energy efficiency. The audience are around the world since the survey is conducted online. There are 475 participants in total, varying between under 18 years; 1.26%; 18-24 years; 5.26%; 25-34 years which is the majority group; 48.42%; 35-44 years 19.58%, 45-54 years; 9.05%; 55-64 years; 13.89% and 65+ years; 2.53%. The participants are 56.42% female and 42.95% male and 0.63% preferred not to answer. The origin country and the residency country are wide-range, around the world. Moreover, the participants answered the question of their profession, which also varies in a diverse range. The country and profession answers are documented in the Appendix of the dissertation.

As an important standpoint, the participants were asked the questions 6 and 7, upon their knowledge on BIM and IoT. Their previous knowledge on BIM is 49.57% positive, 50.43% negative. On the other hand, their previous knowledge on IoT is grater than BIM knowledge, resulted as; 65.12% positive, 34.88% negative.

50.32% of the respondents said that they own their home, while the rest; 49.67 rent and share with others. The majority of the respondents live in 'apartment-flat'; which is 80.60% of total participants. Also, the majority group of the participants have the household between 3-5 which is their family; the majority group is 43.32% of the total participants. The 16.81% live alone; 34.70% shares with their couple or lives with another person; (the rest of the information could be seen in the Appendix chapter).

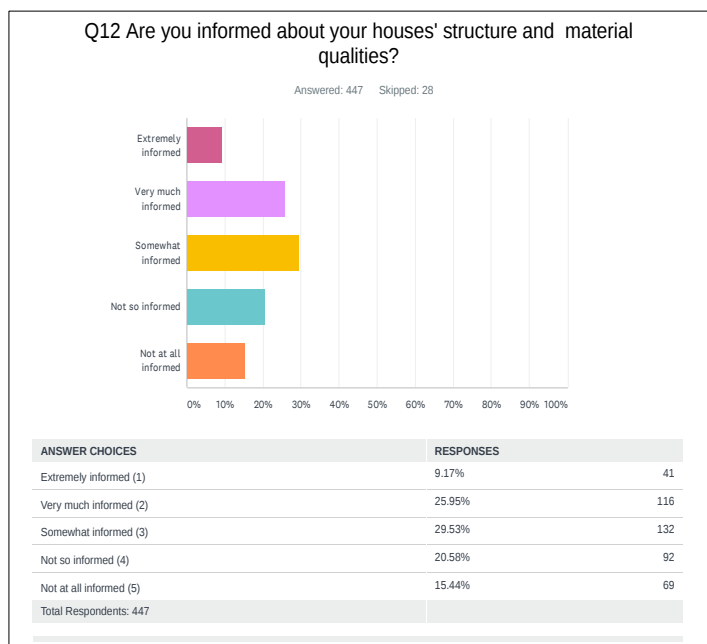
Online Survey - Survey Monkey link:

<https://www.surveymonkey.com/r/YDNQR2Q>



Validation Question 1 (Question 12) :

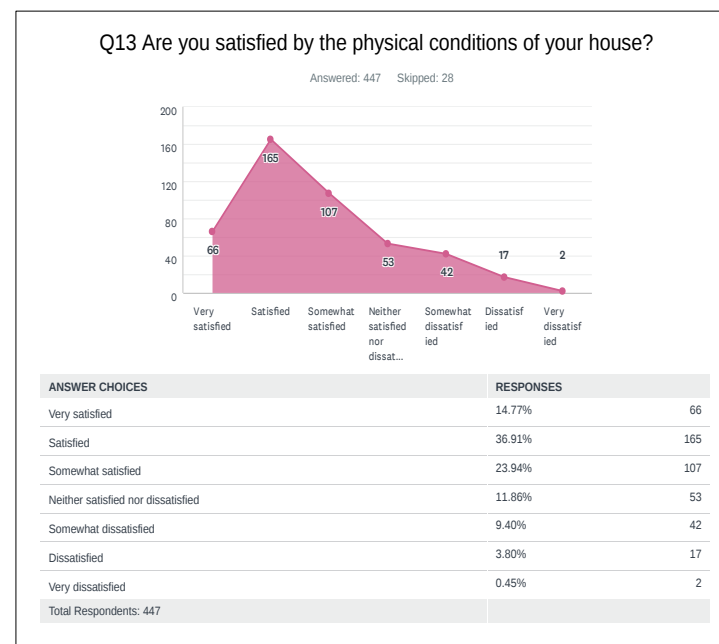
For Question 12: 'Are you informed about your houses' structure and material qualities?'; participants answered as following; Extremely informed 9.17%, Very much informed 25.95%, Somewhat informed 29.53%, Not so informed 20.58%, Not at all informed 15.44%. This information represents the occupants perception and their prior knowledge on the physical quality of the space that they occupy. Eventually, 65.55% of the participants do not have a clear idea of the material, insulation and thermal qualities of their house, which may cause inconvenient acts for thermal comfort and energy efficiency.



Survey Q12 Results

Validation Question 2 (Question 13) :

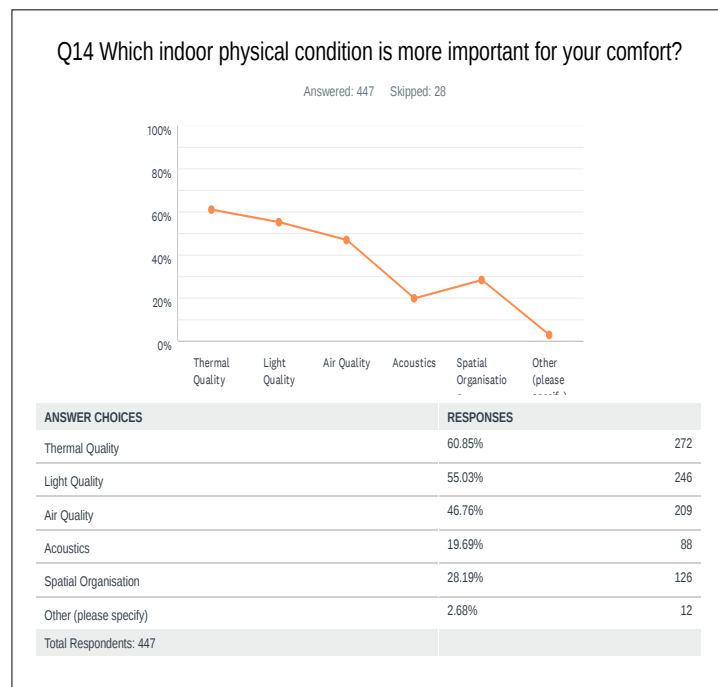
For Question 13: 'Are you satisfied by the physical conditions of your house?', participants react as; 14.77% Very satisfied, 36.91% Satisfied, 23.94% Somewhat satisfied, 11.86% Neither satisfied nor dissatisfied, 9.40% Somewhat dissatisfied, 3.80% Dissatisfied and 0.45% Very dissatisfied. As a result, 49.45% of all, which is almost the half; are not completely satisfied with the physical conditions of their home. This information represents the necessity of the betterment methodologies and also considered as a research gap in the existing literature, that should be examined more profoundly.



Survey Q13 Results

Validation Question 3 (Question 14) :

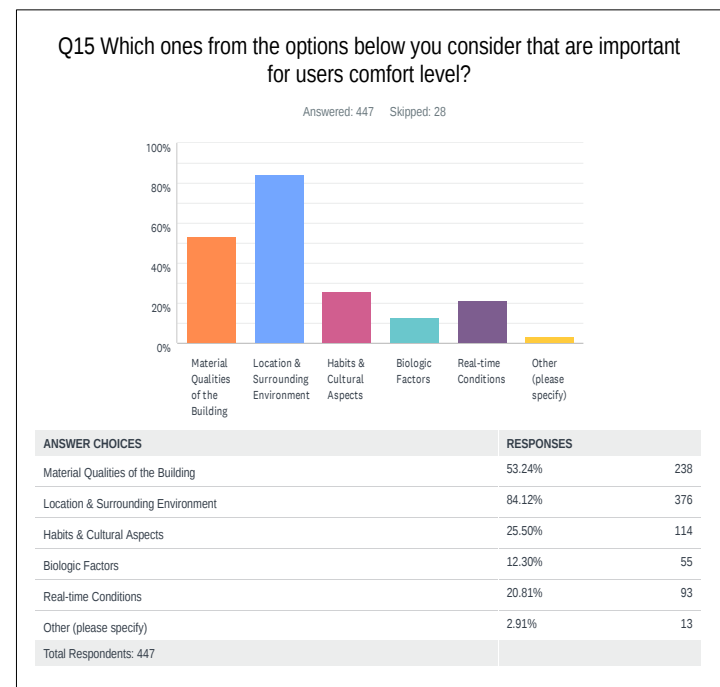
For Question 14: 'Which indoor physical condition is more important for your comfort?', participants answered as majority 'Thermal Quality' with 60.85%, where 'Light Quality' takes 55.03%, 'Air Quality' 46.76%, Acoustics 19.69%, 'Spatial Organization' 28.19% and others 2.68%. For this question, respondents were allowed to choose more than one option, so as not to force them to only one possibility. Even in that case, the thermal conditions are elected as the most essential quality for comfort.



Survey Q14 Results

Validation Question 4 (Question 15) :

For Question 15: 'Which ones from the options below you consider that are important for users comfort level?', they answered, Material Qualities of the Building 53.24%, Location & Surrounding Environment 84.12%, Habits & Cultural Aspects 25.50%, Biologic Factors 12.30%, Real-time Conditions 20.18, and others 2.91%. This information shows the importance of the location and the surrounding environments effect on audiences' perception, as well as the cognition on the importance of material qualities of the building.

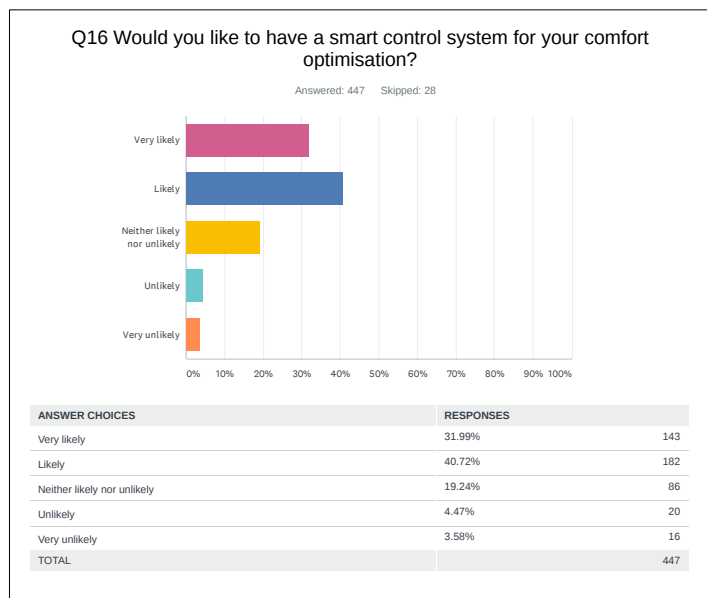


Survey Q15 Results



Validation Questions 5 and 6 (Questions 16-17) :

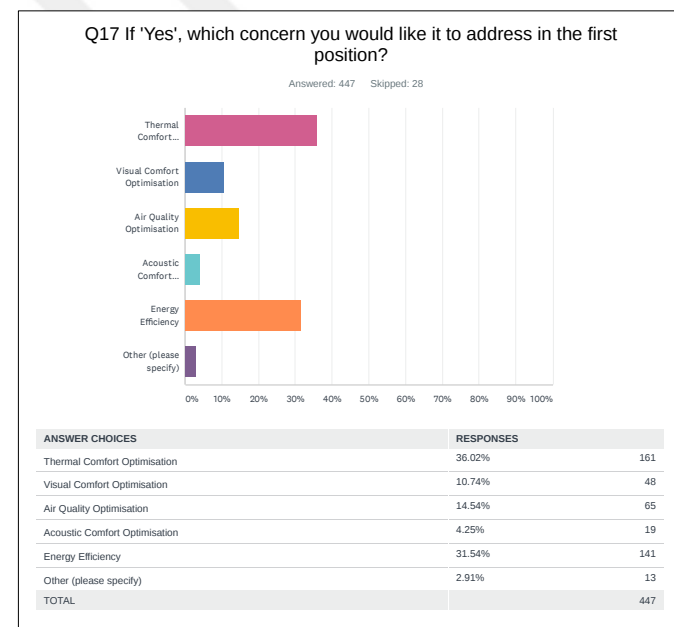
For Questions 16: 'Would you like to have a smart control system for your comfort optimization?' and "Yes', which concern you would like it to address in the first position?', participants answered; 31.99% Very Likely and 40.72%. In total, 72.71% of all answered positive to this question. By extension, 36.02% choose 'Thermal Comfort Optimization' as majority. This fact shows and validates the importance of thermal qualities and thermal comfort in residential spaces once again.



Survey Q16 Results

For Question 17: 'In which cases comfort optimization is more important for you?', majority of participants said Residential with 71.63%. Also the rest elected Work Spaces with 42.79%,

Healthcare with 38.14%, Baby Nursing with 15.81%, Elderly Care 14.65% and Hospitality with 16.52%. For this question, respondents were allowed to choose more than one option, so as not to force them to only one possibility. Even though the previous studies prove that the occupant comfort level show crucial benefits on healthcare environments⁶³, in tis survey, the audience choose residential spaces comfort values for optimization.

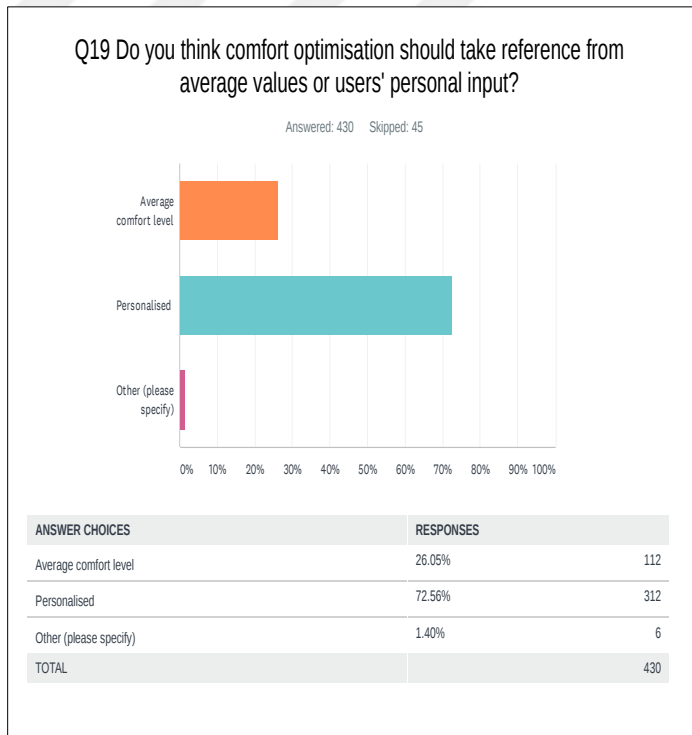


Survey Q17 Results

⁶³ Please see the Symbiotic Data Platform Application Areas section in Symbiotic Data Platform Chaoter.

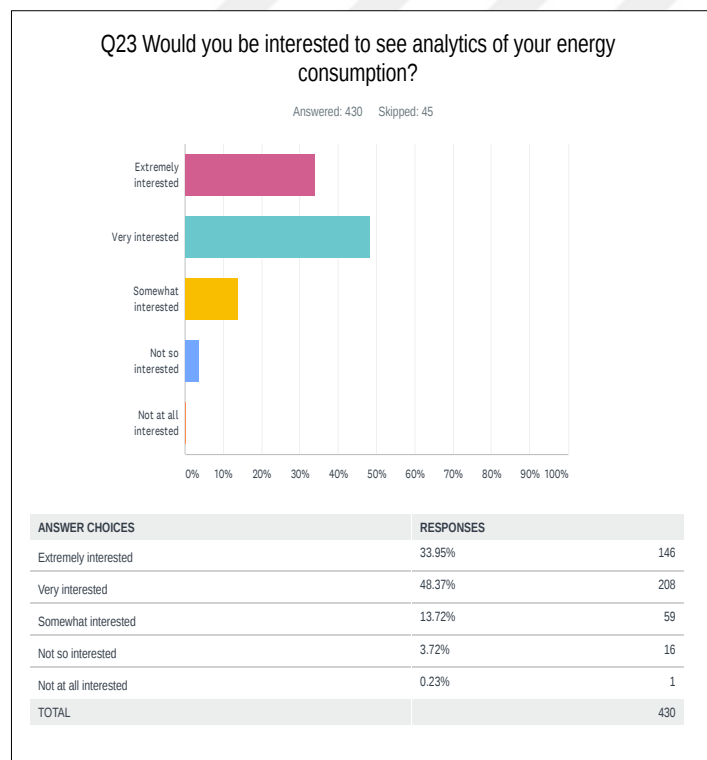
Validation Question 7 (Question 19) :

For Question 19: ‘Do you think comfort optimization should take reference from average values or users' personal input?’, majority of 72.56% answered ‘Personalized’ comfort optimization over Average comfort level references. This information is a validation for the project, on the way of proposing customized and personalized thermal comfort by real-time values and real material information.



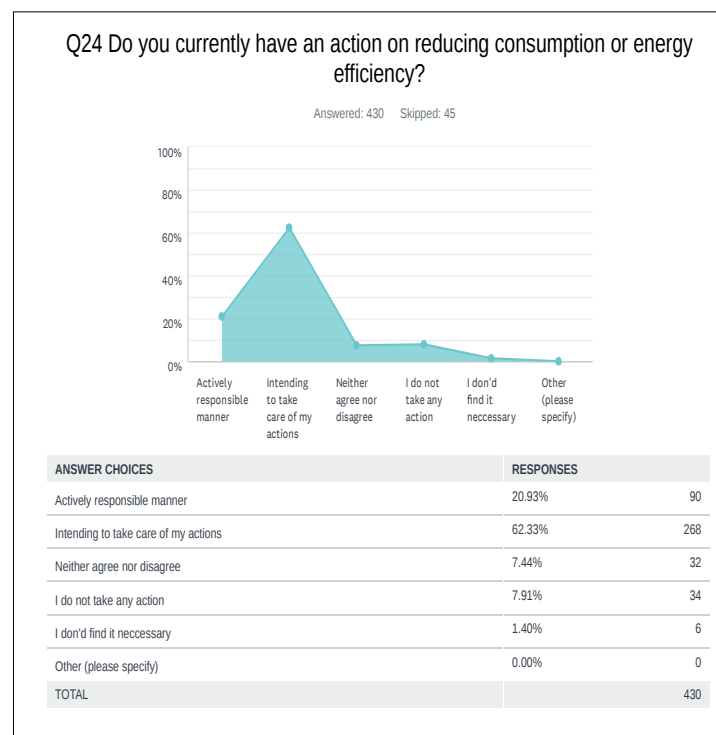


For Question 23: 'Would you be interested to see analytics of your energy consumption?', similarly with the previous question, 33.95% said Extremely interested, 48.37% Very Interested and 13.73% Somewhat Interested. In total 96.05% responded positive where 3.95% responded negative. This fact shows the audiences' cognition on their responsibility energy efficiency, sustainability and climate crisis.



Survey Q23 Results

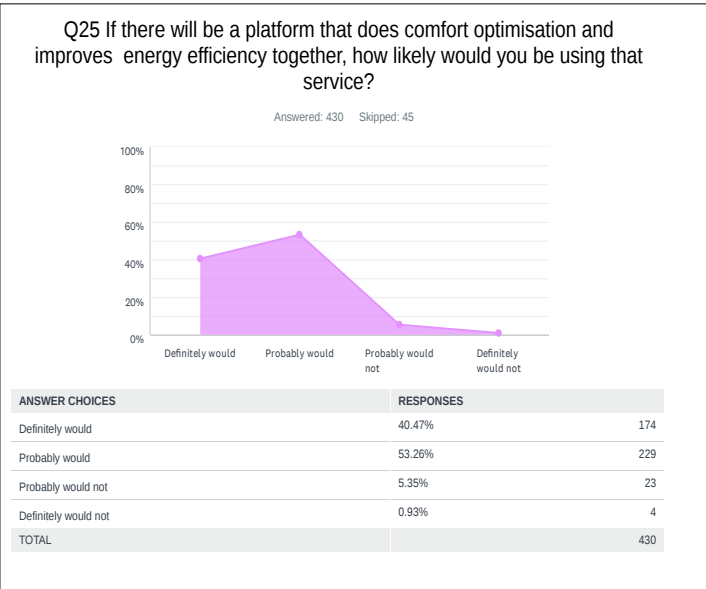
For Question 24: 'Do you currently have an action on reducing consumption or energy efficiency?', majority with 62.33% responded 'Intending to take care of my actions', and 20.93% 'Actively responsible manner'. This fact shows that 83.26% of total respondents have a responsible position on global energy, climate, energy efficiency and sustainability. Since the 21st century generation is a more conscious and deliberative society with responsibility in collective values, their acts are aligned with the current common cognition.



Survey Q24 Results

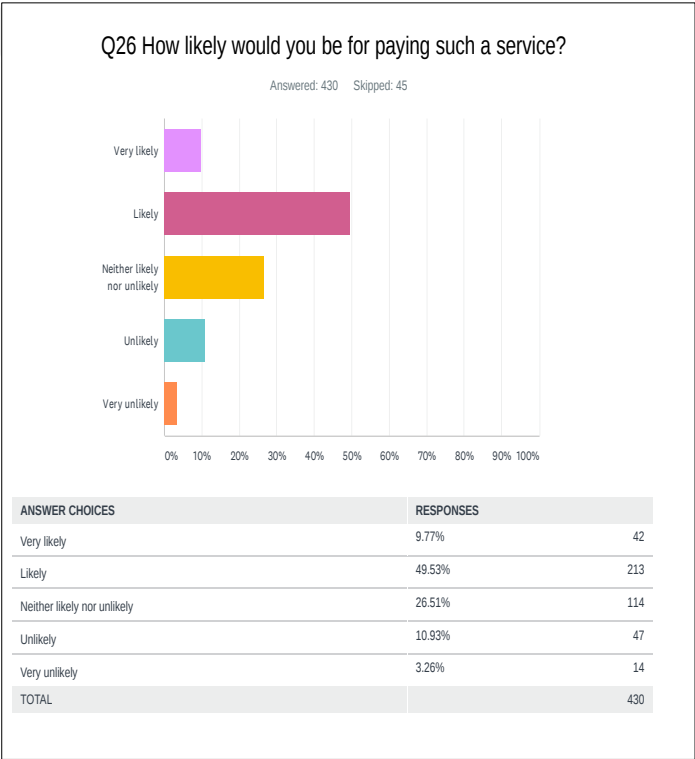
Validation Question 12 and 13 (Question 25 - 26) :

For Question 25: ‘If there will be a platform that does comfort optimization and improves energy efficiency together, how likely would you be using that service?’, 53.26% responded ‘Probably would’ and 40.47% responded ‘Definitely would’. In total, 6.28% of all answers are negative, where the majority is 93.73% positive. This result validates the feasibility and relevance of Symbiotic Data Platform’ project since the audience is willing to receive such service in their daily life. The user is enthusiastic for enabling technologies and applications for comfort optimization and energy efficiency accelerants both in separate technologies and blended means.



Survey Q25 Results

For Question 26: ‘How likely would you be for paying such a service’; majority of 59.3% responded positively and 40.7% responded neutral or negative. This fact shows the validation of applicability of the project to professional industry, regarding to the users will to pay such services as digital applications or as other mediums.



Survey Q26 Results



6.4. IMPLEMENTATION AREAS

Residential Use Application:

Comfort is a term that has been studied by various disciplines, such as physics, psychology and design. Comfort is studied by those disciplines in terms of four factors: thermal comfort, acoustical quality, air quality, and visual quality. Occupant behavior and desire is not easy to estimate and generalize, so that, comfort level is a term that is relatively hard to measure. Even though it's hard, quantitative and qualitative data collection generate norms to study the context. *"In his survey of user satisfaction in buildings with passive solar features, Griffiths in 1990 found that having the 'right temperature' was one of the things people considered most important about a building"* (Nicol, Humphreys, & Roaf, 2012).

Domestic thermal comfort was defined by Heijs and Stringer by specific that implies the place of residence. The terms of comfort optimization in domestic context are as following; perceptual, interactive, facilitative, and personalization comfort (Heijs & Stringer, 1987). Those 4 terms highlight the importance of real-time data, and the responsiveness of the optimization in relation with being perceptual and interactive. And, being easy to use, automatic and accurate in relation with being facilitative and

personalized. Also following the 4 terms on domestic thermal comfort optimization aggrandize the sense of belonging, attachment to the residential place and self identification on private territory. As a result of thermal comfort optimization, the user feel the sense of ownership and consequently, feel more attached, feel more responsible and conscious of the space and surrounding environment.

Into the bargain, taking into account that residential buildings are occupied by multiple users such as couples, families or friends that should live together harmoniously, even though all have different tastes, needs and desires as thermal context. In residential use or in public use buildings, the comfort level has to be studied by optimized standards due to multiple users, socio-cultural habits and biologic differences. Yet, especially in residential use, comfort optimization might conflict with standards. Because of the occupants variety of expectations and desires, the qualitative comfort parameters can be surprisingly diverse. Since residential space is a small scale private form, the desire of the user has to be satisfied not only by standards but also by personalized parameters.

As a matter of fact, if thermal comfort is under consideration, one can desire a warm bedroom, and the other conflicts and want a chill sleeping environment. Or as another case, even the

same person could desire different ambient quality depending on psychology mood, day-night, and physiologic mood of the body of being sick or healthy. Due to the facts stated, personalized optimization decision making has to be real-time, as proposed in the Symbiotic Data Platform project.

At Symbiotic Data Platform project, while focusing on the residential use, the case of considering multiple users is a fact. If the house is occupied by more than one user, the platform has to work to serve the satisfaction of each user. The case of individuals private space /room comfort optimization is personalized, and that data is inserted as an input for the general analysis of the building. Every modification and optimization done by the platform effects the other users depends on the change in thermal condition, the platform should be maintaining the balance between rooms and general ambient by its decision making algorithm.

But if multiple users are in the same room such as living room or dining room, an average of desired temperature is taken into account. On this case, a standardization should be done to create the optimal comfort level in real time, for the specific users. Since all users are using the same server, and same control platform so the data is shared and interacted. Additionally, the development of project could focus on the

machine to machine interaction by connecting the heating and cooling devices (all HVAC network), for a more accurate and well connected platform.

On the other hand, regarding the importance of focusing on the occupation phase of the building rather than the design and construction stages of BIM when considering comfort optimization, is the case of eliminating possible estimation mistakes. Also, taking into account that comfort optimization and energy-efficiency are two factors that are integral. Both has an effect on the other so that, studying those terms in relation with each other is essential. Moreover the built reality might be different than the designed model or constructed building. *“Thermal irregularities and reduced infiltration are not tangible attributes that can be visually observed when buildings are completed. It is difficult for homeowners or governing bodies to determine if the thermal requirements in the built stage have been achieved. In most cases, the measured energy consumption is taken as the determinant factor in verifying the performance of the building envelope, which can lead to bias results”* (Munsami, Prasad, & Ding, 2017). As an tangible example by Munsami, Prasad & Ding, focusing on two homes, A and B, explains the results of the relation between two terms. They also wrote; *“For example, two similar houses, House A with poor thermal envelope may use less energy due to*



occupant behavior and of the lower socio economic group, concerned with increasing energy costs, compared to House B, which is a better thermal performing envelope of a higher socio economic group with the increased use of space heating and cooling. Based on the energy consumption results between House A and House B, it may indicate that House A has better thermal performance” (Munsami, Prasad, & Ding, 2017).

On this research, Symbiotic Data Platform currently works correctly in the single user scenario. The prototype is designed and tested only for a single user, to simplify the results and to prove that the proposal is possible to be developed.⁶⁴ However, the platform can be developed by modifying the code for calculating multiple users’ average body temperature. This calculated value would define the same value for the single user occupying the space alone. Corresponding the body temperature, when multiple users occupy the same space, the algorithm can calculate the average of each users body temperature to generate the input as one.

Health Care and Lodging Application //

Single Patient Hospital Rooms, Elderly Care in Retirement Residence, Child Nursing in Residential Use, Hotel Rooms

Focusing on the ‘Single User’ scenario, apart from the residential application area, public buildings could also take benefit from the Symbiotic Data Platform. The public buildings that has private use spaces, such as hospital rooms, elderly care residents and hotel rooms are addressed on this section.

First of all, taking reference from the existing literature on the importance of thermal quality and thermal comfort optimization for the patients and elderly residents of the care centers have a crucial effect on augmenting the healing rates. The healthcare literature defines comfort by two dimensions: “*The first dimension consists of three states: ‘relief’, ‘ease’, and ‘transcendence’, which have to be experienced by a patient to be comfortable. Relief is the feeling of having had specific needs met, ease is the state of calm and contentment, and transcendence refers to the state where the patient goes beyond problems or pain. The second dimension of comfort deals with the context where comfort happens. The context can be physical – relating to bodily feelings –, it can be psychospiritual – relating to the inner self-, it can be social – relating to family or cultural relationships, or it can be environmental – dealing with light,*

⁶⁴ See chapter ‘Final Prototype: PROTOTYPE VII’ for the results of the prototyping and the tests outcomes.

noise, temperatures, sensations” (Kolcaba, 1994). Symbiotic Data Platform approaches the healthcare environment firstly by the second dimension, which is optimizing the thermal condition by fulfilling the users personal / specific desire. As a consequence of customized thermal comfort, the first dimension would be effected positively as direct correlation with physical comfort increase.

Moreover, in elderly care residences, using sensor systems for both comfort optimization and for health & safety concerns is an efficient and beneficial solution. “Smart homes for eldercare applications are growing at a very fast phase in all parts of the world” (Kainka, 2003). Tracking human activity, or analyzing human behavior of energy usage could give significant data for quantitative comfort optimization methods.

Regarding to the health care thermal comfort optimization; recent studies shows that the desired comfort level catalyze the speed and efficiency of the healing. To improve hospital HVAC systems by concerning energy use, those following norms are listed to be followed by American Society for Healthcare Engineering magazine;

1. An effective optimization solution
2. Protection for operational requirements
3. Full-system testing
4. Robust measurement and verification

Applying those norms to Symbiotic Data Platforms’ design thinking; fulfills the requirements of healthcare standards. By an effective optimization solution; “The system should provide thorough measurement of sensor data and energy use; take a holistic approach to ensure the entire system is optimized rather than just individual components; and deliver continuous and automatic feedback to the HVAC system.”, by protection of operational requirement and full-system testing, “It is critical that the team install and set up all parts of the optimization project properly so that the whole system works as intended.” and by the measurement and verification, “the optimization product should provide ongoing M&V to ensure that the system is meeting energy savings targets” (Peltier, 2019).

Figure 24 shows the impact of external surrounding factors that includes the thermal comfort quality on healing spaces.



Figure 24: Optimal Healing Environments framework (Sakallaris, MacAllister, Voss, Smith, & Jonas, 2015)

In the same research, apart from the internal, interpersonal and behavioral environment, the external environment that is the physical space has a big impact of the healing states. It is stated that, *“healing spaces incorporate evidence-based design and healing principles to optimize and improve the quality of care, outcomes, and experiences of patients and staff. Healing spaces use physical design to enhance the individual’s innate healing potential”* (Sakallaris, MacAllister, Voss, Smith, & Jonas, 2015). Regarding ecological sustainability of the healing space comfort optimization, it is stated that *“organizations and individuals can foster ecological sustainability by reducing their footprint and supporting the health of the planet. The chemical impact and energy use of their operations is considered. Products or*

practices that are resource-intensive can be replaced with more ecologically friendly, less harmful, and cruelty-free alternatives” (Sakallaris, MacAllister, Voss, Smith, & Jonas, 2015).

Importance of improving thermal comfort in hotels is also for optimizing thermal comfort; yet, more importantly; for energy saving and sustainability concerns. Especially in big scaled lodging complexes, the massive amount of energy consumption is a big global problem. Adjusting the thermal quality according to the guests desire consume a great amount of redundant energy. To apply Symbiotic Data Platform as a receptive-responsive network for the hotels could decrease the rate spent energy. Meanwhile arranging the desired comfort levels in relation with the real-time ambient qualities and material thermal

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qualifications, the guests can enjoy the hotel facilities without spending the global resources unnecessarily.

By using Symbiotic Data Platform as a building infrastructure for hotels, hospitals, elderly care residences; a holistic comfort optimization in private spaces could be achieved. In example; improving measurement and verification process on the way of thermal comfort in relation to energy efficiency of each room, would create the database for the hospital. Every room would effect the surrounding surfaces and spaces, while catalyzing the thermal quality improvement and enhancing the energy efficiency of whole building. Moreover, since the platform is a receptive-responsive tool, if it is applied to the public building which has private spaces with single users, all data that is gathered from each private space effects the public spaces comfort quality. The platforms database could work collaboratively to arrange the holistic energy saving by maintaining the buildings general thermal comfort standards.

Flowchart Explanation:

The Figure 25 and Figure 26 explains the flowchart of the Symbiotic Data Platform operation model. Apart from the general design thinking of the project, the platform has a simple equation of data flow.

Variables of the platform are, users (occupant) body temperature in real-time, the thermal coefficients/material information that are supplied from the existing BIM database, the environment's thermal condition, which includes; outside weather information and indoor ambient temperature in real-time.

The interaction starts simply by the users' touch to the data collection device (Prototype). Following the physical interaction, the global data from GIS⁶⁵, (such as; geo-location and open weather info) and the specific case data (such as; interior temperature, user location and body temperature) are collected, and send to the algorithm. Meanwhile, the algorithm takes benefit of already existing BIM files to extract construction details and information, to a new algorithm that will blend real-time weather/thermal information and also, the users' body temperature data by sensor interaction for accurate thermal

comfort adjustment method that corresponds the users desire. The custom-made algorithm of the platform aims to interlace these variables, to create a real-time time energy analysis, which thereafter perform betterment in thermal comfort and energy savings by making the physical adjustments in the HVAC System of the specified space (Birgonul & Cocho-Bermejo, 2018).

⁶⁵ Global Information System



6.6. DUAL DEVELOPMENT

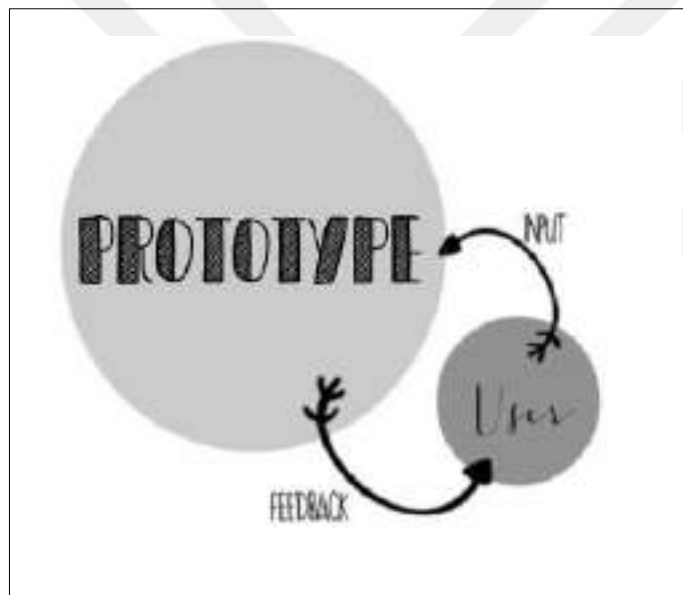


Figure 27: Dual - Development

Once Negroponte wrote; *“This discussion is not about machines that necessarily can do architecture; it is a preface to machines that can learn about architecture and perhaps even learn about learning about architecture. Let us call such machines architecture machines; the partnership of an architect with such a device is a dialogue between two intelligent systems- the man and the machine- which are capable of producing an evolutionary system”* (Negroponte, 1969).

The dialogue between the man and the machine, had been put further until today by all the smart and responsive technologies. And what is more, in current day, the technology allows the man and machine communicate in nearly every field, to address various concerns of environment of mankind.

‘Symbiotic Data Platform’ project gets its function references from last industrial revolution. Thanks to The Fourth Industrial Revolution, contemporary world that is surrounded by efficient and sustainable technologies that have uncountable potentials to create better futures. The technology is developing faster than ever and tools and devices are more accessible for research and development. As a result, the interdisciplinary projects such as ‘Symbiotic Data Platform’ are on demand, thus new technologies that are built upon existing tools are enhancing the productivity of quotidian life and proposing better results in energy efficiency concerns and advancing sustainability. Integration of the two disciplines will proceed the data in the big-data’s open source database that will be the main source of inputs. By the ‘Symbiotic Data Platform’ interface, the user will be passively uploading the data on the automated system by the data capture via embedded sensors. This real-time data pool will guide the interface to take the necessary information to process by mixing with the previously facilitated BIM database.

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As Symbiotic Data Platform is designed as a receptive and responsive tool, by its nature it creates the exchange of data and feedback between the parties. The parties are; the human, the physical space & physical reality, sensors & machines, database and the digital interface. As a matter of fact, the platform objective of comfort optimization together with upgrading energy-efficiency, by using the existing technology. Thereby, linking the user and the digital tools in the cyber network ensues the human-to-computer interaction for an automated optimization system.

Divergently with other smart systems for comfort optimization and/or energy-efficiency, Symbiotic Data Platform generates an ongoing real-time cycle that is pursued by a continuous data and feedback exchange. The modification done by human command to the machine does not end there the machine does its function. In Symbiotic Data Platforms working cycle, the existing physical reality sets the environmental condition, which the user exists and reacts by their physiologic and psychological subsistence. Interaction by the platform generates a cyber connection between the machine to sense and react the human's desire by the designed algorithm, which takes the database from the real-existing factors. The modified reality generates a new data, which is captured automatically by the sensor, (that data could be a passive data from a home

appliances, or temperature of the atmosphere, also it can be an active 'update' that the user generates.) All the data get captured and stimulates the database of the platform. When a new data is received as an input, then the system acts as a gear to feedback the secondary – passive data. As a result, the decision-making by the machine manipulates the physical condition, regarding to the users desire. This modification creates another physical reality, and the user will accept or reject, demand a change, and give another feedback to the system, as the cycles continues.

This continuous-collaborative workflow formulates the interactive relation between the two actuators of the system that address different goals, in an infinite circle of benefits; that could be defined as '**Dual Development**'. The platform creates this ongoing cycle by the betterment of physical factors in the first position, and sustainability outcomes as the end result.

Following, '*the new architectural design understanding*', that is Form + Function + Interaction, 'Dual-Development' offers the optimal environmental quality, by the sustainability concerns. Optimizing the physical condition by addressing energy-efficiency, results as creation of a 'sensitive' approach. That approach empowers the user by their own data, by evoking economic savings, joining the global sustainable movement, and



enhancing efficiency. As much as the benefits and positive outcomes are observed, the user is more encouraged to use the 'sustainable' platforms addressing the global concerns. As a consequence, 'Dual-Development' improves the conscience of the 'smart user' by proving the benefits of sustainability.

First outcome is the personalized physical condition optimization, with real factors and real-time data. By the secondary outcome is the 'sensitive' outcome that follows the physical modification. That 'sensitive' outcome empowers the user by their own data, on the way of facilitating a desired / livable ambient while establishing the best energy consumption for the specific scenario. The two outcomes, physical & sensitive; also creates a 'Dual-Development' for users well-being. It is a win-win theory regarding to have the data from the user, to serve the users own benefits, in a bigger – extended scale. With other words, the individual data will be processed to screen the users desire & action. On the other hand, by BIM system, also the specific local data will be analyzed and proceed by the means of responsive architecture, also it will be monitored in third party softwares and mobile apps. To be more concrete, the people, on behalf of upgrading life quality, will choose to use the interoperable platform of BIM and real-time data of the specific user & surrounding environment, since it is beneficial by many aspects.

Symbiotic Data Platform could form the basis of a new infrastructure by its prototypes' interface. Moreover, on a greater scale, if applied as a digital urban infrastructure; the platform could address a variety of themes different than thermal comfort and energy efficiency with adequate sensor applications. The possibility of other themes could be; water management, mobility, public transport, traffic, public parking, governance, economy, social and cultural issues and community network, security, crime management, health & safety, emergencies and infrastructure & service quality management. The development of the project by a greater scale, with multiply the Dual-Development effect from the private gains to public benefit, via data-sharing and collaboration, as well as a holistic energy – efficiency movement between citizens, which guides the Sustainable Urban Development, that the collective approach would guide the objective of upgrading the smart city through a responsive city⁶⁶.

⁶⁶ Smart City and Responsive City contexts are expained in the last chapter 'Further Research'.

CASE STUDY TESTING

MODELING AND

DATA COLLECTION

7



7. MODELING AND DATA COLLECTION

To be able to test the hypothesis of Symbiotic Data Platform, two BIM cases are modeled. Digital representation of those two cases provides the thermal value database for the prototypes functioning.

Terzidis⁶⁷ wrote about the importance of representation of data as following;

“Representation of the unknown is based on alterations of techniques used in the representation of the known. By observing structures and processes that hold together the real world, one can alter or extrapolate them obtaining unknown or unpredictable results. Simulation is the process of using or operating a model (often a mathematical model encoded in a computer program) to learn about the behavior of the reality

being modeled. But simulations can be performed to learn about the unpredictable behavior of a reality being modeled, such as molecular or weather phenomena. Similarly, simulations can be performed to visualize imaginary scenarios, such as art and movies. These simulations allow us to see beyond reality and to experiment with imaginary structures and processes” (Terzidis, 2015).

Relatively, representation and simulation of the reality is extremely important on socio-economic factors and environmental concerns when considering buildings life-cycle. To achieve a successful and responsible design, the representation of data has to be made accurately and the simulation has to reflect the reality as detailed as possible for better estimations. By Symbiotic Data Platform, the representation of real-time data is highlighted, moreover the represented data is used in the platform for not only visualization & simulation, but also to be used as a decision making criteria for physical conditions' modifications.

Exporting the Thermal Values from BIM (Revit Software):

The thermal values such as R-Values, U-Values, thickness, density, heat transfer coefficient, thermal mass etc. is done by

⁶⁷ Kostas Terzidis is an associate professor at Harvard University's Graduate School of Design. He is an educator, designer, theorist, architect, and computer scientist.

the data extraction from the BIM Model. Those values are automatically calculated from the general material database, depending to the defined values of materials. The values could be exported as a list or as a chart by the material itself and also by the layers such as walls, floors, ceilings, doors, ceilings.

Thanks to the ‘Edit Assembly’ toolbox, the layers could be viewed and edited regarding to the exact material on the construction. So that, the BIM softwares could calculate the thermal values of each and every element on the building specifically.

On [Figure 28](#), the chart by by Autodesk, thermal properties definitions are listed down to facilitate information for Revit software. In ‘Edit Assembly’ and ‘Material Browser’ toolboxes are used to edit, see and modify the material qualities.

The energy analysis is done depending on the models location and material data variables. Revit has the energy and performance analysis feature. For early design decisions and comparative analysis this tool is useful. For occupation stage of BIM, those data could be used for post-occupancy evaluation and comparison. That’s why accuracy and modeling with exact materials are crucially important. The modification toolboxes are developed to give exact calculations for each material and each

layer. Also its stated by Autodesk that for all materials except glass, energy analysis uses only the thermal properties thickness, thermal conductivity, specific heat and density from the Revit model.

Thermal property	Where is this property defined?
Thickness	Defined for each layer in the Edit Assembly dialog for the element type
Thermal Conductivity	Defined on the Thermal tab of the Material Browser for the selected material
Specific Heat	Defined on the Thermal tab of the Material Browser for the selected material
Density	Defined on the Thermal tab of the Material Browser for the selected material

[Figure 28: Revit – Thermal Values Checklist \(Autodesk, 2015\)](#)

Exporting the data by Schedules, are done by following the steps stated below by Autodesk; “*Send schedule data to a delimited text file that spreadsheet programs can open and manipulate. If you add a schedule to a sheet, you can export it as a CAD format. To export a schedule:*

1. Open a schedule view.



2. Click *File* tab > *Export* > *Reports* > *Schedule*.
3. In the *Export Schedule* dialog, specify a name and directory for the schedule, and click *Save*.
 - 3.2. The *Export Schedule* dialog appears.
4. Under *Schedule appearance*, select export options:
 - 4.2. *Export column headers*: specifies whether Revit column headers export.
 - 4.3. *One row*: only the bottom column header exports.
 - 4.4. *Multiple rows, as formatted*: all column headers export, including grouped column header cells.
 - 4.5. *Export group headers, footers, and blank lines*: specifies whether sort group header rows, footers, and blank lines export.
5. Under *Output options*, specify how you want to display the data in the output file:
 - 5.2. *Field delimiter*: specifies whether fields in the output file are separated by tabs, spaces, commas, or semi-colons.
 - 5.3. *Text qualifier*: specifies whether the text in each field of the output file should be enclosed by a single or double quote, or no annotation.
6. Click *OK*.

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Revit saves the file as delimited text, a format that can be opened in spreadsheet programs, such as Microsoft® Excel.”
(Autodesk, 2019).

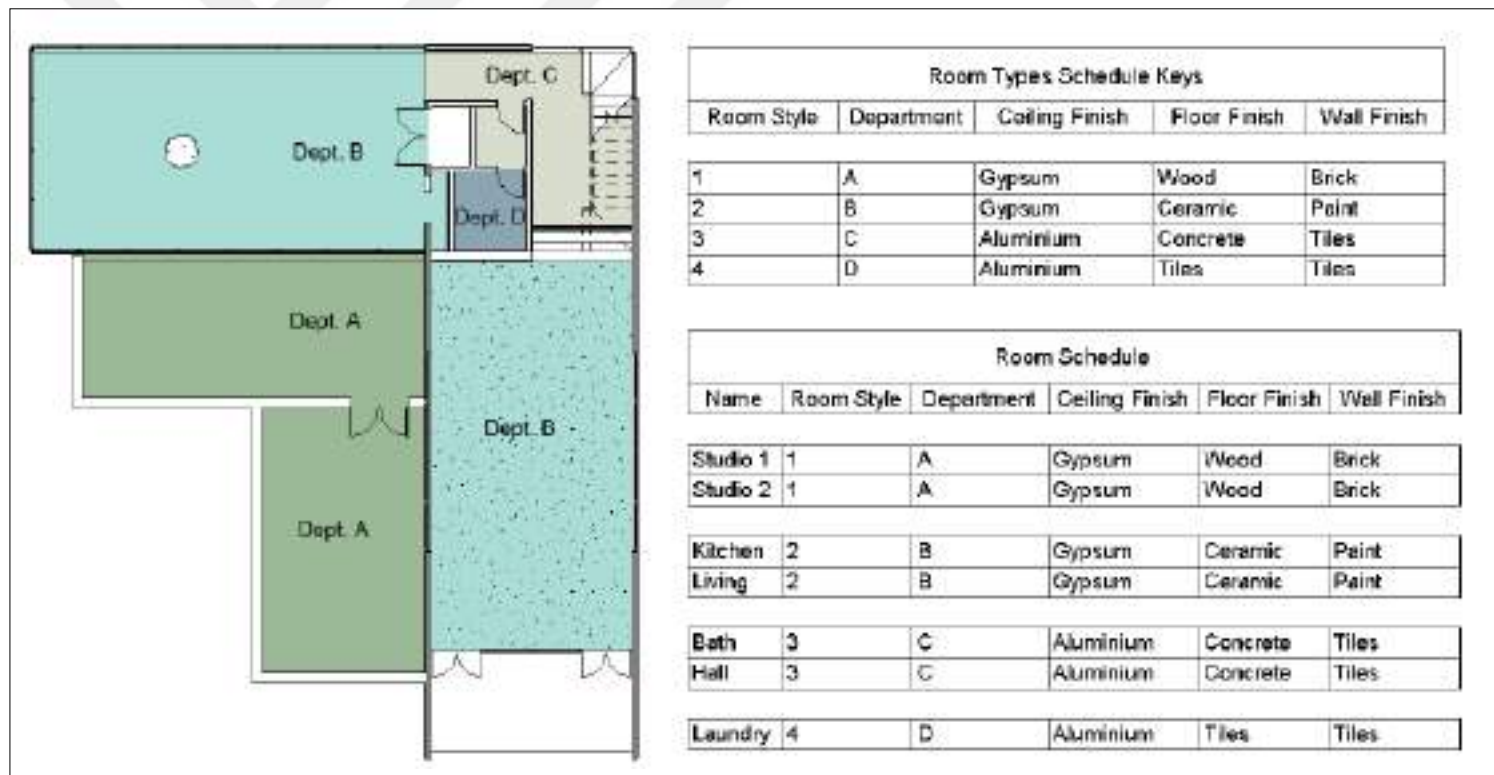


Figure 29: Key Schedules Example Visual
(Molinos, 2016)



7.1. MODEL 1

Residential Building (Rambla del Poblenou, 70, Barcelona)

Without Insulation:

The first case is a residential building in Barcelona. The building is built on 1910, situated in the old industrial part of Barcelona, Poblenou. The buildings' location is a 'Rambla', that directs the axis from mountain to the sea. This specific building is 5 minutes by walk to the Poblenou beach, which creates lot of humidity. The orientation to sun brings the daily sunlight during the afternoon. The information modeling is made as accurate as the municipality registration and the real situation. The first case is a building that has no insulation. Moreover, since it is a considerably old building, the structure is ordinary masonry building type. The building does not have a central cooling or heating system. The case model is the residential apartment situated on the first floor. The apartment is refurbished while conserving the original structure and the original materials including doors, windows and floor tiles. Referring to not having any insulation in rough construction, the openings are limited, yet the original windows are single glass – wooden framed balcony doors. The building has two facades, but the case study

apartment just one façade, facing the entrance of the building, from the street.

After modeling, the information is extracted from the model by using the Schedules of Revit. Those schedules lists the material types, dimensions, tags, thermal values, location and function. Those data are exported for further use in the analysis and to be imported in the algorithm for mechanical decision-making.

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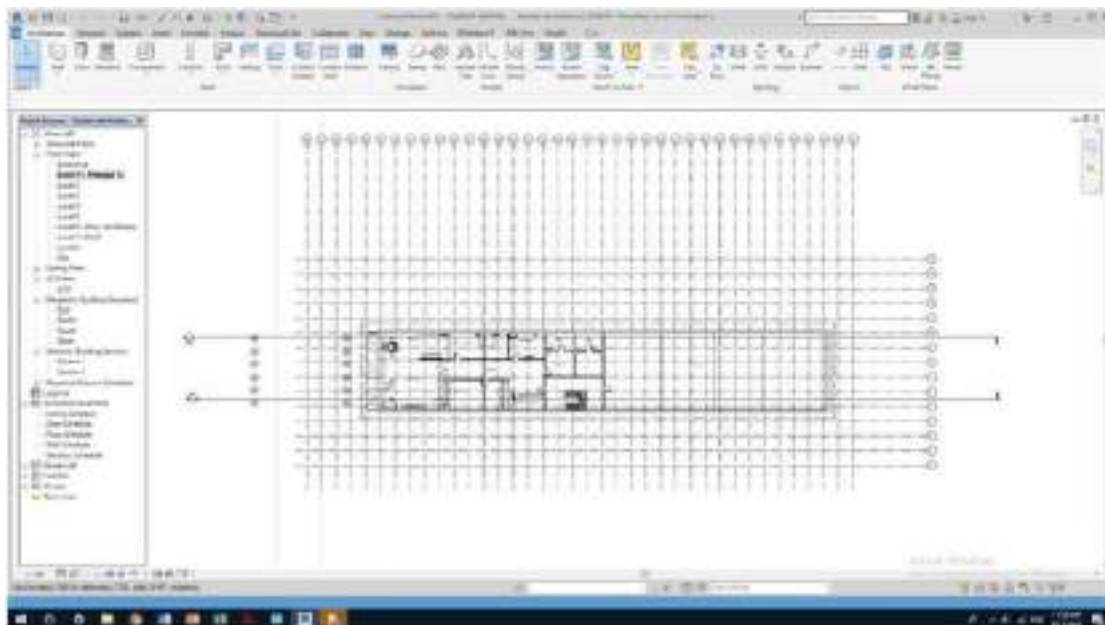
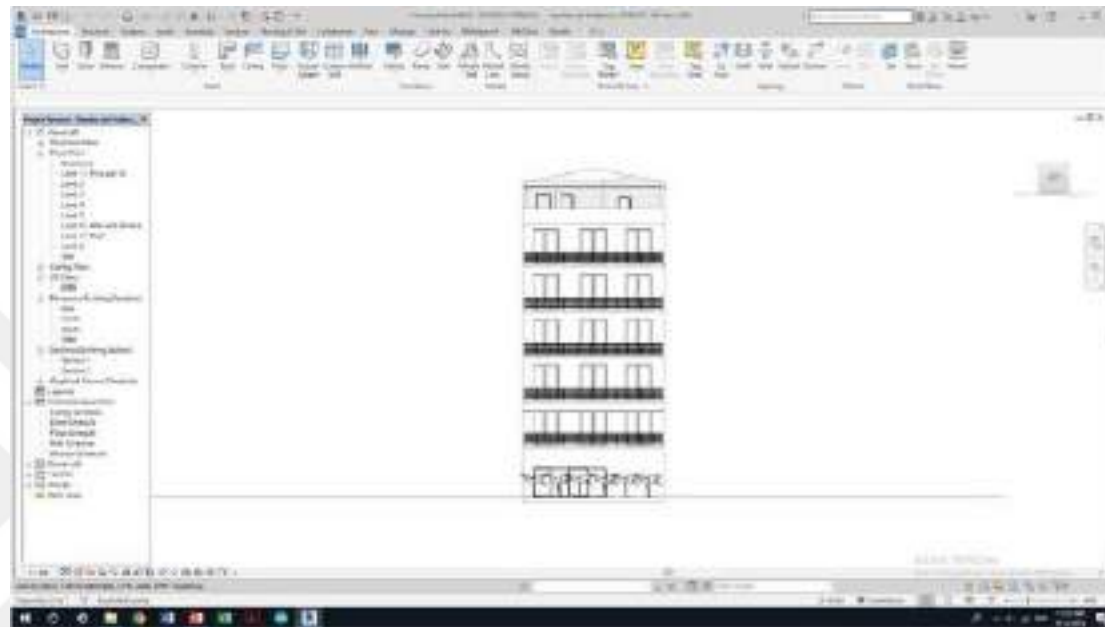


Figure 30: BIM Revit Model 1 // 3
Bedroom Flat – No Insulation

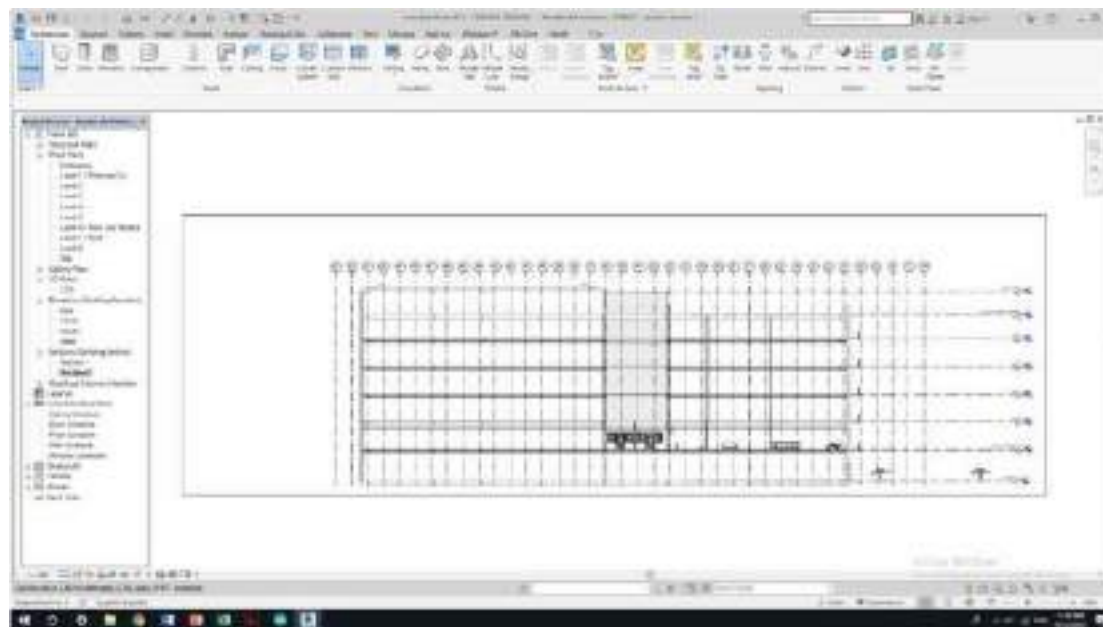
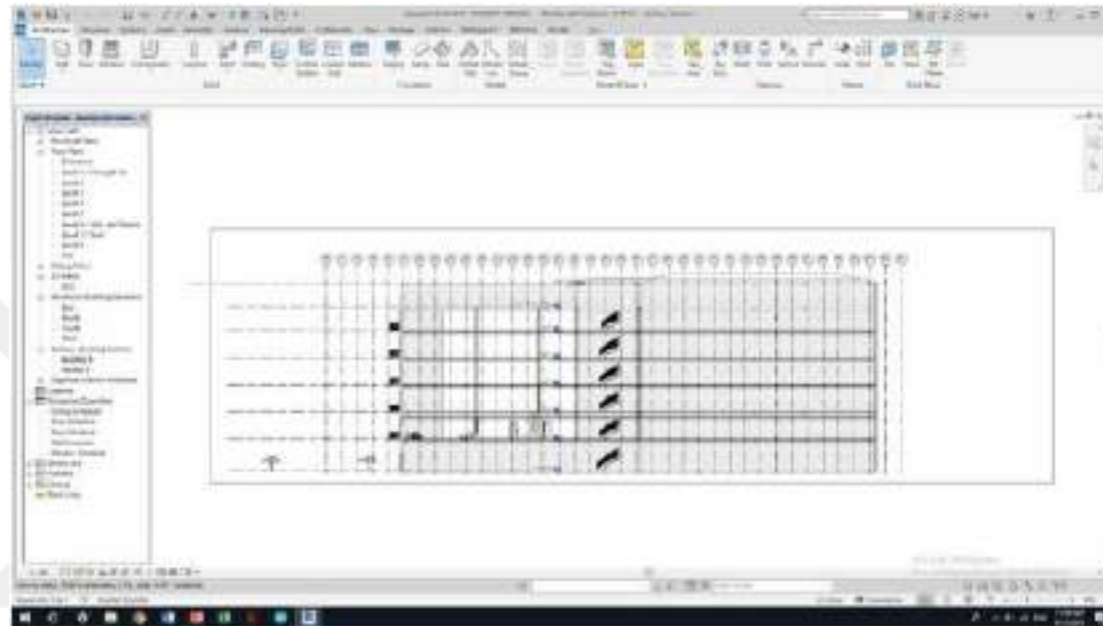


Figure 31: BIM Revit Model 1 // 3 Bedroom
Flat – No Insulation

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Figure 32: BIM Revit Model 1 // Plan

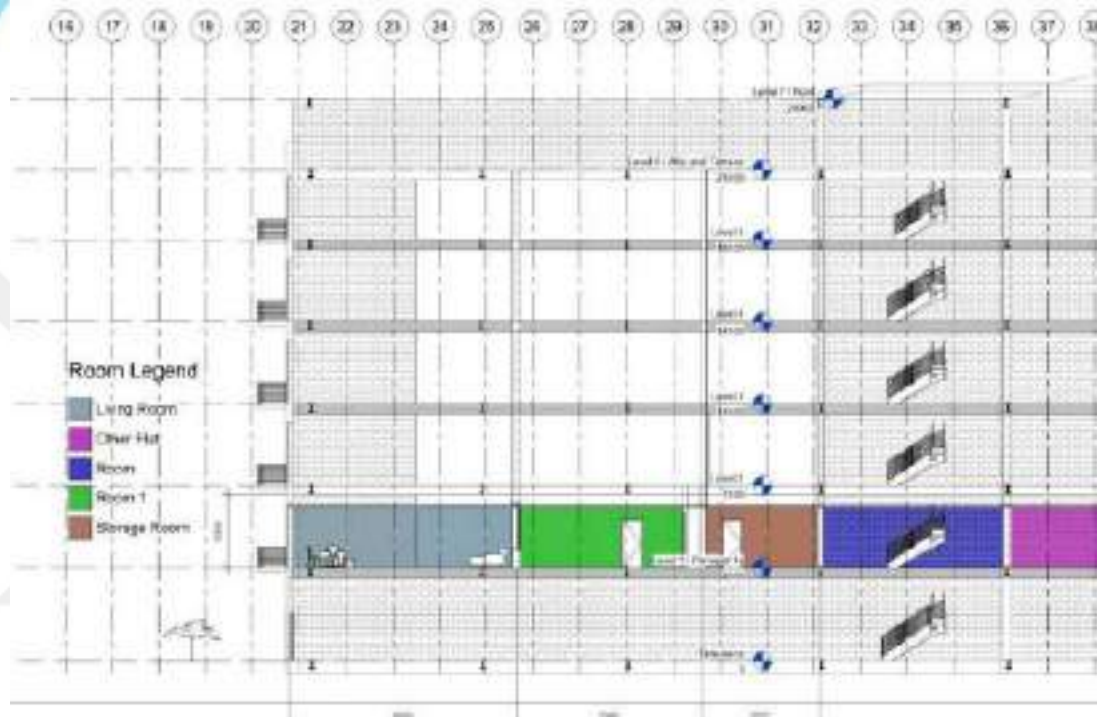


Figure 33: BIM Revit
Model 1 // Section 1

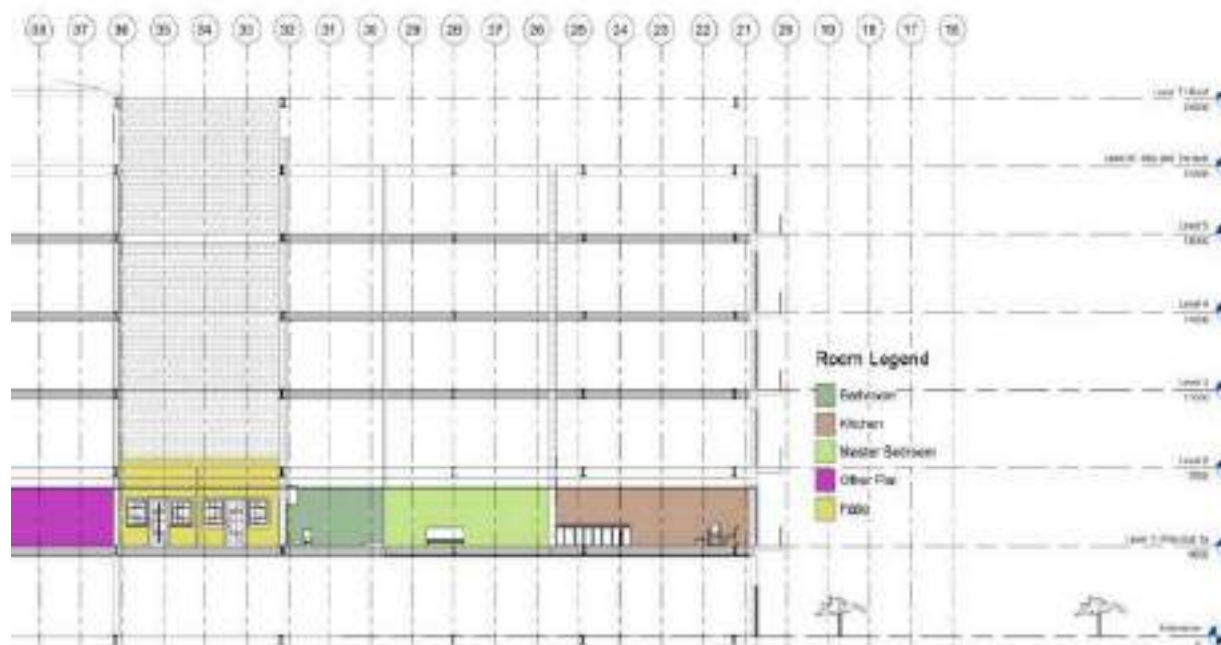


Figure 34: BIM Revit
Model 1 // Section 2

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Model 1 – Schedules data extracted form BIM Model:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Wall Schedule															
2	Absorptance	Structural Material	Type	Volume	Area	Family and Type	Function	Heat Transfer	Structural Material	Structural Use	Thermal mass	Thermal Resist	Analytical	Pin Base	Constraint	Top Constraint
3																
4		0.1 isotropic	Generic - 300mm W	6.71 m³	22 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)	Level 1 / Princ	Up to level: Level 2	
5		0.1 isotropic	Generic - 300mm W	64.05 m³	213 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)	Level 1 / Princ	Up to level: Level 2	
6		0.1 isotropic	Generic - 300mm W	8.15 m³	27 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Non-bearing	42.14 kJ/K	0.1308 m² K/W		Level 1 / Princ	Up to level: Level 2	
7		0.1 isotropic	Generic - 300mm W	64.37 m³	214 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)	Level 1 / Princ	Up to level: Level 2	
8		0.1 isotropic	Interior - 123mm P	5.04 m³	41 m²	Basic Wall: Interior - 123mm Interior		0.2682 W/m²	Metal Stud Layer	Non-bearing	2.76 kJ/K	3.7292 m² K/W		Level 1 / Princ	Up to level: Level 2	
9		0.1 isotropic	Interior - 123mm P	5.24 m³	26 m²	Basic Wall: Interior - 123mm Interior		0.2682 W/m²	Metal Stud Layer	Non-bearing	2.76 kJ/K	3.7292 m² K/W		Level 1 / Princ	Up to level: Level 2	
10		0.1 isotropic	Generic - 300mm W	9.23 m³	31 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)	Level 1 / Princ	Up to level: Level 2	
11		0.1 isotropic	Interior - 123mm P	1.55 m³	13 m²	Basic Wall: Interior - 123mm Interior		0.2682 W/m²	Metal Stud Layer	Non-bearing	2.76 kJ/K	3.7292 m² K/W		Level 1 / Princ	Up to level: Level 2	
12		0.1 isotropic	Generic - 300mm W	4.16 m³	14 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)	Level 1 / Princ	Up to level: Level 2	
13		0.1 isotropic	Generic - 300mm W	4.38 m³	15 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)	Level 1 / Princ	Up to level: Level 2	
14		0.1 isotropic	Generic - 300mm W	10.39 m³	35 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)	Level 1 / Princ	Up to level: Level 2	
15		0.1 isotropic	Generic - 300mm W	8.11 m³	27 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)	Level 1 / Princ	Up to level: Level 2	
16		0.1 isotropic	Generic - 300mm W	5.58 m³	19 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)	Level 1 / Princ	Up to level: Level 2	
17		0.1 isotropic	Interior - 123mm P	1.38 m³	11 m²	Basic Wall: Interior - 123mm Interior		0.2682 W/m²	Metal Stud Layer	Bearing	2.76 kJ/K	3.7292 m² K	Steel	Level 1 / Princ	Up to level: Level 2	
18		0.1 isotropic	Interior - 75mm P	0.67 m³	8 m²	Basic Wall: Interior - 75mm P Interior		0.5752 W/m²	Metal Stud Layer	Non-bearing	3.27 kJ/K	1.7385 m² K/W		Level 1 / Princ	Up to level: Level 2	
19		0.1 isotropic	Generic - 300mm W	11.27 m³	37 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)	Level 1 / Princ	Up to level: Level 2	
20		0.1 isotropic	Generic - 300mm W	0.00 m³		Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
21		0.1 isotropic	Generic - 300mm W	0.00 m³		Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
22		0.1 isotropic	Generic - 300mm W	0.00 m³		Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
23		0.1 isotropic	Generic - 300mm W	0.00 m³		Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
24		0.1 isotropic	Generic - 300mm W	0.00 m³		Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
25		0.1 isotropic	Generic - 300mm W	0.00 m³		Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
26		0.1 isotropic	Generic - 300mm W	0.00 m³		Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
27		0.1 isotropic	Generic - 300mm W	0.00 m³		Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
28		0.1 isotropic	Generic - 300mm W	0.00 m³		Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
29		0.1 isotropic	Generic - 300mm W	0.57 m³	2 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
30		0.1 isotropic	Generic - 300mm W	1.90 m³	6 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
31		0.1 isotropic	Generic - 300mm W	1.90 m³	6 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
32		0.1 isotropic	Generic - 300mm W	0.57 m³	2 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
33		0.1 isotropic	Generic - 300mm W	0.57 m³	2 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
34		0.1 isotropic	Generic - 300mm W	0.34 m³	1 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
35		0.1 isotropic	Generic - 300mm W	0.34 m³	1 m²	Basic Wall: Generic - 300mm Exterior		4.1335 W/m²	Concrete Masonry Units	Bearing	42.14 kJ/K	0.1308 m² K	Concrete(1)			
36																



	A	B	C	D	E	F	G	H
1	Door Schedule							
2	From Room: Level	From Room: Floor Finish	From Room: Wall	Family and Type	Finish	Function	Thermal Resistance (R)	Solar Heat Gain Coefficient
3								
4		Level 1 / Principal 1a	185.07 m ²	Living Room	Balconera practicable, 2 hojas: 1600 x 2200mm	6.8703 W/(m ² ·K)	Exterior	0.1456 (m ² ·K)/W
5		Level 1 / Principal 1a	87.94 m ²	Garden	Balconera practicable, 2 hojas: 1600 x 2200mm	6.8703 W/(m ² ·K)	Exterior	0.1456 (m ² ·K)/W
6		Level 1 / Principal 1a	165.07 m ²	Living Room	Balconera practicable, 2 hojas: 1600 x 2200mm	6.8703 W/(m ² ·K)	Exterior	0.1456 (m ² ·K)/W
7		Level 1 / Principal 1a	84.03 m ²	Room	Puerta de entrada a la vivienda: 900 x 2100mm	3.7021 W/(m ² ·K)	Exterior	0.2701 (m ² ·K)/W
8		Level 1 / Principal 1a	111.50 m ²	Corridor	Balconera practicable, 2 hojas: 1600 x 2200mm	6.8703 W/(m ² ·K)	Exterior	0.1456 (m ² ·K)/W
9		Level 1 / Principal 1a	111.50 m ²	Corridor	Puerta abatible 3: 900 x 2100mm	3.7021 W/(m ² ·K)	Interior	0.2701 (m ² ·K)/W
10		Level 1 / Principal 1a	111.50 m ²	Corridor	Puerta abatible 3: 900 x 2100mm	3.7021 W/(m ² ·K)	Interior	0.2701 (m ² ·K)/W
11		Level 1 / Principal 1a	111.50 m ²	Corridor	Puerta abatible 3: 900 x 2100mm	3.7021 W/(m ² ·K)	Interior	0.2701 (m ² ·K)/W
12		Level 1 / Principal 1a	111.50 m ²	Corridor	Puerta abatible 3: 900 x 2100mm	3.7021 W/(m ² ·K)	Interior	0.2701 (m ² ·K)/W
13		Level 1 / Principal 1a	111.50 m ²	Corridor	Puerta abatible 3: 900 x 2100mm	3.7021 W/(m ² ·K)	Interior	0.2701 (m ² ·K)/W
14		Level 1 / Principal 1a	43.70 m ²	Bathroom	Puerta de cristal abatible 2: 8915 x 2134mm	5.5617 W/(m ² ·K)	Interior	0.1798 (m ² ·K)/W
15		Level 1 / Principal 1a	12.44 m ²	Room 2	Puerta de cristal abatible 2: 8915 x 2134mm	5.5617 W/(m ² ·K)	Interior	0.1798 (m ² ·K)/W
16		Level 1 / Principal 1a	30.57 m ²	Room	Puerta de cristal abatible 2: 8915 x 2134mm	5.5617 W/(m ² ·K)	Interior	0.1798 (m ² ·K)/W
17		Level 1 / Principal 1a	84.03 m ²	Room	Puerta de entrada a la vivienda: 900 x 2100mm	3.7021 W/(m ² ·K)	Exterior	0.2701 (m ² ·K)/W
18								

	A	B	C	D	E	F	G	H	I	J	K	L
1	Floor Schedule											
2	Absorptance	Family and Type	Function	Heat Transfer Coefficient (U)	Structural Material	Thermal mass	Thermal Resistance (R)	Analytical: Phys	Analytical: Area	Level	Structural	Volume
3												
4	0,1	Floor: Generic Floor - 400m Interior		0.0625 W/(m ² ·K)	Structure, Steel Bar Joint Layer	0.04 kJ/K	16.0000 (m ² ·K)/W	Unassigned	634 m ²	Level 1 / Principal 1a	Yes	257.30 m ³
5	0,1	Floor: 160mm Concrete With Exterior		4.9810 W/(m ² ·K)	Concrete, Cast-in-Place gray	29.48 kJ/K	0.2006 (m ² ·K)/W	Concrete(1)	15 m ²	Level 1 / Principal 1a	Yes	2.72 m ³
6	0,1	Floor: Generic Floor - 400m Interior		0.0625 W/(m ² ·K)	Structure, Steel Bar Joint Layer	0.04 kJ/K	16.0000 (m ² ·K)/W	Unassigned	634 m ²	Level 3	Yes	249.75 m ³
7	0,1	Floor: 160mm Concrete With Exterior		4.9810 W/(m ² ·K)	Concrete, Cast-in-Place gray	29.48 kJ/K	0.2006 (m ² ·K)/W	Concrete(1)	15 m ²	Level 3	Yes	2.72 m ³
8	0,1	Floor: Generic Floor - 400m Interior			Default Floor			Unassigned	634 m ²	Level 2	Yes	245.50 m ³
9	0,1	Floor: 160mm Concrete With Exterior		4.9810 W/(m ² ·K)	Concrete, Cast-in-Place gray	29.48 kJ/K	0.2006 (m ² ·K)/W	Concrete(1)	15 m ²	Level 2	Yes	2.72 m ³
10	0,1	Floor: Generic Floor - 400m Interior		0.0625 W/(m ² ·K)	Structure, Steel Bar Joint Layer	0.04 kJ/K	16.0000 (m ² ·K)/W	Unassigned	634 m ²	Level 4	Yes	249.75 m ³
11	0,1	Floor: 160mm Concrete With Exterior		4.9810 W/(m ² ·K)	Concrete, Cast-in-Place gray	29.48 kJ/K	0.2006 (m ² ·K)/W	Concrete(1)	15 m ²	Level 4	Yes	2.72 m ³
12	0,1	Floor: 160mm Concrete With Exterior		4.9810 W/(m ² ·K)	Concrete, Cast-in-Place gray	29.48 kJ/K	0.2006 (m ² ·K)/W	Concrete(1)	15 m ²	Level 5	Yes	2.72 m ³
13	0,1	Floor: Generic Floor - 400m Interior		0.0625 W/(m ² ·K)	Structure, Steel Bar Joint Layer	0.04 kJ/K	16.0000 (m ² ·K)/W	Unassigned	634 m ²	Level 6 / Attic and Terrace	Yes	249.75 m ³
14	0,1	Floor: Steel Bar Joint - VCT e Interior		0.0607 W/(m ² ·K)	Structure, Steel Bar Joint Layer	7.59 kJ/K	16.4766 (m ² ·K)/W	Unassigned	634 m ²	Entrance	Yes	344.46 m ³
15	0,1	Floor: Generic Floor - 400m Interior		0.0625 W/(m ² ·K)	Structure, Steel Bar Joint Layer	0.04 kJ/K	16.0000 (m ² ·K)/W	Unassigned	634 m ²	Level 5	Yes	249.75 m ³
16												

	A	B	C	D	E	F	G	H
1	Window Schedule							
2	Level	Heat Transfer Coefficient (U)	Solar Heat Gain Coefficient	Thermal Resistance (R)	Visual Light Transmittance	From Room: Volume	From Room: Name	From Room: Level
3								
4	Level 1 / Principal 1a	3.6886 W/(m ² ·K)		0,78 / 0.2711 (m ² ·K)/W	0,9	165.07 m ³	Living Room	Level 1 / Principal 1a
5	Level 1 / Principal 1a	3.6886 W/(m ² ·K)		0,78 / 0.2711 (m ² ·K)/W	0,9			
6	Level 1 / Principal 1a	3.6886 W/(m ² ·K)		0,78 / 0.2711 (m ² ·K)/W	0,9	37.62 m ³	Patio	Level 1 / Principal 1a
7	Level 1 / Principal 1a	3.6886 W/(m ² ·K)		0,78 / 0.2711 (m ² ·K)/W	0,9	37.62 m ³	Patio	Level 1 / Principal 1a
8	Level 1 / Principal 1a	3.6886 W/(m ² ·K)		0,78 / 0.2711 (m ² ·K)/W	0,9	30.57 m ³	Room	Level 1 / Principal 1a
9	Level 1 / Principal 1a	3.6886 W/(m ² ·K)		0,78 / 0.2711 (m ² ·K)/W	0,9	30.57 m ³	Room	Level 1 / Principal 1a
10								

	A	B	C	D	E	F
1	Ceiling Schedule					
2	Absorptance	Area	Family and Type	Heat Transfer Coefficient (U)	Thermal mass	Thermal Resistance
3						
4	0,1	655 m ²	Compound Ceiling: 600 x 1200mm grid	3.5625 W/(m ² ·K)	0.58 kJ/K	0.2807 (m ² ·K)/W
5						

7.2. MODEL 2

Residential Building - Duplex Villa:

The second and final case study is a more complex project to be able to compare the results and to have more accuracy in the testing of the algorithm. This case is a duplex private villa, in the coast. This is a hypothetical project, yet the location on Revit is defined as the same as the previous case. So that the comparison of the results won't make a conflict. The building is designed with good insulation qualities, and with good quality materials, which are adequate to Mediterranean climate. The location is near the beach, so the building has high humidity level. The project has 17 spaces, which will define the space tags on the further stages. This case study is modeled just to access a material database of a well-insulated building.

As in the previous case, the same information is exported from Revit to Excel. The data of material types, dimensions, tags, thermal values, location and function are listed for further use, in the algorithm. The observation of those schedules shows that, the thermal coefficients and values are higher than the first example. Even though this case has 4 facades and many more openings, the thermal quality is better, since the materials and the insulation are adequate to the location. Unfortunately, with

recent version, it is not possible to achieve a thermal value of a room or space, when the schedules are exported from Revit. Therefore, a custom made calculation is designed for calculating the required value via Dynamo visual programming language. The generated value is used at the processing in the Arduino code of Prototypes.

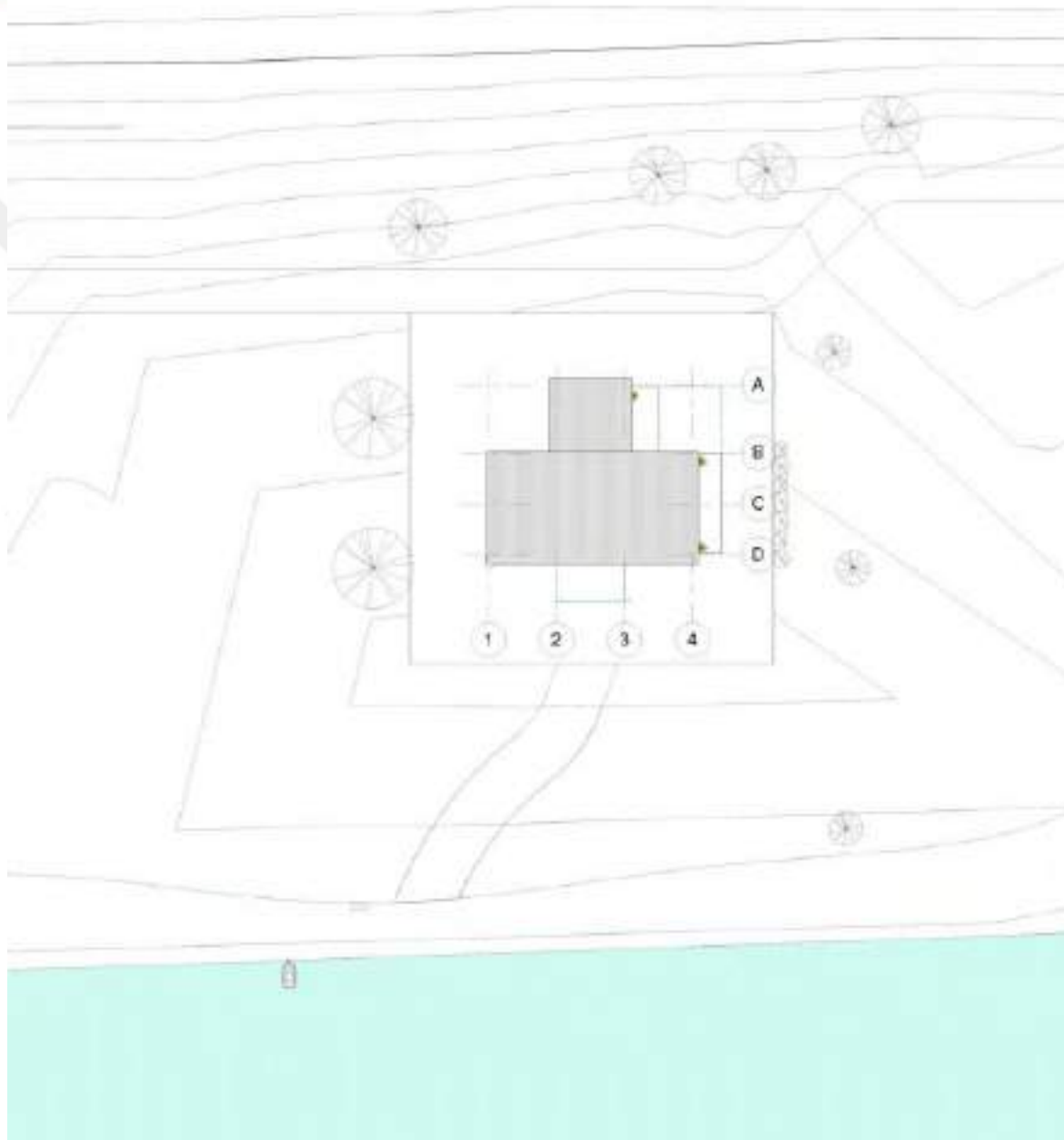


Figure 35: BIM Revit Model 2 // Duplex
Villa

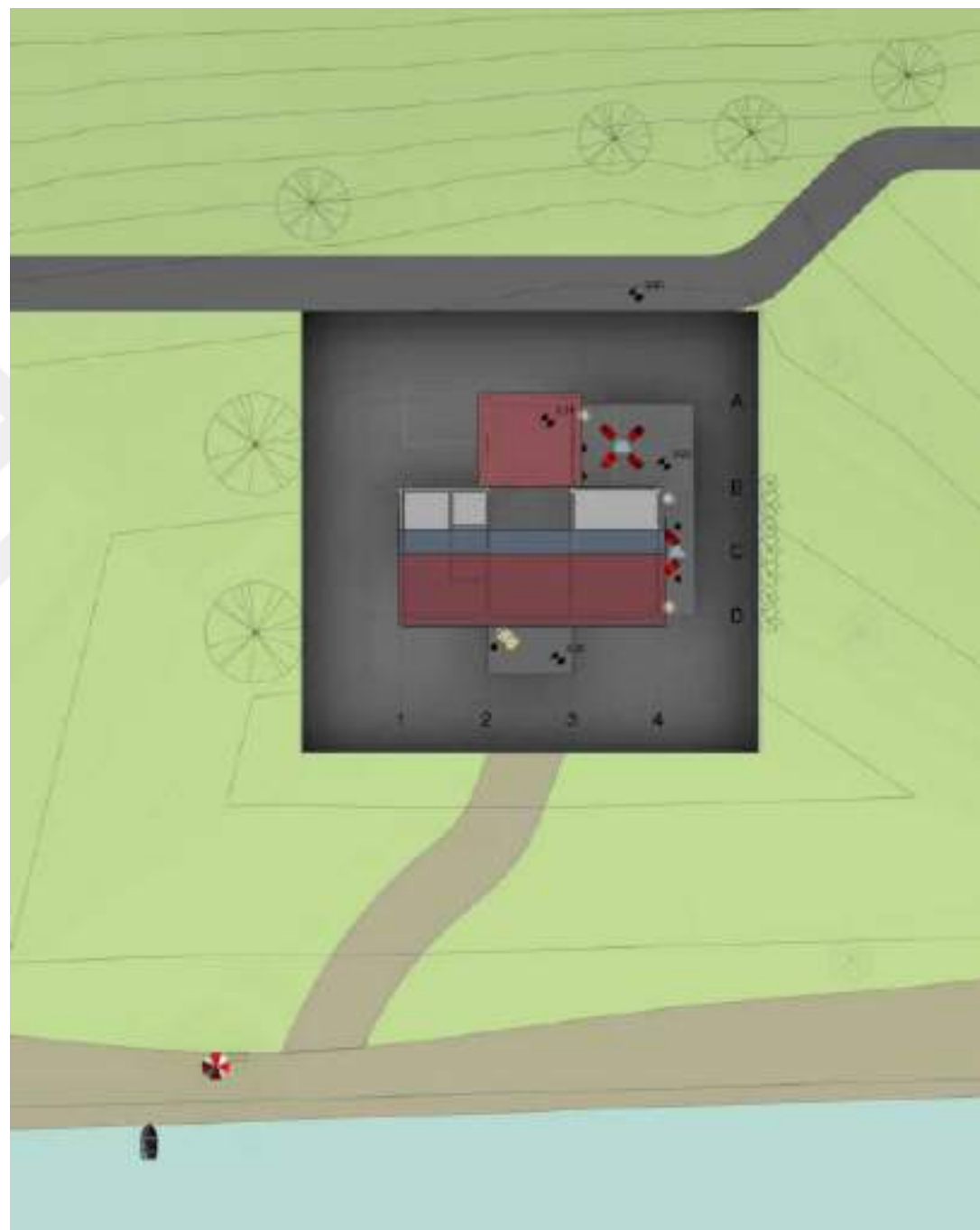


Figure 36: BIM Revit Model 2 // Duplex Villa – Top View



Figure 37: BIM Revit Model 2 // Duplex
Villa General view

SYMBIOTIC DATA PLATFORM

symbiötiety & symbiötiety

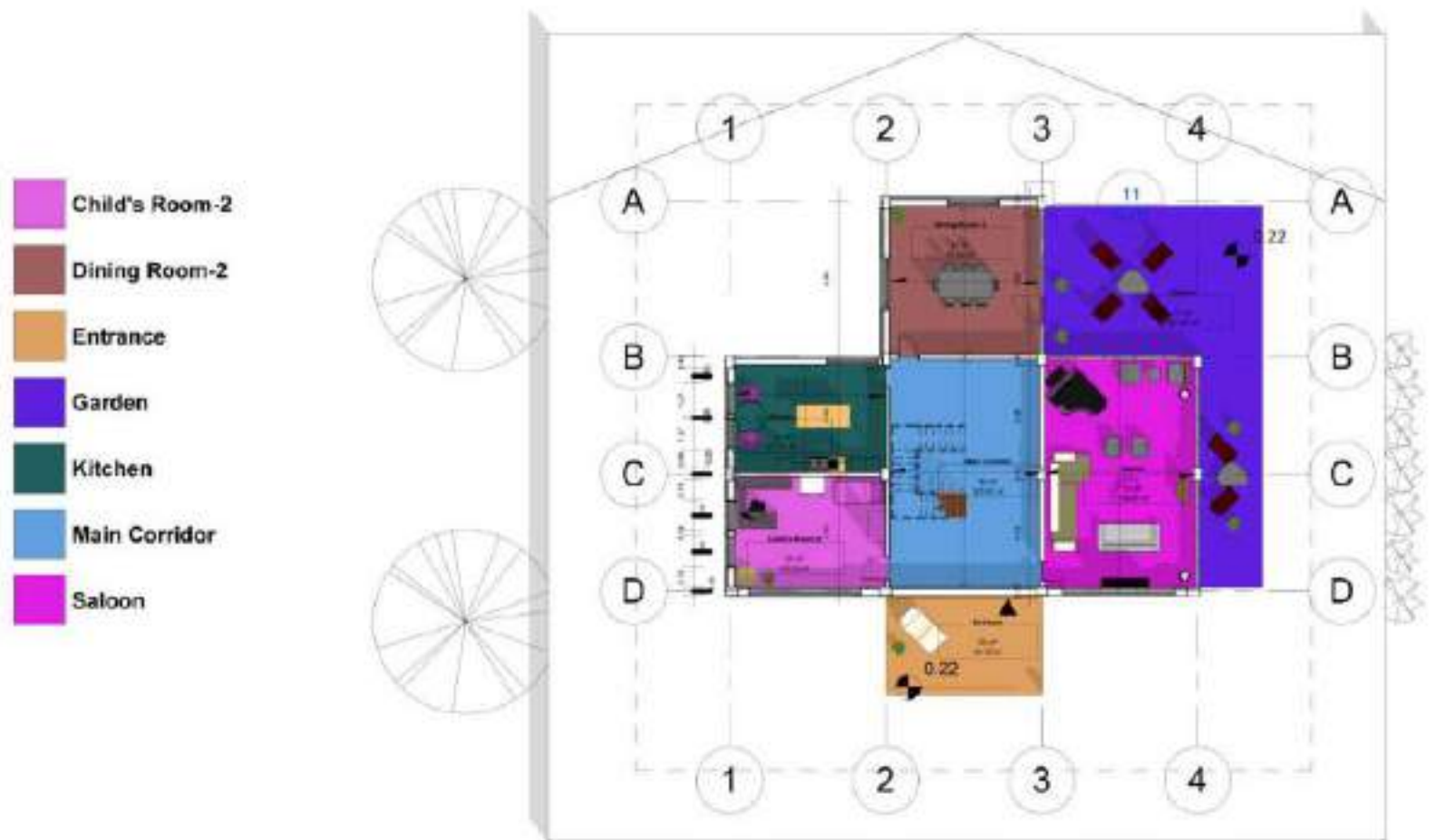


Figure 38: BIM Revit Model 2 // Duplex
Villa – First Floor

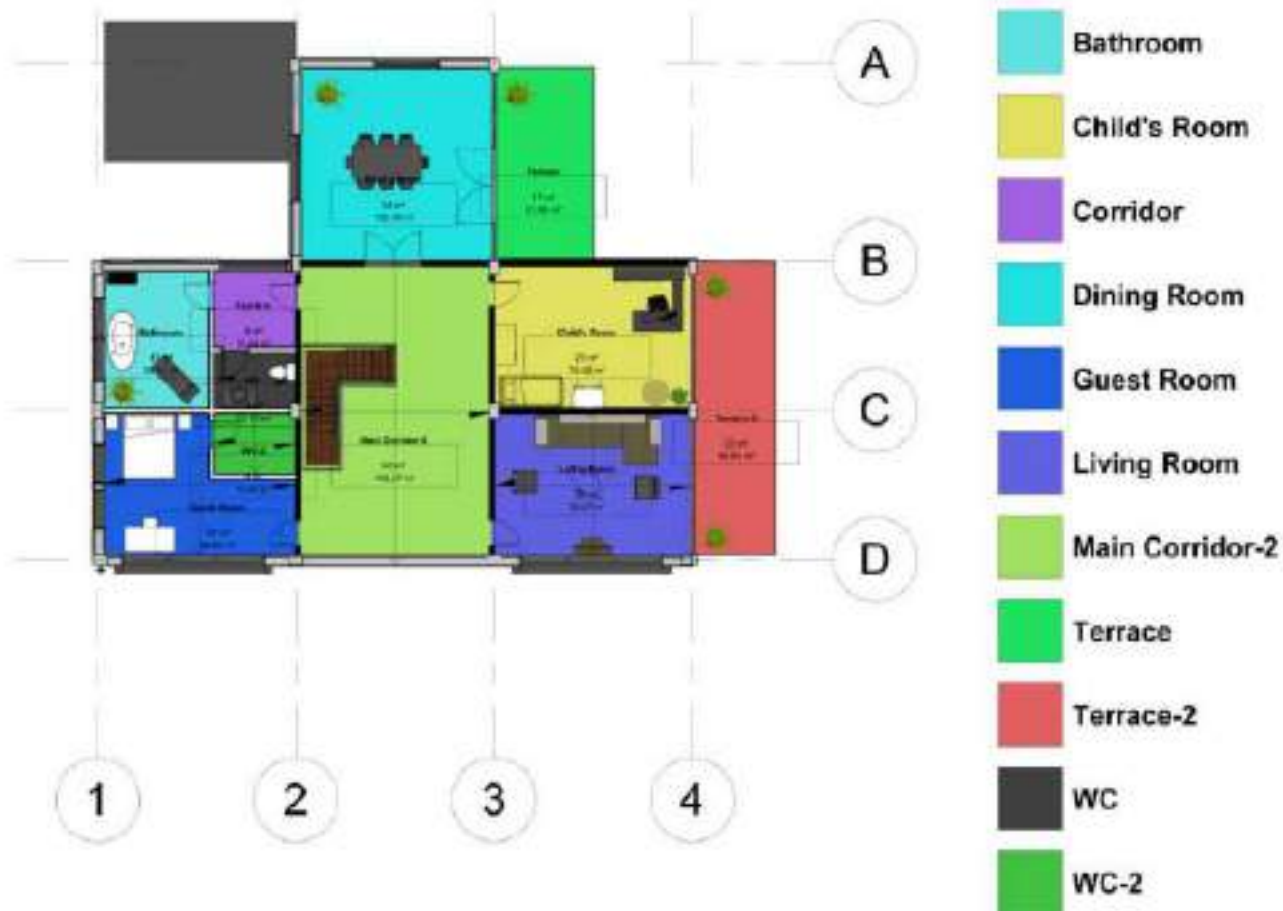


Figure 39: BIM Revit Model 2 // Duplex
Villa - Second Floor

SYMBIOTIC DATA PLATFORM

resilibility & resiliency



Figure 40: BIM Revit Model 2 // Duplex
Villa – Exterior View



Figure 41: BIM Revit Model 2 // Duplex
Villa – East View

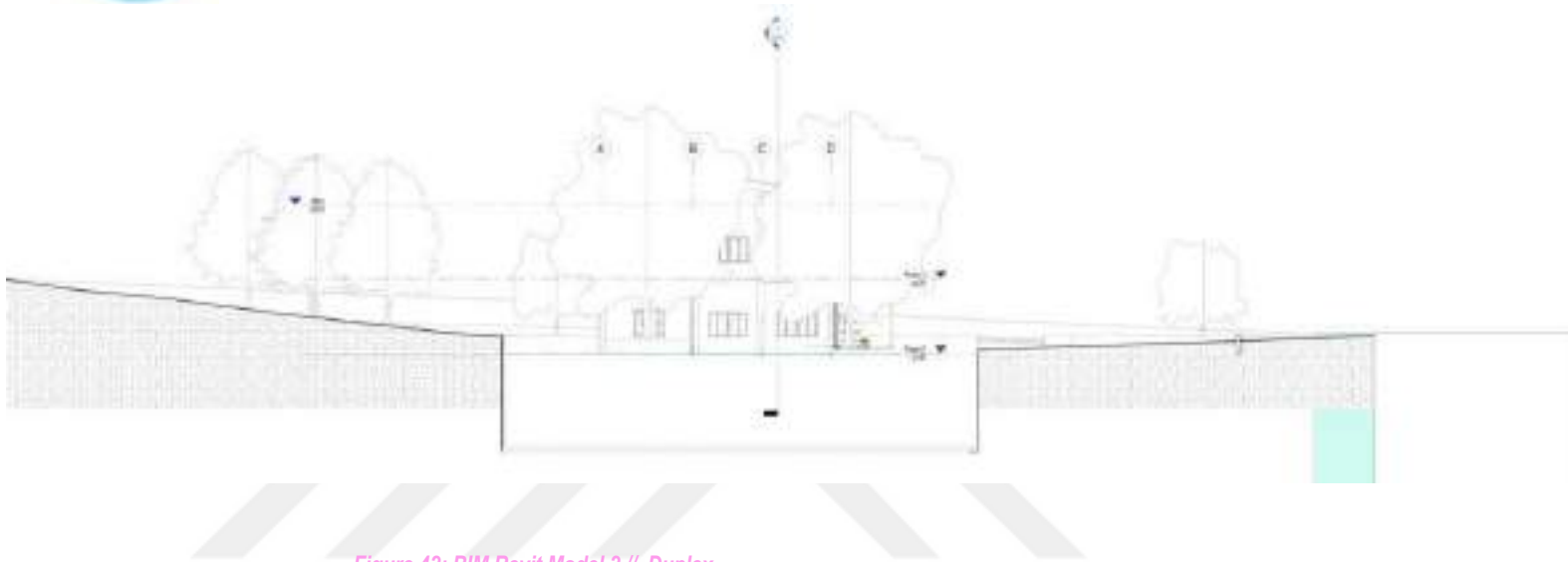


Figure 42: BIM Revit Model 2 // Duplex
Villa – West View



Figure 43: BIM Revit Model 2 // Duplex
Villa – North View

SYMBIOTIC DATA PLATFORM

symbiōtcity & symbiōtcity



Figure 44: BIM Revit Model 2 // Duplex
Villa – South View



Figure 45: BIM Revit Model 2 // Duplex
Villa – Section 1

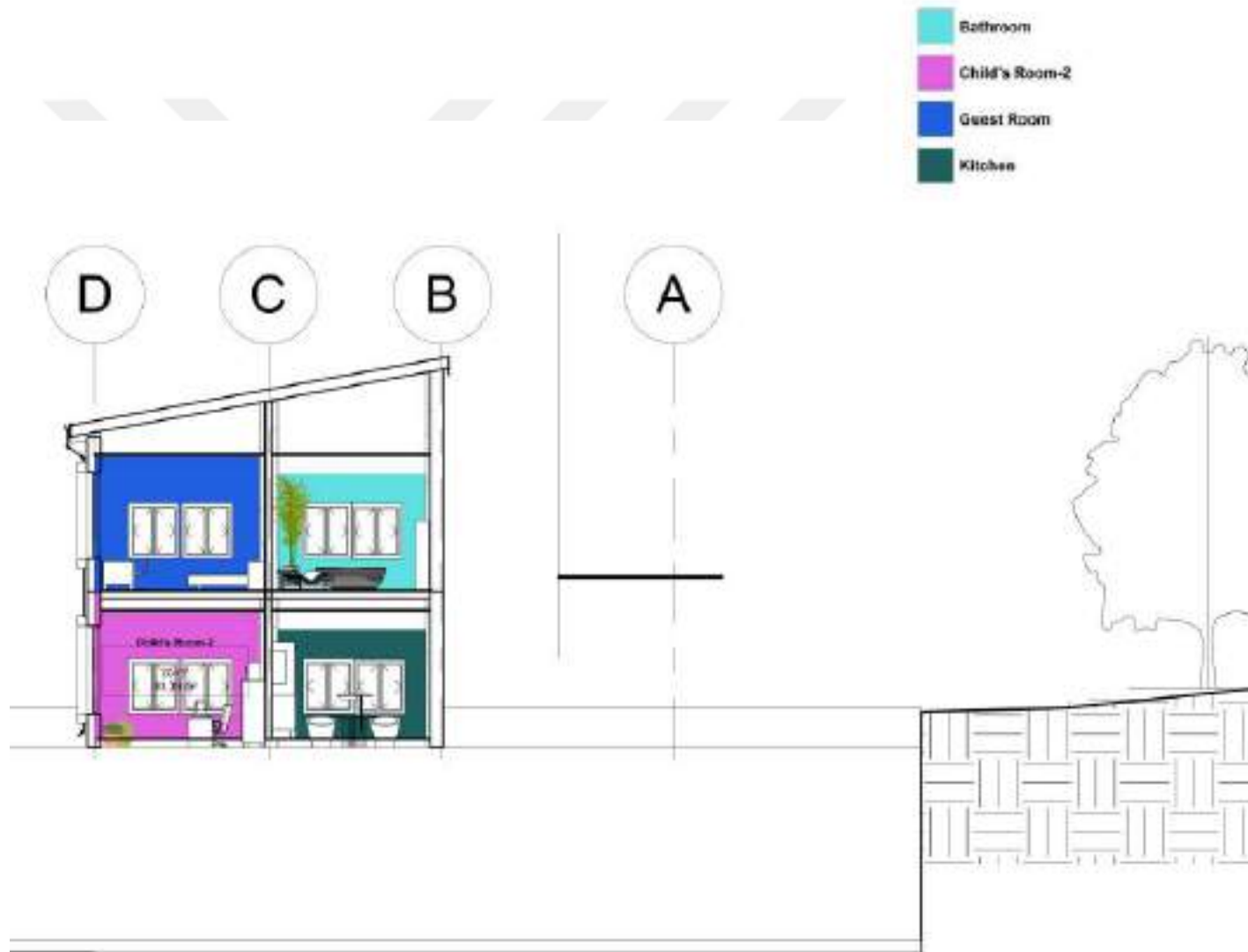


Figure 46: BIM Revit Model 2 // Duplex
Villa - Section 1

SYMBIOTIC DATA PLATFORM

symbiosis & sensitivity

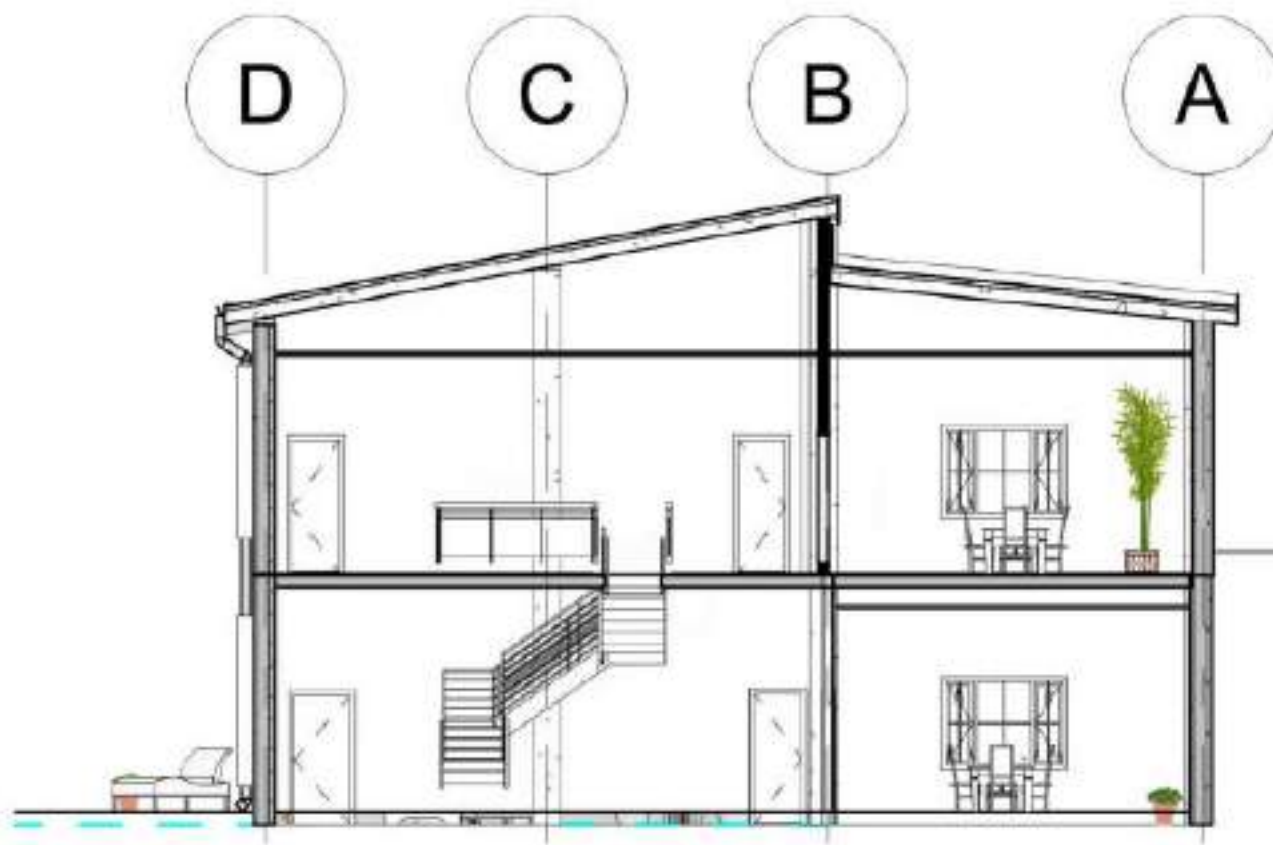


Figure 47: BIM Revit Model 2 // Duplex
Villa – Section 2



*Figure 48: BIM Revit Model 2 // Duplex
Villa - Entrance Floor Interior View*

Model 2 – Schedules data extracted form BIM Model:

ROOM	ELEMENT	ID	MATERIAL	THERMAL CONDUCTIVITY	AREA	TXA MATERIAL	ROOM THERMAL VALUE
Corridor	Floor	651417	15-Granit Kaplama	3,49	24,15713	84,30836625	481,9206086
Corridor	Floor	651417	Concrete, Cast-in-Place gray	1,046	223,4286	233,7063364	481,9206086
Corridor	Floor	656903	Concrete, Cast-in-Place gray	1,046	49,73821	52,02616277	481,9206086
Corridor	Floor	656903	Gypsum Wall Board	0,65	99,37381	64,59297692	481,9206086
Corridor	Floor	656903	Insulation - Fiberglass	0,019	49,78951	0,946000601	481,9206086
Corridor	Wall	320600	Default	1,5	23,85855	35,787825	481,9206086
Corridor	Wall	320600	Acoustic Ceiling Tile 48x 48	0,057	23,85855	1,35993735	481,9206086
Corridor	Wall	333614	Glass	1,1	4,056144	4,4617584	481,9206086
Corridor	Wall	333614	Nerez matny	0,72	0,031879	0,022953027	481,9206086
Corridor	Wall	333614	Drvo Borovice	0,42	5,060016	2,12520672	481,9206086
Corridor	Wall	333614	Pricel	0,52	0,31776	0,1652352	481,9206086
Corridor	Ceiling	653086	Door - Frame	0,084	6,340632	0,532613128	481,9206086
Corridor	Ceiling	653086	Door - Panel	0,18	10,47354	1,885236768	481,9206086
Guest Room	2000x1500	450601	15_Renkli Aşşap	0,15	26,08088	3,91213125	735,7690305
Guest Room	2000x1500	450601	Concrete, Cast-in-Place gray	1,046	223,4286	233,7063364	735,7690305
Guest Room	AŞŞAP KAPI	558005	Concrete, Cast-in-Place gray	1,046	92,3139	96,56034107	735,7690305
Guest Room	AŞŞAP KAPI	558005	Gypsum Wall Board	0,65	218,7317	142,1756128	735,7690305
Guest Room	AŞŞAP KAPI	558005	Insulation - Fiberglass	0,019	91,28533	1,734421273	735,7690305
Guest Room	AŞŞAP KAPI	558005	BMCD2AR3\Solid Materials \Matte\Tr	1,5	140,5299	210,7948816	735,7690305
Guest Room	AŞŞAP KAPI	558305	Default	1,5	24,6335	36,95025	735,7690305
Guest Room	AŞŞAP KAPI	558305	Acoustic Ceiling Tile 48x 48	0,057	24,6335	1,4041095	735,7690305
Guest Room	AŞŞAP KAPI	650856	Glass	1,1	4,605866	5,06645216	735,7690305
Guest Room	AŞŞAP KAPI	650856	Sash	0,18	10,8194	1,947492554	735,7690305
Guest Room	AŞŞAP KAPI	650856	Trim	0,15	4,017648	0,602647131	735,7690305
Guest Room	Floor	321816	Door - Frame	0,084	2,142317	0,179954652	735,7690305
Guest Room	Floor	321816	Door - Panel	0,18	4,08	0,7344	735,7690305
Kitchen	Wall	319471	Concrete, Cast-in-Place gray	1,046	32,48385	33,97810816	77,63025761
Kitchen	Wall	319471	Gypsum Wall Board	0,65	64,9677	42,22900632	77,63025761
Kitchen	Wall	319471	Insulation - Fiberglass	0,019	32,48385	0,617193169	77,63025761
Kitchen	Wall	333611	Door - Frame	0,084	2,113544	0,177537709	77,63025761
Kitchen	Wall	333611	Door - Panel	0,18	3,491179	0,628412256	77,63025761
Chid's Room-2	Wall	346923	Concrete, Cast-in-Place gray	1,046	24,90311	26,04865817	59,81022136
Chid's Room-2	Wall	346923	Gypsum Wall Board	0,65	49,80623	32,37404935	59,81022136
Chid's Room-2	Wall	346923	Insulation - Fiberglass	0,019	24,90311	0,473159183	59,81022136
Chid's Room-2	AŞŞAP KAPLAMA PENCERE	331748	Door - Frame	0,084	2,142317	0,179954652	59,81022136
Chid's Room-2	AŞŞAP KAPLAMA PENCERE	331748	Door - Panel	0,18	4,08	0,7344	59,81022136
Saloon	90 x 210 cm Aşşap Kapı	348068	Concrete, Cast-in-Place gray	1,046	11,8596	12,4051382	28,85389628
Saloon	90 x 210 cm Aşşap Kapı	348068	Gypsum Wall Board	0,65	23,71919	15,41747578	28,85389628
Saloon	90 x 210 cm Aşşap Kapı	348068	Insulation - Fiberglass	0,019	11,8596	0,225332338	28,85389628
Saloon	AŞŞAP KAPI	650856	Door - Frame	0,084	2,113544	0,177537709	28,85389628
Saloon	AŞŞAP KAPI	650856	Door - Panel	0,18	3,491179	0,628412256	28,85389628
Dining Room-2	Wall	319971	Concrete, Cast-in-Place gray	1,046	39,27986	41,08673	93,70281082
Dining Room-2	Wall	319971	Gypsum Wall Board	0,65	78,55971	51,06381358	93,70



Main Corridor	Wall	321061 Concrete, Cast-in-Place gray	1,046	22,38781	23,4176527	56,27938296
Main Corridor	Wall	321061 Gypsum Wall Board	0,65	44,77563	29,10415727	56,27938296
Main Corridor	Wall	321061 Insulation - Fiberglass	0,019	22,38781	0,425368452	56,27938296
Main Corridor	90 x 210 cm Ahşap Kapı	348068 Door - Frame	0,084	8,48295	0,71256778	56,27938296
Main Corridor	90 x 210 cm Ahşap Kapı	348068 Door - Panel	0,18	14,55354	2,619636768	56,27938296
Dining Room	AHŞAP KAPI	650856 17-Açık Alan AHşap Malzeme	0,18	93,31324	16,79638272	619,2786224
Dining Room	AHŞAP KAPI	650856 Cherry	0,18	33,35443	6,003797024	619,2786224
Dining Room	AHŞAP KAPI	650856 Concrete, Cast-in-Place gray	1,046	223,4286	233,7063364	619,2786224
Dining Room	AHŞAP KAPI	653218 Concrete, Cast-in-Place gray	1,046	59,46176	62,1969974	619,2786224
Dining Room	AHŞAP KAPI	653218 Gypsum Wall Board	0,65	139,0932	90,41054965	619,2786224
Dining Room	AHŞAP KAPI	653218 Insulation - Fiberglass	0,019	59,34776	1,127607375	619,2786224
Dining Room	AHŞAP KAPI	653218 BMCD2AR3\Solid Materials \Matte\T	1,5	81,13456	121,7018407	619,2786224
Dining Room	AHŞAP KAPI	653418 Default	1,5	32,55248	48,8287125	619,2786224
Dining Room	AHŞAP KAPI	653418 Acoustic Ceiling Tile 48x 48	0,057	32,55248	1,855491075	619,2786224
Dining Room	Floor	468426 Glass	1,1	8,112288	8,9235168	619,2786224
Dining Room	Floor	468426 Nerez matny	0,72	0,063758	0,045906053	619,2786224
Dining Room	Floor	468426 Drevo Borovice	0,42	10,12003	4,25041344	619,2786224
Dining Room	Floor	468426 Pricel	0,52	0,63552	0,3304704	619,2786224
Dining Room	Floor	652029 Glass	1,1	4,619802	5,081782089	619,2786224
Dining Room	Floor	652029 Aluminum	230	0,074839	17,2128688	619,2786224
Dining Room	Floor	652029 Door - Frame	0,084	2,113544	0,177537709	619,2786224
Dining Room	Floor	652029 Door - Panel	0,18	3,491179	0,628412256	619,2786224
Main Corridor-2	Floor	656903 17-Açık Alan AHşap Malzeme	0,18	93,31324	16,79638272	661,8689535
Main Corridor-2	Floor	656903 10- Fayans Döşeme	1,2	51,67883	62,01459306	661,8689535
Main Corridor-2	Floor	656903 Concrete, Cast-in-Place gray	1,046	223,4286	233,7063364	661,8689535
Main Corridor-2	Wall	320947 Gypsum Wall Board	0,65	172,1585	111,9030372	661,8689535
Main Corridor-2	Wall	320947 BMCD2AR3\Solid Materials \Matte\T	1,5	105,0028	157,504216	661,8689535
Main Corridor-2	Wall	320947 Concrete, Cast-in-Place gray	1,046	73,46819	76,84773066	661,8689535
Main Corridor-2	Wall	320947 Insulation - Fiberglass	0,019	72,43962	1,376352824	661,8689535
Main Corridor-2	Wall	333616 Door - Frame	0,084	4,255861	0,357492361	661,8689535
Main Corridor-2	Wall	333616 Door - Panel	0,18	7,571179	1,362812256	661,8689535
Terrace	Wall	653184 17-Açık Alan AHşap Malzeme	0,18	93,31324	16,79638272	272,79737
Terrace	Wall	653184 Concrete, Cast-in-Place gray	1,046	223,4286	233,7063364	272,79737
Terrace	Ceiling	653504 Default New Material(6)		33,78621		272,79737
Terrace	Door-Curtain-Wall-Single-Glas	323416 Glass	1,1	4,619802	5,081782089	272,79737
Terrace	Door-Curtain-Wall-Single-Glas	323416 Aluminum	230	0,074839	17,2128688	272,79737
Terrace-2	AHŞAP KAPI	653218 17-Açık Alan AHşap Malzeme	0,18	93,31324	16,79638272	250,5027192
Terrace-2	AHŞAP KAPI	653218 Concrete, Cast-in-Place gray	1,046	223,4286	233,7063364	250,5027192
Garden	Wall	650570 Concrete, Cast-in-Place gray	1,046	11,8596	12,4051382	28,85389628
Garden	Wall	650570 Gypsum Wall Board	0,65	23,71919	15,41747578	28,85389628
Garden	Wall	650570 Insulation - Fiberglass	0,019	11,8596	0,225332338	28,85389628
Garden	AHŞAP KAPI	650856 Door - Frame	0,084	2,113544	0,177537709	28,85389628
Garden	AHŞAP KAPI	650856 Door - Panel	0,18	3,491179	0,628412256	28,85389628
Entrance	Floor	656903 Concrete, Cast-in-Place gray	1,046	22,38781	23,4176527	52,94717842
Entrance	Floor	656903 Gypsum Wall Board	0,65	44,77563	29,10415727	52,94717842
Entrance	Floor	656903 Insulation - Fiberglass	0,019	22,38781	0,425368452	52,94717842
Bathroom	Door-Curtain-Wall-Single-Glas	323416 15-Granit Kaplama	3,49	24,15713	84,30836625	696,7140531

SYMBIOTIC DATA PLATFORM

usability & sensitivity

Bathroom	Door-Curtain-Wall-Single-Glas	323416 Concrete, Cast-in-Place gray	1,046	223,4286	233,7063364	696,7140531
Bathroom	Floor	468426 Concrete, Cast-in-Place gray	1,046	79,43892	83,09311112	696,7140531
Bathroom	Floor	468426 Gypsum Wall Board	0,65	180,6281	117,4082851	696,7140531
Bathroom	Floor	468426 Insulation - Fiberglass	0,019	79,49022	1,510314195	696,7140531
Bathroom	Floor	468426 BMCD2AR3\Solid Materials \Matte\Tı	1,5	87,41156	131,1173359	696,7140531
Bathroom	Floor	656903 Default	1,5	23,85855	35,787825	696,7140531
Bathroom	Floor	656903 Acoustic Ceiling Tile 48x 48	0,057	23,85855	1,35993735	696,7140531
Bathroom	Wall	321412 Glass	1,1	4,605866	5,06645216	696,7140531
Bathroom	Wall	321412 Sash	0,18	10,8194	1,947492554	696,7140531
Bathroom	Wall	321412 Trim	0,15	4,017648	0,602647131	696,7140531
Bathroom	Wall	321497 Door - Frame	0,084	2,113544	0,177537709	696,7140531
Bathroom	Wall	321497 Door - Panel	0,18	3,491179	0,628412256	696,7140531
Child's Room	Wall	650446 17-Açık Alan Ahşap Malzeme	0,18	93,31324	16,79638272	438,6802486
Child's Room	Wall	650446 12-Ahşap_Döşeme_Koyu	0,12	52,32891	6,279469481	438,6802486
Child's Room	Wall	650446 Concrete, Cast-in-Place gray	1,046	223,4286	233,7063364	438,6802486
Child's Room	AHŞAP KAPI	653418 Gypsum Wall Board	0,65	15,33536	9,967984602	438,6802486
Child's Room	AHŞAP KAPI	653418 BMCD2AR3\Solid Materials \Matte\Tı	1,5	61,34144	92,01216555	438,6802486
Child's Room	Wall	650570 Default	1,5	51,32814	76,99220602	438,6802486
Child's Room	Wall	650570 Acoustic Ceiling Tile 48x 48	0,057	51,32814	2,925703829	438,6802486
Living Room	Wall	319806 17-Açık Alan Ahşap Malzeme	0,18	93,31324	16,79638272	580,4025029
Living Room	Wall	319806 12-Ahşap_Döşeme_Koyu	0,12	52,32891	6,279469481	580,4025029
Living Room	Wall	319806 Concrete, Cast-in-Place gray	1,046	223,4286	233,7063364	580,4025029
Living Room	Wall	320600 Concrete, Cast-in-Place gray	1,046	62,93998	65,83521617	580,4025029
Living Room	Wall	320600 Gypsum Wall Board	0,65	139,0967	90,41287109	580,4025029
Living Room	Wall	320600 Insulation - Fiberglass	0,019	61,91141	1,17631671	580,4025029
Living Room	Wall	320600 BMCD2AR3\Solid Materials \Matte\Tı	1,5	56,98137	85,47205049	580,4025029
Living Room	Wall	333612 Default	1,5	51,32814	76,99220602	580,4025029
Living Room	Wall	333612 Acoustic Ceiling Tile 48x 48	0,057	51,32814	2,925703829	580,4025029
Living Room	Wall	346923 Door - Frame	0,084	2,113544	0,177537709	580,4025029
Living Room	Wall	346923 Door - Panel	0,18	3,491179	0,628412256	580,4025029
WC	Ceiling	653086 15-Granit Kaplama	3,49	24,15713	84,30836625	501,290129
WC	Ceiling	653086 Concrete, Cast-in-Place gray	1,046	223,4286	233,7063364	501,290129
WC	130/120 cm Ahşap Pencere	331618 Gypsum Wall Board	0,65	21,85289	14,20437806	501,290129
WC	130/120 cm Ahşap Pencere	331618 BMCD2AR3\Solid Materials \Matte\Tı	1,5	87,41156	131,1173359	501,290129
WC	AHŞAP KAPLAMA PENCERE	331797 Default	1,5	23,85855	35,787825	501,290129
WC	AHŞAP KAPLAMA PENCERE	331797 Acoustic Ceiling Tile 48x 48	0,057	23,85855	1,35993735	501,290129
WC	Floor	468426 Door - Frame	0,084	2,113544	0,177537709	501,290129
WC	Floor	468426 Door - Panel	0,18	3,491179	0,628412256	501,290129
WC-2	Floor	652115 15_Renkli Ahşap	0,15	26,08088	3,91213125	509,603821
WC-2	Floor	652115 Concrete, Cast-in-Place gray	1,046	223,4286	233,7063364	509,603821
WC-2	Floor	656903 Gypsum Wall Board	0,65	35,13248	22,83611218	509,603821
WC-2	Floor	656903 BMCD2AR3\Solid Materials \Matte\Tı	1,5	140,5299	210,7948816	509,603821
WC-2	Wall	321307 Default	1,5	24,6335	36,95025	509,603821
WC-2	Wall	321307 Acoustic Ceiling Tile 48x 48	0,057	24,6335	1,4041095	509,603821

Figure 49: Schedules Extracted after Revit + Dynamo Calculation // Definition



7.3. THERMAL VALUES

Related Thermal Terms⁶⁸:

- Ambient Air: The air surrounding a building; outside air
- Air Change: The term air change is a rate at which outside air replaces indoor air in a space. It can be expressed in one of two ways: the number of changes of outside air per unit of time air changes per hour (ACH); or the rate at which a volume of outside air enters per unit of time - cubic feet per minute (CFM).
- Building Envelope: The term building envelope indicates the surfaces that separate the inside from the outdoors. This includes the parts of the building: all external building materials, windows, walls, floor and the roof. Essentially the building envelope is a barrier between the conditioned indoor environment and the outdoors.
- Building Location Data: Building location data refers to specific outdoor design conditions used in calculating heating and cooling loads.
- Cooling Load: The rate at which heat is removed from a space to maintain the constant temperature and humidity at the design values.
- Comfort Zone: The range of temperatures, humidity's and air velocities at which the greatest percentages of people feel comfortable.
- Design Conditions: Cooling loads vary with inside and outside conditions. A set of conditions specific to the local climate is necessary to calculate the expected cooling load for a building. Inside conditions of 75°F and 50% relative humidity are usually recommended as a guideline. Outside conditions are selected for the 2.5% climate occurrence.
- Exfiltration: Uncontrolled air leakage out of a building through window and door openings.
- Enthalpy: Heat content or total heat, including both sensible and latent heat.
- Heating load: The heating load is a rate at which heat is added to the space to maintain the indoor conditions.
- Infiltration: Leakage of air inward into a space through walls, crack openings around doors and windows or through the building materials used in the structure.
- Latent Cooling Load: The net amount of moisture added to the inside air by plants, people, cooking, infiltration, and any other moisture source. The amount of moisture in the air can be calculated from a combination of dry-bulb and wet-bulb

⁶⁸ Definitions are taken from (California Energy Commission, 1995) , (Bhatia, 2005) , (Grondzik, Kwok, & Stein, 2010)

temperature measurements. The latent loads will affect absolute (and relative) humidity.

- Latent Heat Gain: It is the energy added to the space when moisture is added to the space by means of vapor emitted by the occupants, generated by a process or through air infiltration from outside or adjacent areas.
- Radiant Heat Gain: The rate at which heat absorbed by the surfaces enclosing the space and the objects within the space is transferred by convection when the surface or objects temperature becomes warmer than the space temperature.
- Sensible Cooling Load: The heat gain of the building due to conduction, solar radiation, infiltration, appliances, people, and pets. Burning a light bulb, for example, adds only sensible load to the house. This sensible load raises the dry-bulb temperature.
- Space Heat Gain: The rate at which heat enters to and/or is generated within a space during a time interval.
- Space Heat Loss: The rate at which energy is lost from the space during a time interval.
- Shading: The effectiveness of a fenestration product plus shade assembly in stopping heat gain from solar radiation is expressed as the Solar Heat Gain Coefficient (SHGC). SHGC values range from 0 to almost 1. The more effective at stopping heat gain, the lower the SHGC value.

- Thermal Conductivity: It is the time rate of heat flow through a unit area and unit thickness of a homogenous material under steady conditions when a unit temperature gradient is maintained in the direction perpendicular to the area.
- Thermal Transmittance or Coefficient of Heat Transfer (U-value): It is the time rate of heat flow per unit area under steady conditions from the fluid on the warm side of a barrier to the fluid on the cold side, per unit temperature difference between the two fluids.
- Thermal Conduction: It is the process of heat transfer through a material medium in which kinetic energy is transmitted by particles of the material from particle to particle without gross displacement of the particles.
- Thermal Convection: It is the transfer of heat by movement of fluid. Forced convection is the transfer of heat from forced circulation of fluid as by a fan, jet or pump. Natural convection is the transfer of heat by circulation of gas or liquid due to differences in density resulting from temperature changes.
- Thermally Light Buildings: A building whose heating and cooling requirements are proportional to the weather is considered a thermally light building. That is, when the outdoor temperature drops below the desired room temperature, heating is required and when the outdoor temperature goes above the desired room temperature,



cooling is needed. In a thermally light building, the thermal performance of the envelope becomes a dominant factor in energy use and can usually be seen as seasonal fluctuations in utility consumption.

- **Thermally Heavy Buildings:** When factors other than weather determine the heating and cooling requirements, the building can be considered thermally heavy. The difference between thermally light and thermally heavy buildings is the amount of heat generated by people, lighting, and equipment within the building. Thermally heavy buildings typically have high internal heat gains and, to a certain extent, are considered to be self-heating and more cooling dominated. This need to reject heat makes them less dependent on the thermal performance of the building envelope.
- **Zone:** Occupied space or spaces within a building which has its heating or cooling controlled by a single thermostat or zone is a space or group of spaces within a building with heating and/or cooling requirements sufficiently similar so that comfort conditions can be maintained throughout by a single controlling device. And 'zoning' is a system in which living areas or groups of rooms are divided into separate spaces and each space's heating/air conditioning is controlled independently.

R-Value:

The R-value is a measure of how well a two-dimensional barrier, such as a layer of insulation, a window or a complete wall or ceiling, resists the conductive flow of heat. R-value is the temperature difference per unit of heat flux needed to sustain one unit of heat flux between the warmer surface and colder surface of a barrier under steady-state conditions. (Lechner, 2014). The R-value is expressed as $\text{m}^2\text{K/W}$. The heat flow through a building construction depends on the temperature difference across it, the conductivity of the materials used and the thickness of the materials. Of course the temperature difference is an external factor. The thickness and the conductivity are properties of the material. A greater thickness means less heat flow and so does a lower conductivity. A construction element with a high thermal resistance (e.g. rock wool) is a good insulator; one with a low thermal resistance (e.g. concrete) is a bad insulator (GreenSpec, 2019). The lower the value, the better the insulating capacity of the product (for a given thickness).

The 'R-Value' equation for materials:

$$R = t / \lambda$$

where

't' is the thickness of the material in meters

λ is the Thermal Conductivity (Also known as the K-value)⁶⁹

U-Value:

Thermal Transmittance or Coefficient of Heat Transfer (U-Factor or U-Value) is the time rate of heat flow per unit area under steady conditions from the fluid on the warm side of a barrier to the fluid on the cold side, per unit temperature difference between the two fluids (Lechner, 2014).

A component might be a homogeneous material (such as a concrete retaining wall) or a series of materials in contact (such as in a cavity wall). The U-value of a building component like a wall, roof or window, measures the amount of energy (heat) lost through a square meter (m²) of that material for every degree (K) difference in temperature between the inside and the outside. Energy flows along in watts (which is a measure of energy in 'joules' flowing over a period of time in 'seconds'). Temperature is measured in degrees Kelvin – which practically is degrees Celsius (GreenSpec, 2019).

⁶⁹ Lambda (λ) Value means the Thermal Conductivity, and Lambda value λ (w/mK) is a measure of the rate at which heat passes through a material. The units are watts per unit thickness per degree temperature difference across that unit thickness. Examples include Glass mineral wool Loft roll at 0.044w/mk, and Celotex GA4000 PIR board at 0.022w/mk. (Renewable Energy Hub, 2019)

The R-value (reciprocal of U-value) means the Thermal Resistance or how much of a fight the material puts up against the heat passing through it, for a given thickness and area. The value is measured in watts at the rate of heat transfer. The lower the U-Value of a material the better insulator it will be (Insulation Express, 2018).

The essential equation is this:

$$U = 1/R \text{ in W/m}^2\text{K}$$

Thermal Mass:

Relatively with U-Values; 'Thermal Mass'⁷⁰ is the ability of a material to absorb and store heat energy. A lot of heat energy is required to change the temperature of high-density materials like concrete, bricks and tiles. They are therefore said to have high thermal mass. Lightweight materials such as timber have low thermal mass. Appropriate use of thermal mass throughout the building can make a big difference to comfort and heating and cooling bills (Renewable Energy Hub, 2019).

⁷⁰ 'For example water and concrete have a high capacity to store heat and are referred to as 'high thermal mass' materials. Insulation foam, by contrast, has very little heat storage capacity and is referred to as having 'low thermal mass'.



Thermal Mass Checklist:

The simple rules of thumb set out here help determine appropriate thermal mass levels in different climate zones — heating dominated temperate and cold climates, cooling dominated temperate climates, and heating dominated climates with no northerly solar access. Mass levels vary according to:

- solar access (glazing type, orientation, area and shading)
- cool breeze and cool night air access (including mechanical)
- diffuse and ambient heat gains in summer
- night-time sleeping comfort
- occupation patterns and heating/cooling system use seasonal extremes (climate zone) (Reardon, McGee, & Milne, 2013).

Thermal Conductivity:

Thermal conductivity (often denoted by k , λ , or κ) refers to the intrinsic ability of a material to transfer or conduct heat. It is one of the three methods of heat transfer, the other two being convection and radiation. Heat transfer processes can be quantified in terms of appropriate rate equations. The rate equation in this heat transfer mode is based on Fourier's law of heat conduction. Thermal conductivity occurs through molecular agitation and contact, and does not result in the bulk movement of the solid itself. Heat moves along a temperature gradient, from an area of high temperature and high molecular energy to an area with a lower temperature and lower molecular energy. This transfer will continue until thermal equilibrium is reached. The rate at which heat is transferred is dependent upon the magnitude of the temperature gradient, and the specific thermal characteristics of the material. Thermal conductivity is quantified using the International Systems of Unit (SI unit) of $W/m \cdot K$ (Watts per meter per degree Kelvin), and is the reciprocal of thermal resistivity, which measures an objects ability to resist heat transfer (Thermtest, 2019).

Thermal conductivity can be calculated using the following equation:

$$k = Q \cdot L / A(T_2 - T_1)$$

where:

Q = heat flow (W)

L = length or thickness of the material (mm)

A = surface area of material (m²)

$T_2 - T_1$ = temperature gradient (K)

7.4. ROOM THERMAL VALUE CALCULATION

To include the thermal value to the algorithm (via Arduino IDE), one single value for each room has to be calculated. The data extraction from BIM provides the thermal values such as each material R-values, U-values and dimensions, yet, this datasets has to be revised and simplified. Unfortunately, BIM does not give a single number for each room. There is no automatic calculation that is made by the software. Only individual materials or surface thermal values can be exported. A custom made calculation has to be made by using the provided information. The value that is used from each material is the R-value, that stands for the insulation rate in terms of thermal resistance, which also indicates the resistance to heat flow. The higher the R-value, the greater is the insulating effectiveness. This fact defines the threshold values for decision-making of the algorithm.

Heat Loss Coefficient:

'Heat Loss Coefficient' is the heat loss coefficient of the building determines the rate of heat flow through the buildings' envelope when a temperature difference exists between the indoor air and the outdoor air under steady state conditions. Additionally, the total heat flow (H) is the sum of the heat flow by conduction through the various parts of the envelope and the heat flow by air infiltration through the building (when its windows are assumed to be closed) (Givoni, 1985). The heat loss is divided into two groups:

1. The conductive heat losses through the building walls, floor, ceiling, glass, or other surfaces
2. The convective infiltration losses through cracks and openings, or heat required to warm outdoors air used for ventilation.

Normally, the heating load is estimated for winter design temperature usually occurring at night; therefore, in determining the heating load, credit for heat generation from internal heat sources such as lights, machinery, appliances, and people is usually ignored. Also in determining the heating load, credit for solar heat gain is usually NOT included and is generally ignored. Credit for solar heat gain is a plus factor in winter heating (Bhatia, 2005). The overall heat transfer rate for combined



modes is usually expressed in terms of an overall conductance or heat transfer coefficient, U-value. The heat transfer coefficient is the reciprocal of thermal insulation. This is used for building materials (R-value) and for clothing insulation. Higher numbers are good when comparing the Thermal Resistance and R-Values of products. Low numbers are good when comparing U-Values. The U-Value is the most accurate way to judge a material's insulating ability, taking into account all the different ways in which heat loss occurs, however it is more difficult to calculate.

There are numerous methods for calculating the heat transfer coefficient in different heat transfer modes, different fluids, flow regimes, and under different thermo-hydraulic conditions. Often it can be estimated by dividing the thermal conductivity of the convection fluid by a length scale. The total fabric heat loss flow rate, Q_f , will be the sum of all the U-values of the individual elements of the external fabric, walls, roof, floor, windows and doors multiplied by their respective areas multiplied by the inside–outside temperature difference, ΔT (The Open University, 2019).

The equation of heat loss is: (Cork Institute of Technology, 2011)

$$\text{Heat loss} = U \times A \times dT$$

where :

U = U-value (W/m²K)

Thermal transmittance A = Area of surface (m²)

dT = Temperature difference inside to outside (K)

Units of heat loss = Watts

Calculation of the Heat Loss Coefficient of the Room:

The Heat Loss Coefficient is the reference for the calculation of Symbiotic Data Platforms’ algorithm. ‘dT = Temperature difference inside to outside (K)’ is not included in this equation because, the thermal values are going to be used as other inputs in the algorithm, (real-time values) which is explained separately in the following section, by Arduino IDE Calculation test and Revit-Dynamo Calculation Test.

- Floor U-Value x Floor area: *F*
- Ceiling U-Value x Ceiling area: *C*
- Wall U-value x Wall area: *Wa*
- Window U-Value x Window area: *Wi*
- Door U-Value x Door area: *D*

Room Value = $F + C + Wa + Wi + D$

Calculate $\Sigma(AU)$			
Surface	A (m ²)	U (W/m ² K)	A x U (W/K)
External walls	83.95	0.25	20.99
Roof	63	0.15	9.45
Floor	63	0.20	12.60
Windows	31.5	1.70	53.55
Door	1.85	3.00	5.55
$\Sigma(AU)$			102.14

Figure 50: Room Thermal Value Calculation Example



ARDUINO IDE TEST

Arduino IDE is a simple programming language based on C/C++. C++, which is a superset of C, adds classes and changes the behavior of structs in subtle ways. The Arduino IDE is a development environment that combines a text editor and access to the compiler, linker, and uploader in an easy to use method. This development environment can control the physical computing tools and make every desired physical interaction possible.

In this first phase of the calculation, Model 1 is used. In the second phase the calculation is tested for Model 1 yet the final calculation for Symbiotic Data Platform is made by using Model 2 is used since it is more complex and more useful to understand the final testing of the Prototype VII ⁷¹. Through Model 1, the material database that consists the thermal values coefficients have achieved. The database is exported as 'Schedules', from Revit to Excel. By this database, the necessary values are detected to be used for the calculation.

Currently, BIM (Revit, ArchiCAD, etc.) does not have a direct access to Arduino IDE. There are plug-ins and some access

tools by Visual programming softwares such as Dynamo and Grasshopper. Yet, for a unique, new platform, such as Symbiotic Data Platform, a simple and direct data access is needed. During the very first tests of Prototype I and Prototype II, BIM is not included in the Platform. On Prototype III and Prototype IV; BIM data is introduced as a secondary decision making criteria. On the Prototypes III and IV, the BIM database is introduced manually to the code. The extracted data is unified and defined as a simple chart. Then by grouping by the rooms, the U-values of walls, floors, ceiling, doors and windows are introduced to the code for calculation. Below, the structure the calculation by using Arduino IDE code can be seen. This part of the example code is dedicated to the Living Room values of Model 1.

The calculation is done by Revit-Dynamo and Orchid Plug-in as it is explained previously. The room thermal value calculation is done by using this equation:

Wall (Area x λ)

Floor (Area x λ)

Ceiling(Area x λ)

Window(Area x λ)

Door(Area x λ)

Room Thermal Value = Wall (Area x λ) + Floor (Area x λ) +

Ceiling (Area x λ) + Window (Area x λ) + Door (Area x λ)

⁷¹ Check Prototypes Chapter and The Final Prototype: Prototype VII Chapter.

SYMBIOTIC DATA PLATFORM

symbiosis & sensitivity

Room Thermal Value Calculation Algorithm // Prototype III and Prototype IV Receiver Code Part:

```
struct Room {
    float value;
    float threshold;
    String name;
    LinkedList<Detail> *details;
    Coord coord_A;
    Coord coord_B;
    Coord coord_C;
    Coord coord_D;
    float altitude;
};
LinkedList<Room> *singleBIM = new LinkedList<Room>();

Servo Heater ;
Servo Vantilator;
String dataString = "";
String data[2] = {"", "" };
int temp1 , temp2 ;

void setup() {
    Serial.begin(9600);
    // BluetoothHC05.begin(9600);
    Heater.attach(hPin);
    Vantilator.attach(vPin);
    SetupStruct_1();
    SetupStruct_2();
    SetupStruct_3();
    SetupStruct_4();
    SetupStruct_5();
    SetupStruct_6();
    SetupStruct_7();
}

void loop() {
    Serial.print(singleBIM->size());
    for(int k = 0; k < singleBIM->size(); k++){
        Serial.print("\tRoom: " + singleBIM->get(k).name);
        Serial.print("\tValue: " + String(singleBIM->get(k).value));
        Serial.println("\tThreshold: " + String(singleBIM->get(k).threshold));
    }
    /*
    while (BluetoothHC05.available() > 0) {
        dataString = BluetoothHC05.readStringUntil('\n');
        int j = 0 , c = 0;
        Serial.print("/t dataRead: " + String(dataString));
    }
    */
}
```

```
for (int i = 0; i < dataString.length() + 1 ; i++) {
    if (dataString.substring(i, i + 1) == ",") {
        data[c] = dataString.substring(j, i);
        j = i + 1;
        c++;
    }
}
temp1 = data[0].toInt();
Serial.print("\t temp1: ");
Serial.println(String(temp1));
temp2 = data[1].toInt();
Serial.print("\t temp2: ");
Serial.println(String(temp2));
bool u = false;
int h = 0;
while((h < singleBIM->size())&&(!u)){
    if((singleBIM->get(h).value < singleBIM->get(h).threshold)){
        u = true;
    }
    h++;
}
if((u) && (data[1].toInt() < 25)){
    Serial.println("Heater ON");
    TurnOnHeater();
} else if((u) && (data[1].toInt() > 38)){
    Serial.println("Vantilator ON");
    TurnOnVantilator();
} else if((data[1].toInt() >= 25) && (data[1].toInt() <= 38)){
    Serial.println("Both Off");
    Heater.write(0);
    Vantilator.write(0);
}
}*/

void TurnOnHeater() {
    Vantilator.write(0);
    for (int angle = 0; angle < 180; angle += 1)
    {
        Heater.write(angle);
        delay(15);
    }
    delay(1000);
    for (int angle = 180; angle >= 1; angle -= 1)
    {
        Heater.write(angle);
        delay(5);
    }
    delay(1000);
}

void TurnOnVantilator() {
    Heater.write(0);
}
```



```
for (int angle = 0; angle < 180; angle += 1)
{
    Ventilator.write(angle);
    delay(15);
}
delay(1000);

for (int angle = 180; angle >= 1; angle -= 1)
{
    Ventilator.write(angle);
    delay(5);
}
delay(1000);
}

void SetupStruct_1(){
    //default config
    struct Coord nullCoord;
    nullCoord.lat = "";
    nullCoord.lng = "";
}
```

```
struct Detail floor;
floor.u_value = 4.981;
floor.r_value = 0.04;
floor.area = 64;
floor.description = "floor";
```

```
struct Detail wall_ext;
wall_ext.u_value = 4.3333;
wall_ext.r_value = 0.2308;
wall_ext.area = 58;
wall_ext.description = "wall exterior";
```

```
struct Detail wall_int;
wall_int.u_value = 0.2682;
wall_int.r_value = 3.7292;
wall_int.area = 36.8;
wall_int.description = "wall interior";
```

```
struct Detail ceiling;
ceiling.u_value = 3.5626;
ceiling.r_value = 0.2827;
ceiling.area = 63;
ceiling.description = "ceiling";
```

```
struct Detail door_ext;
```

```
door_ext.u_value = 6.8703;
door_ext.r_value = 0.1456;
door_ext.area = 7.04;
door_ext.description = "door exterior";
```

```
struct Detail door_int;
door_int.u_value = 5.5617;
door_int.r_value = 0.1798;
door_int.area = 3.52;
door_int.description = "door interior";
```

```
struct Detail window;
window.u_value = 3.6886;
window.r_value = 0.2711;
window.area = 9.48;
window.description = "window";
```

```
struct Room living;
living.threshold = 0.5;
living.name = "LivingRoom";
living.details = new LinkedList<Detail>();
living.details->add(0, floor);
living.details->add(1, wall_ext);
living.details->add(2, wall_int);
living.details->add(3, ceiling);
living.details->add(4, door_ext);
living.details->add(5, door_int);
living.details->add(6, window);
living.coord_A = living.coord_B = living.coord_C =
living.coord_D = nullCoord;
living.altitude = 0;
living.value = calcValue(living);
singleBIM->add(living);
}
```

```
float calcValue(Room living){
    float result = 0;
    int h = 0;
    while(h < living.details->size()){
        result = result + (living.details->
>get(h).u_value * living.details->get(h).area);
        h++;
    }
    return (result);
}
```

DYNAMO TEST

Dynamo Definition for Generation the Room Thermal Values:

The second Case study is done for testing the Revit-Dynamo Visual programming option for calculating the 'Room Thermal Value' before exporting the schedules and making the calculation inside the algorithm. By this method, the room thermal value is calculated by the visual programming software, with a designed definition for generating this specific value.⁷²



Figure 51: Dynamo Test

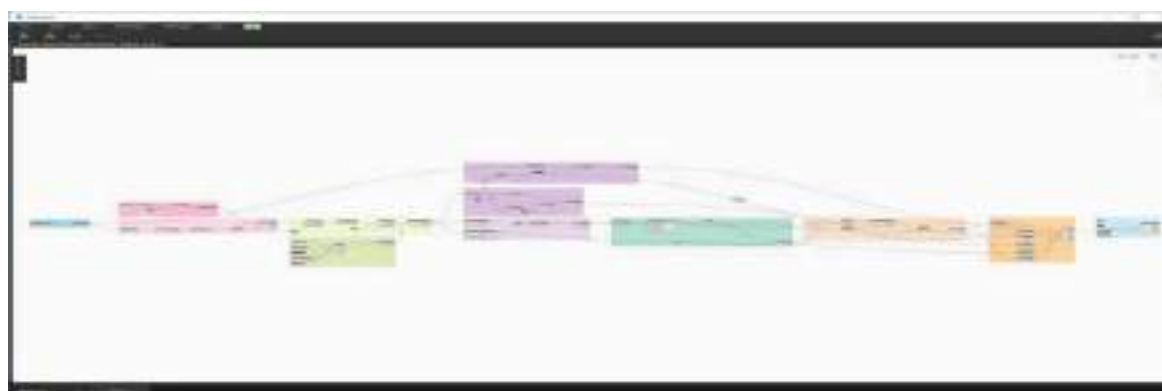


Figure 52: Dynamo Visual Final

⁷² The Dynamo definition for generating room thermal value is explained in detail in the next section.



Orchid Plug-in for Revit + Dynamo:

To have a particular numeric value to be further used in the physical computing code, a single value is needed. Revit is not giving a single thermal value for each room, but in Symbiotic Data Platform, simplifying the dataset by a single numeric value is required to develop the mechanical control decision making in the Arduino code. Previously, an unitary value had to be calculated, as tested in the first phase of the project. On this phase, a similar calculation method by using visual programming language Dynamo is tested.

Revit for Dynamo is creating datasets and makes calculations regarding to achieve the desired value by taking reference to the buildings' information model. To import the thermal values from Revit to Dynamo is complex and not efficient without additional plug-in supports. So that, the most important tool while

calculating those values is the 'Orchid Plug-in' for Dynamo.

"Orchid is a solution designed for use in the Dynamo environment. The solution is designed to support practical, technical, logical, and mathematical issues. In particular, is the solution designed to handle nD-list issues. In addition, are solutions for applications included in the BIM wheel supported, which not necessarily are Autodesk products" (Efajo, 2019). This plug-in allows the user to export the thermal values of each material, by classifying per room or other variables.

The calculation made for each room, by using the data extracted from the BIM Model. In the following section the 8 steps for the specific room thermal value calculation by Dynamo and Orchid Plug-in can be seen.

SYMBIOTIC DATA PLATFORM

usability & sensitivity

1. Inserting Room Tags from the Project:

First of all, calling the Room Tags, from the Revit model is required. By this very first step, 'categories' are defined. The categories are the rooms, and the sub categories are the 'all elements of category' which are the rooms' walls, floors, doors, windows and ceilings.

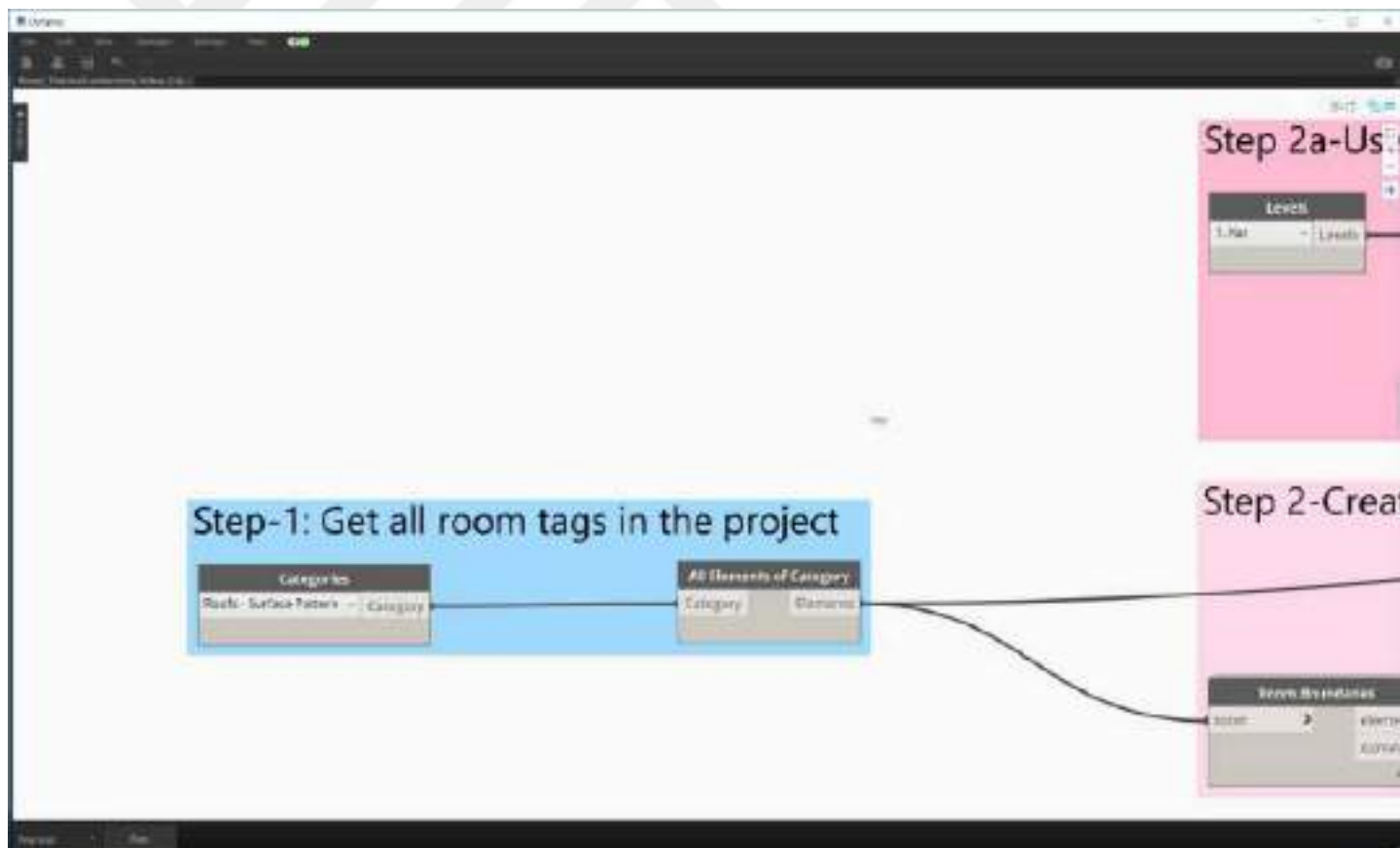


Figure 53: Dynamo Step 1



2. Creating a Cuboid for Room Tags:

Secondly, by taking the all elements reference, a cuboid with the boundaries of room tags is created. This step generates a path to access the dimensions of each room. Additionally, Using 'levels' tool to indicate the cuboid height gives the required height information of the rooms. To conclude the cuboid definition, the room areas height, surface and thickness values are achieved.

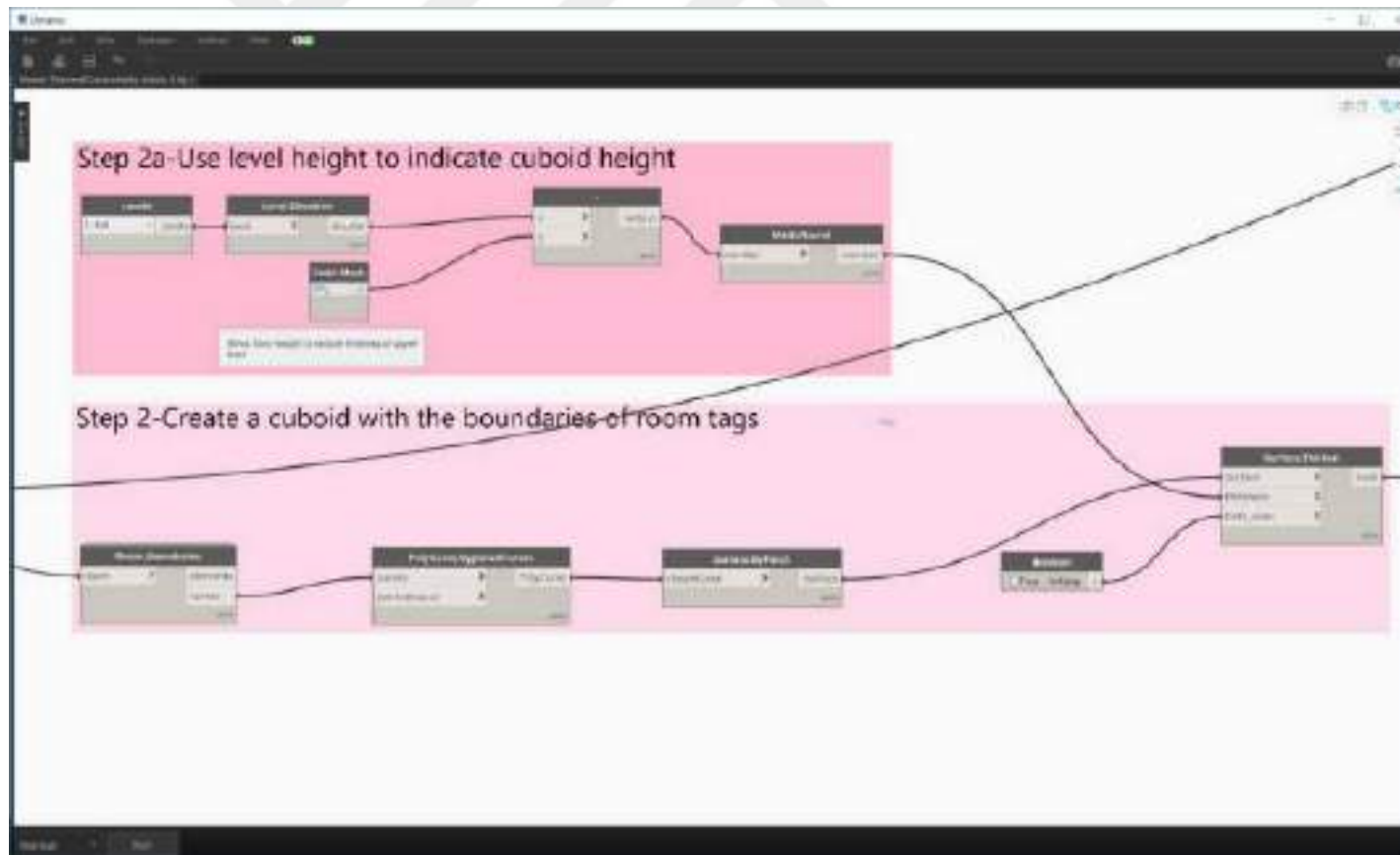


Figure 54: Dynamo Step 2

3. Selection of Required Data:

After receiving the material tags and the dimensions of the rooms, the cuboid is transformed into a bounding box that choose the elements inside of the room tags. To do so, a decision making definition is done by subcategorizing the elements by walls, floors, doors, windows and ceilings (on Step 3a). Then the lists are simplified and as conclusion of this step, the elements are exported to the step 4.

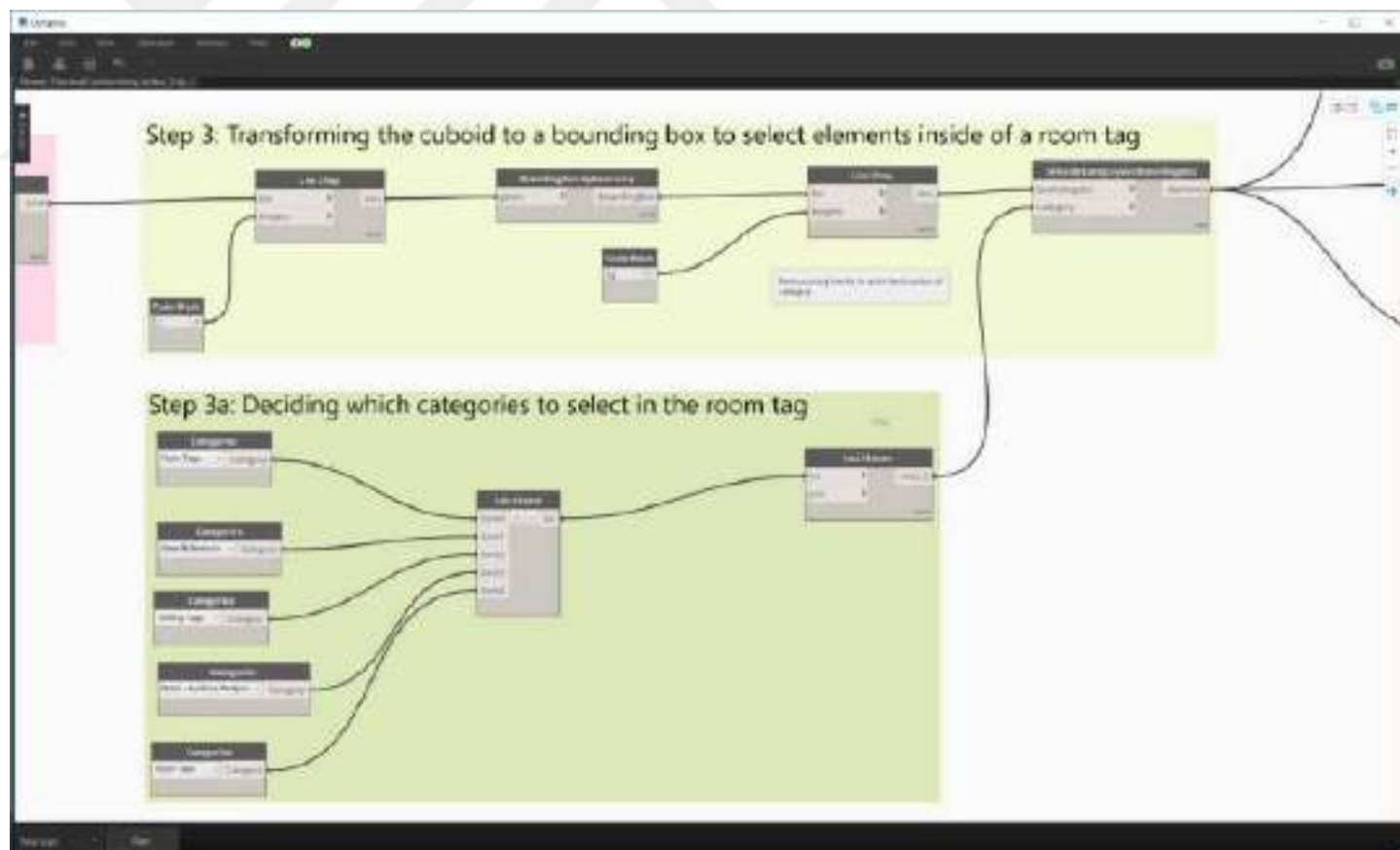


Figure 55: Dynamo Step 3

The extracted list of the materials subcategorized, creates another list by 'Element.Materials+' tool, that unites the elements material, elements area and elements volume.

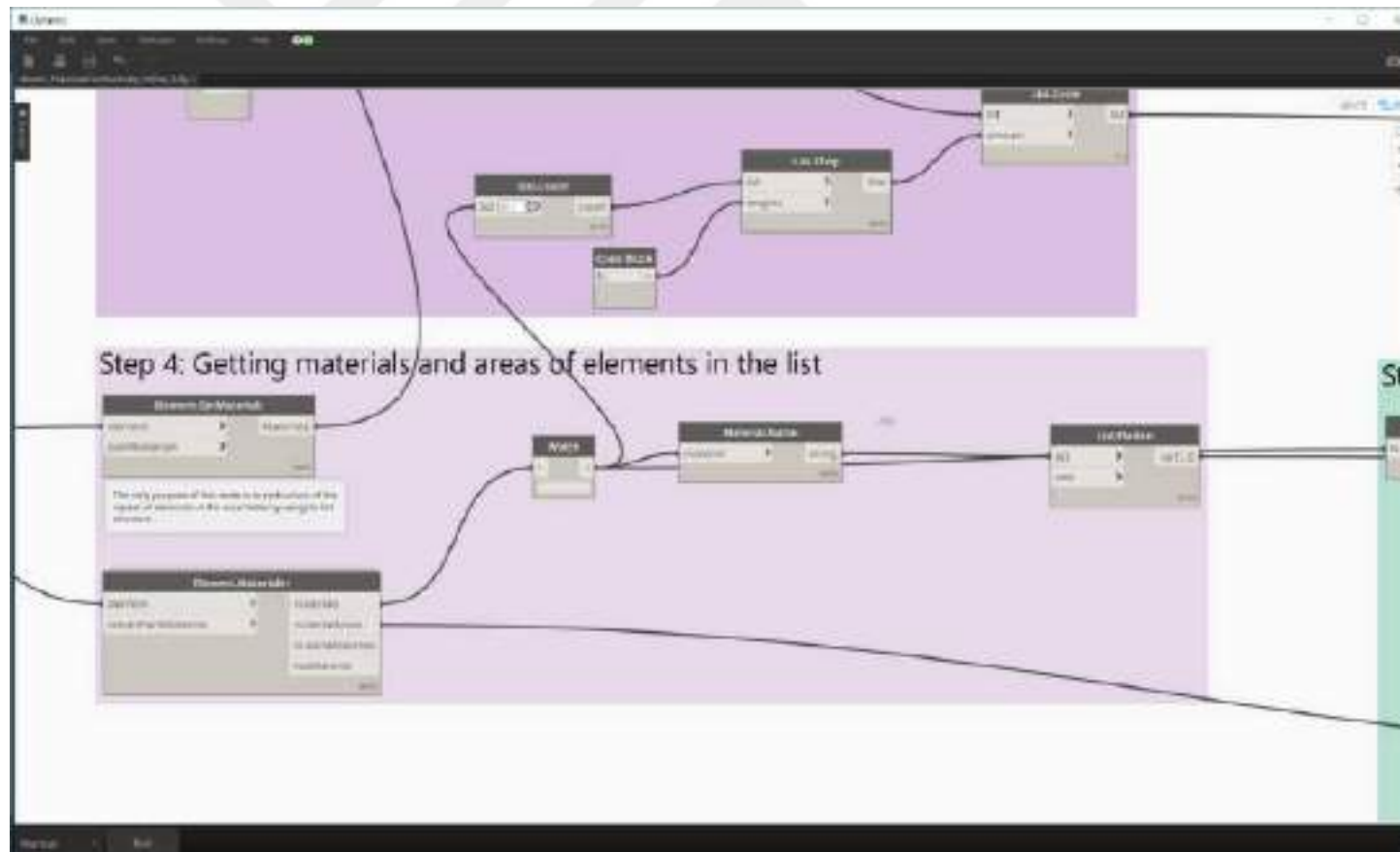


Figure 56: Dynamo Step 4

SYMBIOTIC DATA PLATFORM

resilibility & sensitivity

4a and 4b. Organization of data for Excel Sheet:

The Step 4 list gives reference to both 4a and 4b, by repeating the element names as many as material layers count and by repeating the room tags as many as material layers count for the final step that will export the calculate the value and export the result as an excel chart.

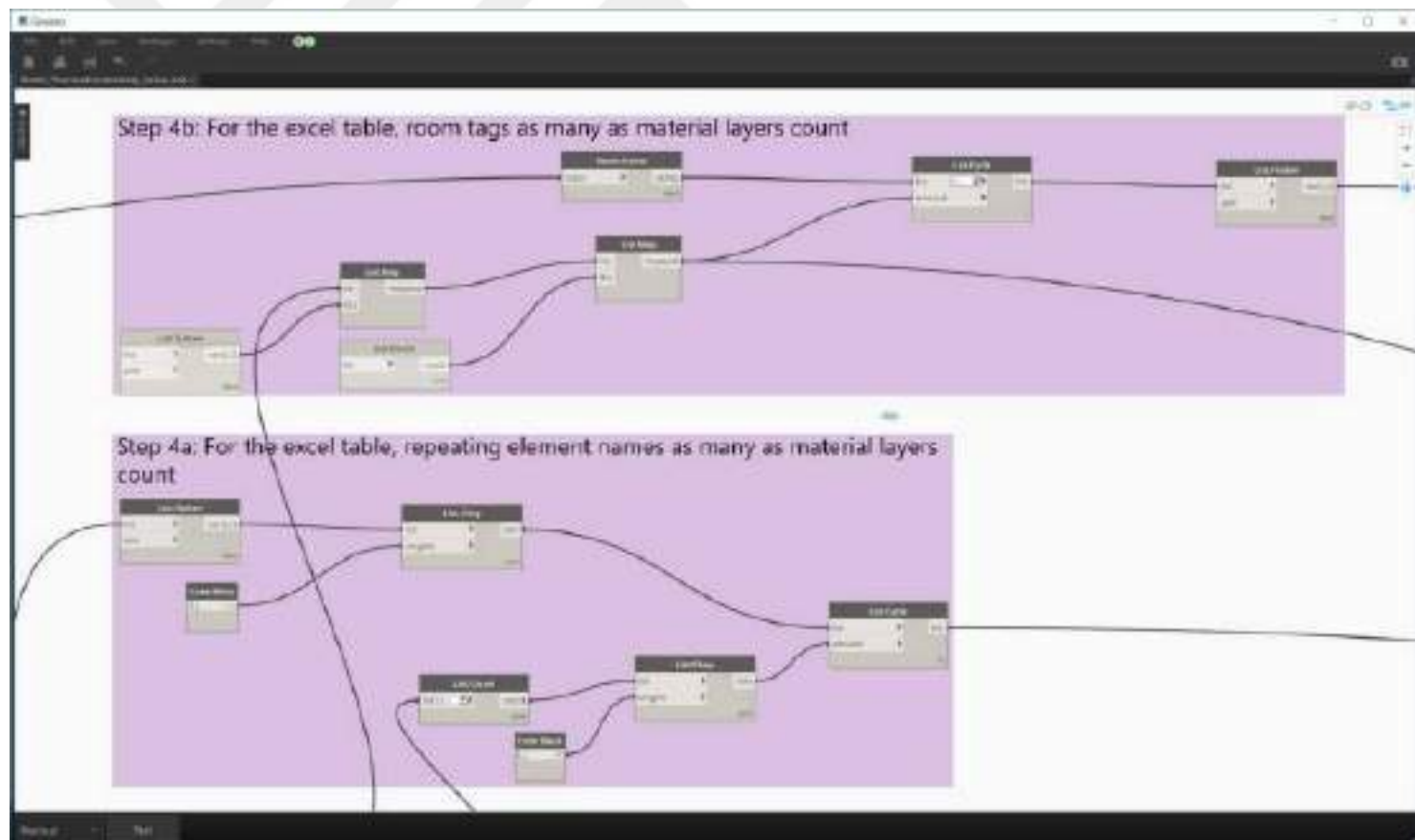


Figure 57: Dynamo Step 4a and Step 4b



5. Calculating the Thermal Conductivity:

The references taken from the previous step, the 'Thermal Conductivity' value is calculated by 'ThermalAsset.GetBasicThermal' tool. The thermal conductivity of a material is a measure of its ability to conduct heat. It is commonly denoted by k , λ : lambda, or κ : kappa. By this step, the thermal conductivity is calculated by each subcategory, and multiplied by the area, so that a unique numeric value is achieved.

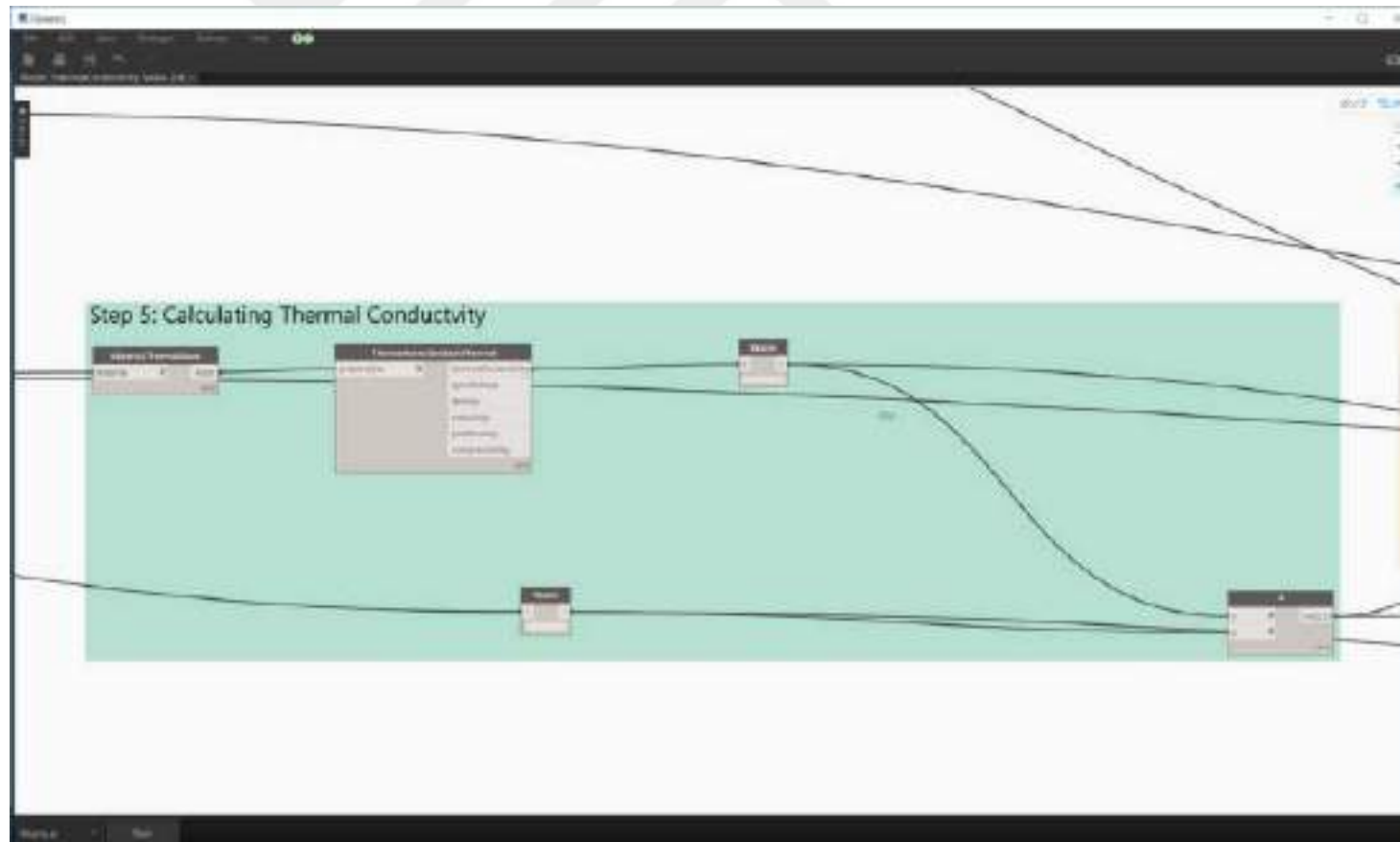


Figure 58: Dynamo Step 5

6. Calculating the Room Thermal Value:

After generating a thermal conductivity coefficient of each material, under the subcategories of each room tag, the associate subcategorized elements are summed up. This calculation generates the 'room thermal value'. On Step 6, calculation of room thermal vale and repeating the value as many as the materials layers count generates the new database for the excel chart.

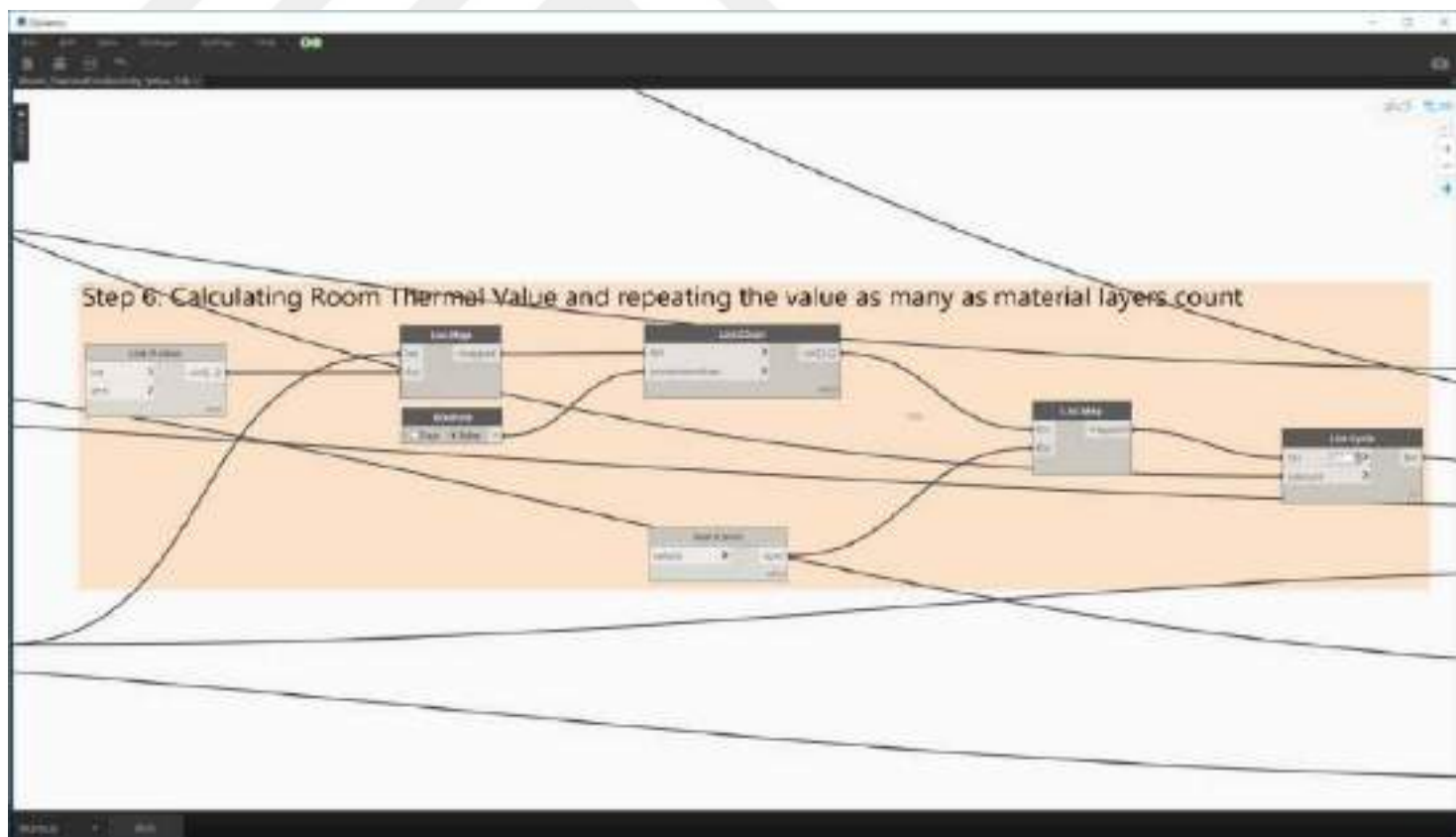


Figure 59: Dynamo Step 6



7. Transposing the List:

To rearrange and list down the values in a correct order, the previous steps are transposed by using 'List.Flatten' and 'List.Create' tools. The items are named as item 0,1,2,3,4,5,6,7 which are the calculated thermal values of rooms and the dimensions.

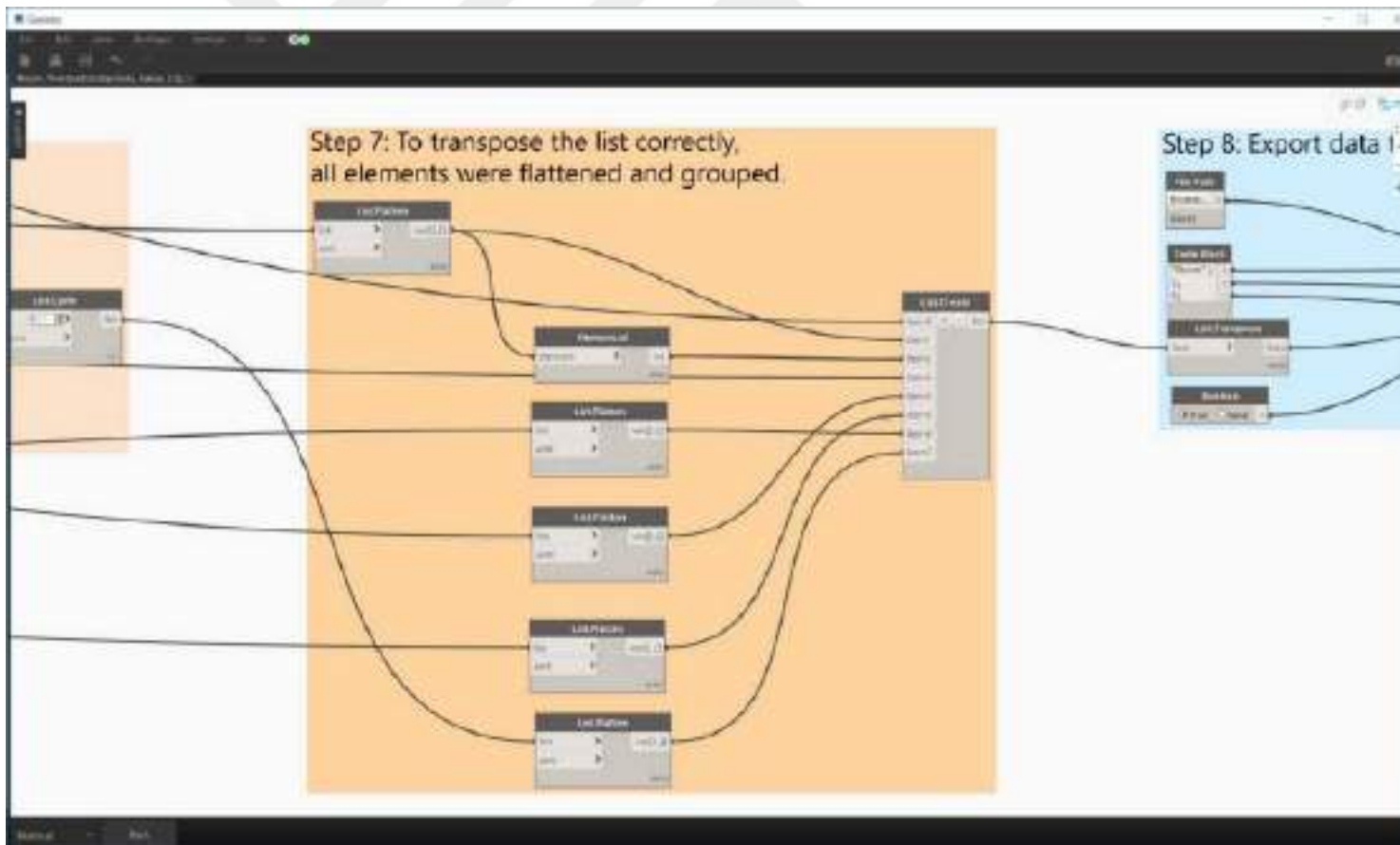


Figure 60: Dynamo Step 7

8. Exporting the data to Excel Sheet:

By the last list, using the 'List.Transpose' tool, the data is imported, to be exported to the excel sheet. The file path is defined as Excel, and the 'Data.ExportExcel' tool concludes the data variables. The exported excel sheet can be seen in the following section.

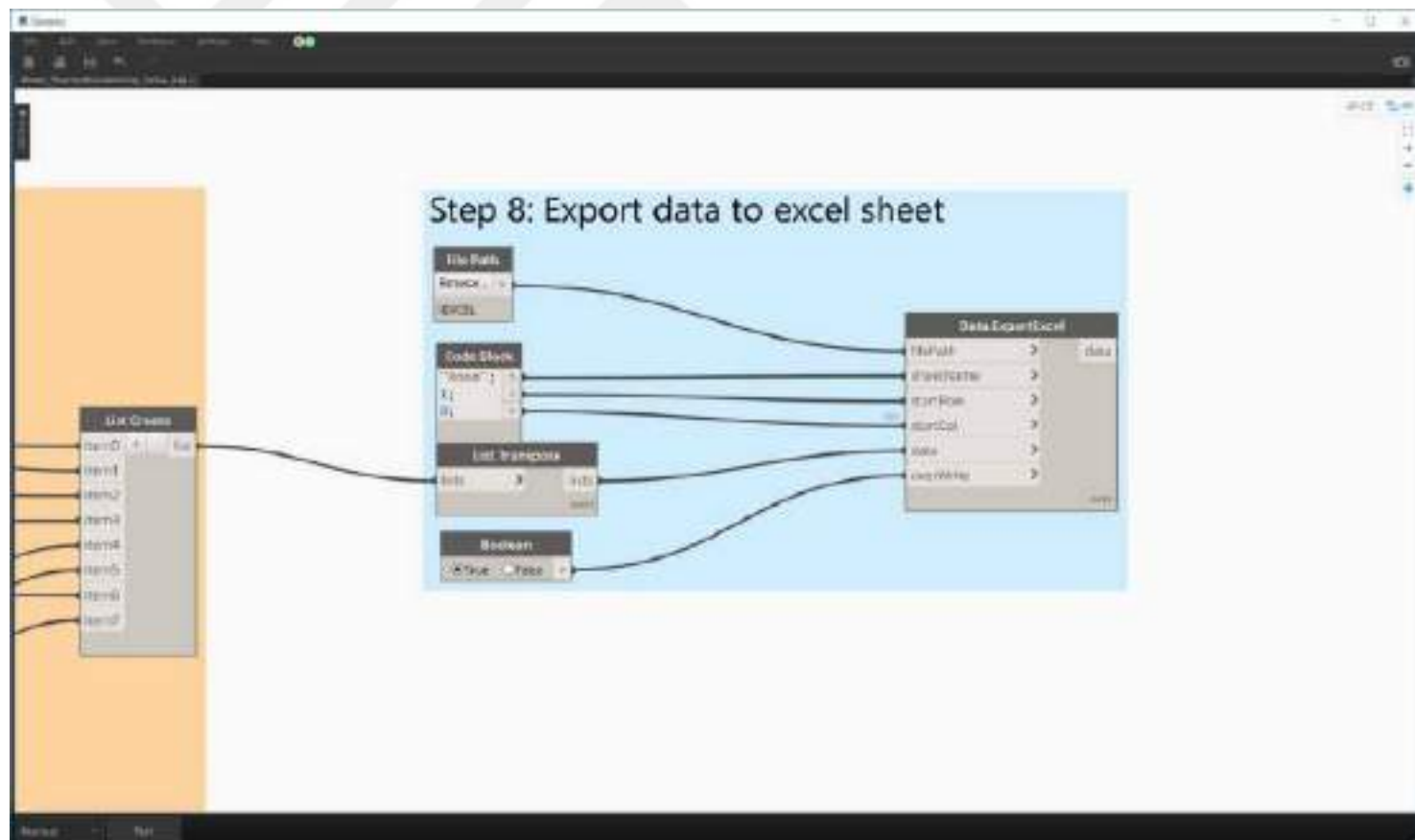


Figure 61: Dynamo Step 8



Results from the calculation:

ROOM NAME	CALCULATED THERMAL VALUE
Enterance	52,94717842
Main Corridor	56,27938296
Corridor	481,9206086
Main Corridor - 2	661,8689535
Guest Room	735,7690305
Kitchen	77,63025761
Childs Room - 1	438,6802486
Childs Room - 2	59,81022136
Saloon	28,85389628
Dining Room	619,2786224
Dining Room - 2	93,70281082
Bathroom	696,7140531
Living Room	580,4025029
WC - 1	501,290129
WC - 2	509,603821
Terrace	272,79737
Terrace - 2	250,5027192
Garden	28,85389628

Figure 62: Dynamo Calculation for Room
Thermal Value / Duplex Villa Results



In this specific case the values are between 0 and 1000, where the best thermal quality has the highest numeric value. Yet, in this test, the highest value is 735,7690305, from the 'Guest Room'. Controversially, the lowest value is 28,85389628 from the 'Saloon', which is a very negative outcome. Apart from the interiors, the semi-open exterior spaces can also have the thermal value calculated, such as 'Garden'.

Those values are variable even in the same house and from the global location, because, the location of the room, sun-position, material, openings and heating-cooling elements. Also, inside of the same building, the rooms thermal quality might show a significant variation between each other, depending on the same factors listed above.

Most importantly, the calculated room thermal value is the data that defines the threshold for the Prototypes decision-making. The numeric values give a reference for the thermal quality of the room to the system. The platform is responsible to identify the insulation quality and the surrounding environments thermal quality, also by evaluation the real time exterior weather and interior thermal information.

By this holistic evaluation approach that is processed in real time would give the desired thermal comfort for each user. The user

is the occupant of the building by taking real references from real situations and using BIM without any prior knowledge required. By this platform, occupants can access and use actively the existing BIM data. Consequently, using accurate and exact data eliminates the excess energy consumption and the superfluous use of natural recourses. As a result, the thermal comfort is optimized while spent energy is decreased and expanses are reduced.

8
PROTOTYPES

8. PROTOTYPES

Establishing the hypothesis of Symbiotic Data Platform requires the testing of the proposed system to be proven, and it is necessary to demonstrate the function of the possibility is approved. To do so, right after modeling the cases and extracting the database, the design and development of the prototypes have been done. The prototypes and the interactive platform enable the building to feel and react to the current thermal condition and correspondingly; the occupants' body by thermal comfort. Main aim is to optimize the users thermal comfort by using real material information, and users real-time body temperature. The main objective to design a personal data collection device is to define the 'real-time data tracking' stage and to create 'human to machine', 'machine to machine', 'machine to human' and 'human to environment' interactions.

In this specific project, the prototypes are designed as lightweight wearable or mobile devices, that are going to be one of the daily-life objects. In current practice, the Symbiotic Data Platform Prototypes are simple and raw sensors, yet in further research, the prototype could be embedded to a smartphone as

an additional feature, and the interface could be a default application for smart user. Even, with this foresight, this project could propose a network of shared data, for a bigger scale energy efficiency image. *"Wearable computers allow a much closer association with the user... The sensors allow the wearable to see what the user sees, hear what the user hears, sense the user's physical state, and analyze what the user is typing. If this information is combined into a user model, an intelligent agent may be able to analyze what the user is doing and try to predict the resources he will need next or in the near future"* (Starner, et al., 1997). As Starner stated back in 1997, currently, it is proven that his foresight became a reality. For the future, using the input from these interface devices and sensors, a long-term goal of this project is to model the user's actions, anticipate his or her needs, and perform a seamless interaction between the virtual and physical environments.



Figure 63: MLX90614 Non-contact Infrared Thermometer / Sensor (Melexis, 2013)



The most important device of this test is the **Non-contact Infrared Thermometer MLX 90614 by Adafruit Industries**. This cybertronic looking sensor hides a secret behind its glimmering eye. Unlike most temperature sensors, this sensor measures infrared light bouncing off of remote objects so it can sense temperature without having to touch them physically. Simply by pointing the sensor towards the object to detect the temperature by absorbing IR waves emitted. Because it doesn't have to touch the object it's measuring, it can sense a wider range of temperatures than most digital sensors: from -70°C to $+380^{\circ}\text{C}$. It takes the measurement over a 90-degree field of view so it can be handy for determining the average temperature of an area. This sensor comes in an easy-to-use metal can. It is

easily soldered according to the required design, or it can be plug it into a breadboard. The four pins are used for power, ground, i2c clock and i2c data. There are two versions, one for 3V power and logic levels and one for 5V power and logic levels. *"Thanks to its low noise amplifier, 17-bit ADC and powerful DSP unit, a high accuracy and resolution of the thermometer is achieved"* (Melexis, 2013). Some specifications of MLX90614: *Factory calibrated, -40°C to $+125^{\circ}\text{C}$ for sensor temperature - 70°C to $+380^{\circ}\text{C}$ for object temperature $\pm 0.5^{\circ}\text{C}$ accuracy around room temperatures High accuracy of 0.5°C over wide temperature 90° Field of view, 5V version: 4.5 to 5.5V power, 3V version: 2.6 to 3.6V power, I2C interface, 0x5A is the fixed 7-bit address* (Melexis, 2013).

PROTOTYPE



8.1. PROTOTYPE I

PROTOTYPE I	Transmitter	Receiver
Time Period	January - February 2018	January - February 2018
Variables	Ambient Temperature User Body Temperature	-
Hardware		
Micro-Controller	Arduino Lilypad	Arduino Uno
Sensor	MLX90614 Infrared Thermometer	-
Motors	-	1 Servo Motor
Other Tools	FDTI Cable	Battery
Wiring Type	Wired	Wired
Connection Type	Wired	Wired
Software		
Processing	Arduino IDE	Arduino IDE
Purpose	Testing the connections	Testing the connections
Function	Proving the connection	Proving the connection
BIM Data	No	No
Errors	-	-
Conclusion	The connection between Arduino Lilypad + MLX90614 Infrared Thermometer and the Servo-Motors that symbolize the heater and Cooler is set up successfully.	

Figure 64: Prototype I – Checklist

SYMBIOTIC DATA PLATFORM

symbiosis & sensitivity

The prototypes of Symbiotic Data Platform are creations of a new tool, by combining two existing technologies, 'BIM and IoT' (real-time data). This also can be described as: 'interactive // occupant operated BIM Tool'. To do so, the first attempt to test is the 'Prototype 1'. **This prototype collects the body temperature data by only surfaces, to collect real-time relation with existing thermal condition of the space.** By the hardware, the sensor collects the body temperature of the user 'passively, by some time periods,' and the algorithm, checks if any change has to be done to stabilize the desired & personified thermal comfort level. Aim of the prototype is, visualizing occupant behavior and controlling the optimum comfort of the occupant and enhance energy efficiency and productivity. Collecting data is processed by the data tracking device / Prototype 1. The collected data is used for personalizing the thermal quality of the private space within the real-time crosscheck that is provided by the IoT system, and the BIM data verification by the custom-made code.

Arduino UNO Board:

Arduino Uno is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16

MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.. You can tinker with your UNO without worrying too much about doing something wrong, worst case scenario you can replace the chip for a few dollars and start over again. "Uno" means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases.

The Uno board is the first in a series of USB Arduino boards, and the reference model for the Arduino platform; for an extensive list of current, past or outdated boards see the Arduino index of boards (Arduino, 2019). The Arduino UNO is the best board to get started with electronics and coding. It is the most used and documented board of the whole Arduino family regarding its simplicity and quality of required results. Connection of the UNO board with an A B USB cable; sometimes this cable is called a USB printer cable. In the first prototypes, Arduino Uno is used as the Receiver Device microcontroller.



Figure 65: Arduino Board (Arduino, 2016)

Arduino Lilypad Board:

The LilyPad is designed for e-textiles and wearables projects. It can be sewn to fabric and similarly mounted power supplies, sensors and actuators with conductive thread. The LilyPad Arduino Main Board is based on the ATmega168V (the low-power version of the ATmega168) or the ATmega328V. The LilyPad Arduino was designed and developed by Leah Buechley and SparkFun Electronics. The device can be powered via the USB connection or with an external power supply. If an external power supply is used, it should provide between 2.7 and 5.5 volts. This can come either from an AC-to-DC adapter (wall-wart) or battery (Arduino, 2019).

Features:

- 5 Digital I/O pins and 4 Analog pins
- ATmega328
- Built-in ON/OFF switch
- Built-in power supply socket (JST connector) for a 3.7V LiPo battery and charging circuit (no additional battery charger needed)
- Simplified layout with less pins, giving more space for sewing or less complex projects (Sparkfun, 2017).

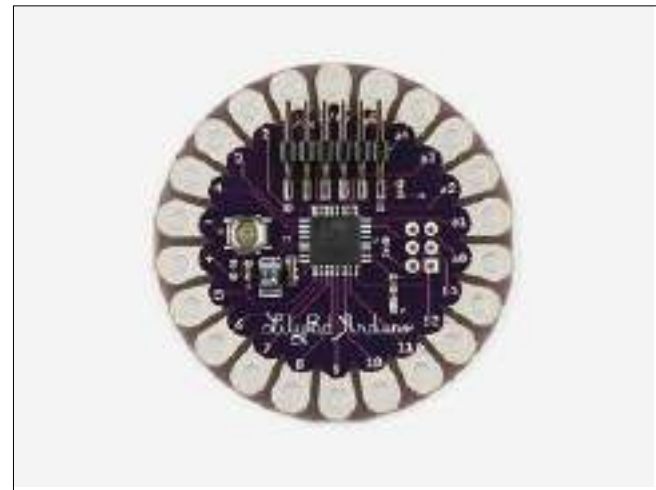


Figure 66: Arduino Lilypad Main Board (Arduino, 2019)

SYMBIOTIC DATA PLATFORM

symbiosis & sensitivity

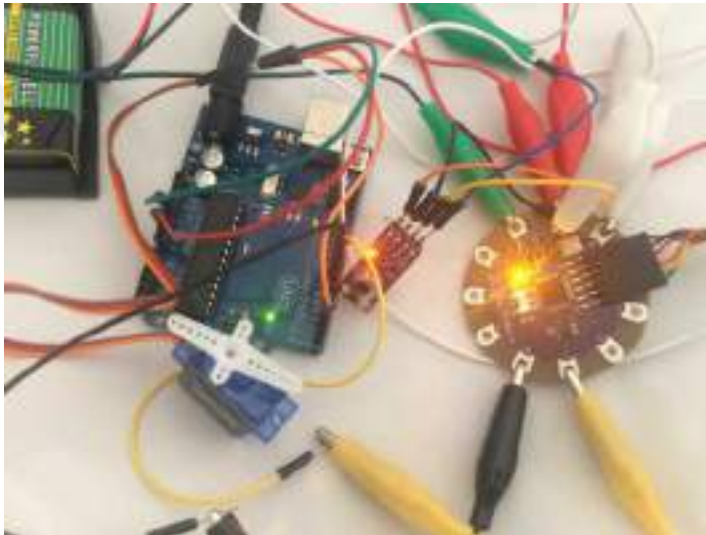


Figure 67: Prototype I - Schematic

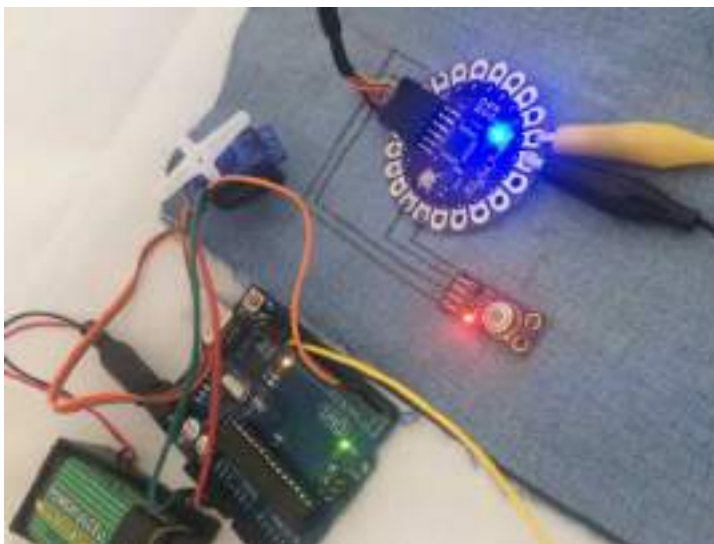
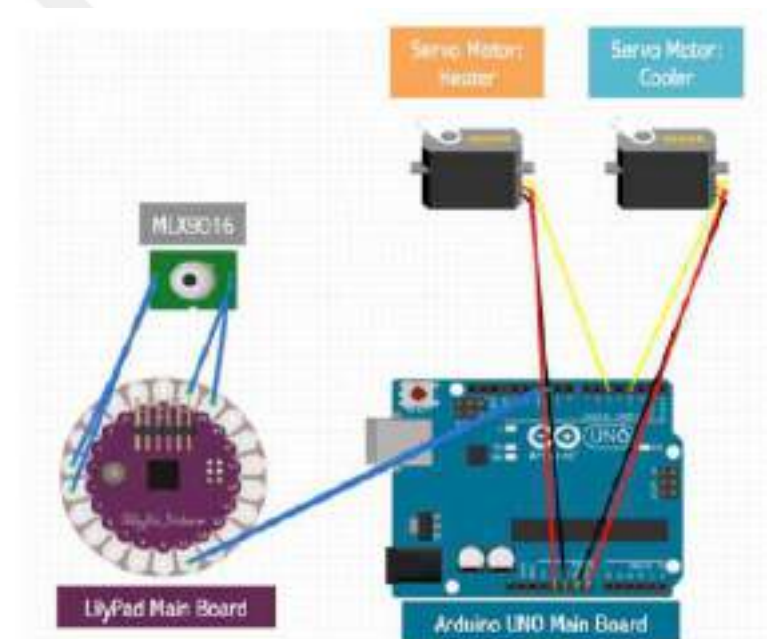


Figure 68: Prototype I

Figure 69: Prototype I



This Prototype is the first trial on the way of testing if the sensor and the Arduino boards are compatible. To do so, simply, 1 Arduino Lilypad main board is connected to 1 MLX90614 Non-Contact Infrared Temperature Sensor Module. This first part is defined as 'Transmitter Module'. Followingly, this transmitter module is connected from the pins, 10 and 11 (because they act as the TX and RX pins on Arduino Lilypad Main board), to the TX and RX pins on the Arduino Uno Main Board, which is the 'Receiver Module'.

The Receiver Module is connected to 2 Servo - motors, that symbolize the 'Heater' and the 'Cooler' devices. In theory, those Servos – motors, on a bigger scale would be the electronic controller of the heater system (Electric water heater, natural gas central heating boiler, or the HVAC system (ventilator, or AC).

On this very first Prototype, there is no BIM data interaction. Hence, the code is simple and there is no additional data is embedded in the code. The programming language is chosen as Arduino IDE. As a result, when the user gets closer by hand, or touches the MLX90614 Non-Contact Infrared Temperature Sensor, the system automatically calculates the indoor and the surface (hand) temperature and uploads it to the receiver module. Then the receiver module checks if any modification on

HVAC (2 symbolic servo motors) should be done. The threshold for the surface (users' hand) temperature is defined as 18 Celcius degrees for heater activation, and 27 Celcius degrees for cooler activation. This test does not give satisfactory results for motor control. After many tests to define the hand temperature treshold, final definition is done as 36 Celcius degrees for heater activation, and 38 Celcius degrees for cooler activation.

PROTOTYPE



8.2. PROTOTYPE II

PROTOTYPE II	Transmitter	Receiver
Time Period	March - April 2018	March - April 2018
Variables	Ambient Temperature User Body Temperature Location (GPS)	BIM Extracted Material data
Hardware		
Micro-Controller	Arduino Lilypad	Arduino Uno
Sensor	MLX90614 Infrared Thermometer	-
Motors	-	2 Servo Motors (Heater and Cooler)
Other Tools	FDTT Cable GPS Module Battery	Battery
Wiring Type	Wired	Wired
Connection Type	Wired	Wired
Software		
Processing	Arduino IDE	Arduino IDE
Purpose	~~Design and simplification~~ Proving the location tracking Testing the location tracking	Testing the connections
Function	Sensing the real-time object temperature	Proving the material data
BIM Data	No	Yes
Errors	Location accuracy Connectivity Material quality	-
Conclusions	Global location tracking is set up successfully, yet, the results are not as accurate as to be used for indoor location tracking.	

Figure 70: Prototype II – Checklist

Since the data-flow constantly updates the HVAC system, without the user giving commands of making manual changes; the house can adjust the optimum thermal state for the user. On further stages of the research project, the platform will be developed as an interactive mobile app. As it can be seen on the mock-up examples of the application proposals for 'Symbiotic Data Platform', the simulations and the energy usage visualizations are guiding the user for developing a conscience for energy efficiency and sustainable use, as well as automatically modifying the thermal condition in real-time by the automatized / personalized code.

On this second prototype, the objective is to modify the initial device and the interface of the platform is to investigate on making benefit of already existing BIM files to extract construction details and information, to a new algorithm that will blend real-time weather/thermal information and also, the users' body temperature data by sensor interaction. Also the users' comfort threshold is tested again. The custom algorithm of the platform aims to interlace these variables, to create a real-time energy analysis, which thereafter optimizing thermal comfort by users real-time data and energy savings by making the physical adjustments in the HVAC System of the specified space.

Arduino Lilypad GPS Module:

Lilypad GPS Module, also known as Flora Wearable Ultimate GPS Module is used in this prototype. This module is the best way to add a GPS to your wearable project. It's part of the Adafruit Flora series of wearable electronics, designed specifically for use with the Flora motherboard. Installed on the PCB is the latest of our Ultimate GPS modules, a small, super-thin, low power GPS module with built in data-logging capability. This module is easy to use and powerful due to location tracking. Has 165 dBm sensitivity, 10 Hz updates, 66 channels. It is designed for wearable use with the Flora system and only 20mA current draw is used. It is RTC battery-compatible - sew a battery on to create an atomic-precision real time clock. It has a built-in data logging and internal patch antenna + u.FL connector for external active antenna. Shows the working status by the fix status LED (Adafruit, 2019).

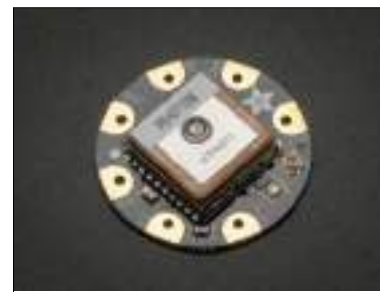


Figure 71: Flora GPS Module (Adafruit, 2019)



Hardware – Prototype II

Hardware of the prototype includes for the transmitter; the Arduino Lilypad Mainboard, GPS Module, a button for confirming the location, and for receiver, the same as Prototype I. The data transfer is made with wired connection, as shown in the schematic (see Figure 72).

The application will collect real time data of body temperature. Following the data collection, the program will analyze the environmental comfort qualities, and adapt the personal real-time data to the existing ambient situation. The variables are BIM - material data of the building, body temperature, environmental thermal analysis, HVAC types and efficiency, daily energy analysis. The output of the algorithm is the users desired thermal quality, and the modification of the HVAC according to an automated platform through the integration of BIM and IoT in real-time. Also the location information is added by the GPS Module, and the push button is used for marking the location. When the user is entering the indoor location, the button is pushed.

The device simply collects the users body-temperature within 10-minute time lapses. Every time that the user holds the smartphone, is a passive data collection for the platform. The data constantly get uploaded to the system. Additionally, the

user can monitor and visualize the collected data, as well as the energy usage datasets, the 3D BIM of the private space and also the real-time mapping of the energy analysis. The prototype and the algorithm working vice-versa will stabilize the energy usage, enhance productivity, optimize occupant satisfaction, create a sustainable solution and act as a responsible factor in contemporary world.

The Interface – Prototype II:

The transmitter code is the same for Prototype I and Prototype II since the devices are the same. The only change of the code is on the receiver part, by the variables of the prototype. Also, inclusion of BIM data is tested in this prototype. On this phase, R-Values of the materials are introduced manually and calculated with a simple calculation in the algorithm to generate a single room thermal value. The values are added to the receiver code then the calculation makes an average regarding to the thermal mass calculation.



The Variables of the Prototype II is as following:

1. BIM Extracted:

Construction materials, opening details, location and orientation and insulation materials coefficients' data (R-Values and Area & Dimension information)

2. Real-time ambient (interior) temperature data:

Indoor thermal information from the infrared thermometer 'Prototype II'.

3. Real-time body temperature data of the user:

Users' body temperature data form the 'Prototype II'.

4. Location Data from Flora GPS Module:

Gives the location of the transmitter prototype in global positioning system.

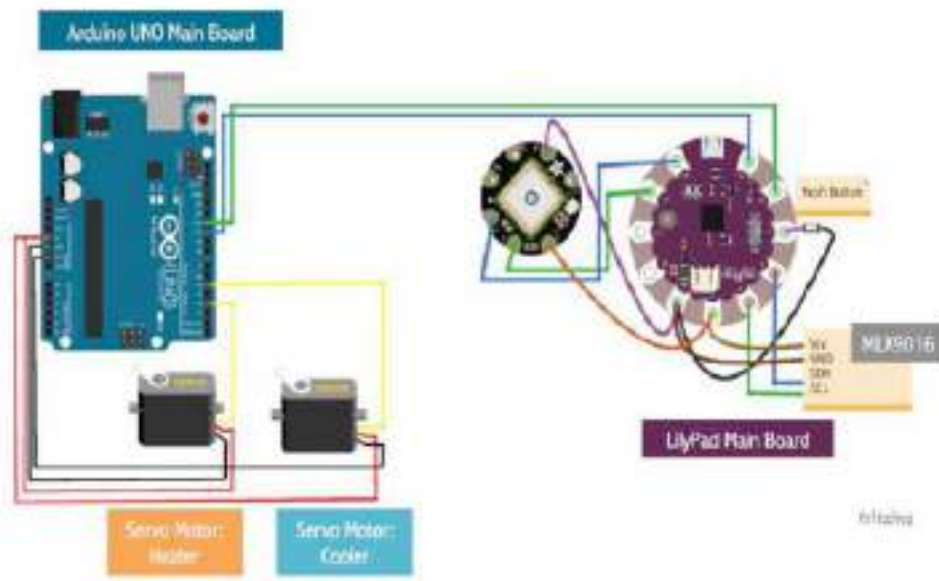


Figure 72: Prototype II – Schematic

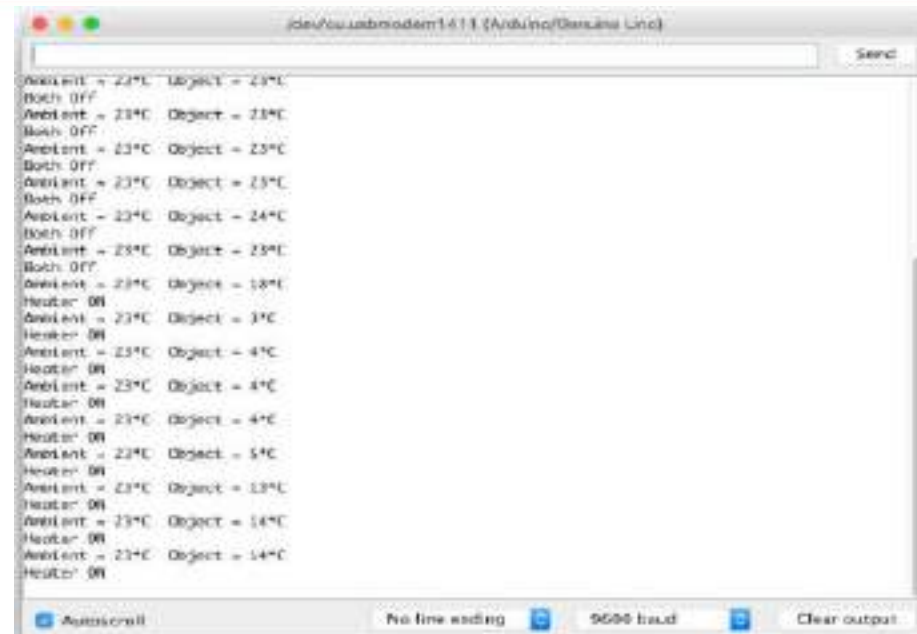


Figure 73: Prototype II – Serial Monitor



On Figure 73, as the serial monitor shows, the symbolic heater and cooler servo motors function according to the real time temperature data can be seen. Additionally, the code for the transmitter device and the receiver device (see Figure 74 and Figure 75) and the results of the HVAC operation are documented.

Currently, the importance of digital and technological transformation is incontrovertible while designing and developing projects with added values. Since the platform has a receptive hardware and responsive software, it offers a personalized environment to the user and, it determines the ideal comfort situation, and sets the ideal energy usage for the daily life.



```

% Parameters
fc = 100e6; % Carrier frequency (Hz)
fs = 100e6; % Sampling rate (Hz)
N = 10000; % Number of samples
M = 16; % Modulation order (16-QAM)

% Generate random data
data = randi(15, N, 1);

% Modulate the data
[re, im] = modulate(data, M, fc, fs);

% Plot the modulated signal
plot(re, im, 'b');
axis([-10, 10, -10, 10]);
title('Modulated signal (re, im)');

```

Figure 74: Prototype II – Transmitter Code

```

% Parameters
fc = 100e6; % Carrier frequency (Hz)
fs = 100e6; % Sampling rate (Hz)
N = 10000; % Number of samples
M = 16; % Modulation order (16-QAM)

% Demodulate the signal
[re, im] = demodulate(re, im, M, fc, fs);

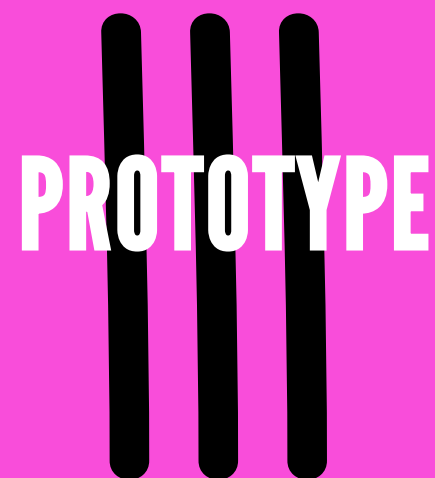
% Plot the demodulated signal
plot(re, im, 'b');
axis([-10, 10, -10, 10]);
title('Demodulated signal (re, im)');

% Recover the data
data = demodulate(re, im, M, fc, fs);

% Plot the recovered data
plot(data, 'b');
axis([0, N, 0, 15]);
title('Recovered data');

```

Figure 75: Prototype II – Receiver Code





8.3. PROTOTYPE III

PROTOTYPE III	Transmitter	Receiver
Time Period	May – June 2018	May – June 2018
Variables	Ambient Temperature User Body Temperature Location (GPS)	BIM Extracted Material data
Hardware		
Micro-Controller	Arduino Lilypad	Arduino Uno
Sensor	MLX90614 Infrared Thermometer	-
Motors	-	2 Servo Motors (Heater and Cooler)
	FDTI Cable GPS Module	
Other Tools	XB24C ZigBee Xbee Shiled XB24C ZigBee Wireless Connection Board Push button Battery Cells, Coin Battery	Battery XB24C ZigBee Xbee Shiled XB24C ZigBee Wireless Connection Board
Wiring Type	Sewed	Wired
Connection Type	Wired	Wired
Software		
Processing	Arduino IDE	Arduino IDE
Purpose	Wearable Patch Wireless Connection Location tracking	Testing the connections
Function	Proving the location tracking Testing the location tracking	Proving the material data
BIM Data	No	Yes
Errors	Location accuracy Connectivity Material quality	-
Conclusion	Wireless connection is set up successfully, but the location tracking is not working as desired. The design and the connections have to be secured, the prototype is very sensitive and fragile.	

Figure 76: Prototype III – Checklist

In this prototype, the objective is to install the wireless connection, so as to enable the prototype to be mobile. The added value of wireless connection method is pointed out as following;

“This “wirelessness” is essential whenever you want to place sensors where no cables can be installed, or where such tethering is undesirable. With radio, you can employ sensing and actuation in pristine natural settings, minimalist building interiors, or complex urban environments. Mobile devices like children’s toys can benefit greatly by being communicative without being chained to the wall or to each other. Sensors can be attached to people or animals in a humane manner that doesn’t hinder their movement. In short, lots of data can move freely from where it is gathered to where it can do the most good. That’s why wireless is worth it” (Faludi, 2010).

Arduino Lilypad Main Board, Arduino Lilypad Xbee Shield, (2x - XB24C - ZigBee Connection), MLX90614 Non-Contact Infrared Temperature Sensor Module, 2x - Xbee Explorer Modules, cables, battery holders and coin cell batteries, and the ‘Receiver’ device is consisted of a main Arduino Uno Board, 2 Servo Motors (that symbolizes the heater and cooler devices), a main computer and a smartphone.

The device have been designed as a smartphone cover, yet could be used as any other wearable when it’s detached; since it’s lightweight and simple. Also, this device can connect both the smartphone and the main computer by the XBee Bluetooth Shields via the application, so that the mobile phones’ GIS information is also available for the platforms network.

Xbee Module:

To have a wireless connection, in this prototype the Xbee devices are used, due to Arduino Lilypad has a specific module for Xbee’s. Xbee devices have 2 series; “Series 1 XBee modules are quite popular with the do-it-yourself crowd, while Series 2 hardware supports the full ZigBee protocol. Series 1 is great for simple cable replacements and smaller-sized systems. Series 2 is designed with larger sensor networks in mind and is essential for the robust interactions with the ZigBee standards-based systems that are now being widely deployed in residential, academic, and commercial settings. The Series 2 hardware has a little better range and uses slightly less power than the Series 1; yet these small improvements would not be a reason to choose one format over the other. Both use the same physical footprint and can be easily interchanged, often with only minor changes to the underlying software. However, the Series 2 will



not talk to or interoperate with the Series 1 at all. Each network must use only one version” (Faludi, 2010).. **Figure 77** shows a summary of the similarities and differences.

	Series 1	Series 2
Typical (in door/urban) range	30 meters	40 meters
Best (line of sight) range	120 meters	120 meters
Transmit/Receive current	45/50 mA	40/40 mA
Firmware (typical)	802.15.4 point-to-point	802.15.4 ZigBee mesh
Digital input/output pins	8 (plus 1 input-only)	11
Analog input pins	7	4
Analog (PWM) output pins	2	None
Low power, low bandwidth, low cost, addressable, standardized, small, popular	Yes	Yes
Interoperable mesh routing, ad hoc network creation, self-healing networks	No	Yes
Point-to-point, star topologies	Yes	Yes
Mesh, cluster tree topologies	No	Yes
Single firmware for all modes	Yes	No
Requires coordinator mode	No	Yes
Point-to-point configuration	Simple	More involved
Standards-based networking	Yes	Yes
Standards-based applications	No	Yes
Underlying chipset	Freescale	Siem
Firmware available	802.15.4 (IEEE standard), DigiMesh (proprietary)	ZB (ZigBee 2007), ZNet, 2.3 (obsolete)
Up-to-date and actively supported	Yes	Yes

Figure 77: Series 1 versus Series 2 for regular XBees (Faludi, 2010)

Xbees always work as a pair, a transmitter and a receiver. They are manufactured and sold by various vendors such as; Digi International, Maker SHED, SparkFun Electronics and DigiKey. Also; Xbee types are various. Whip or wire antenna, Chip antenna, PCB antenna, U.FL connector, RPSMA connectors are the types of available Xbee Modules. In this prototype, the wire antenna type is used. Wire type is chosen for this initial test because it is cheaper and it is satisfactory as its' specifications for this test. To start with the wireless connection, the Xbee explorer modules were necessary for the setup. After the discovery and assignment of transmitter and receiver roles are done, the Xbees are ready to work with the prototype.

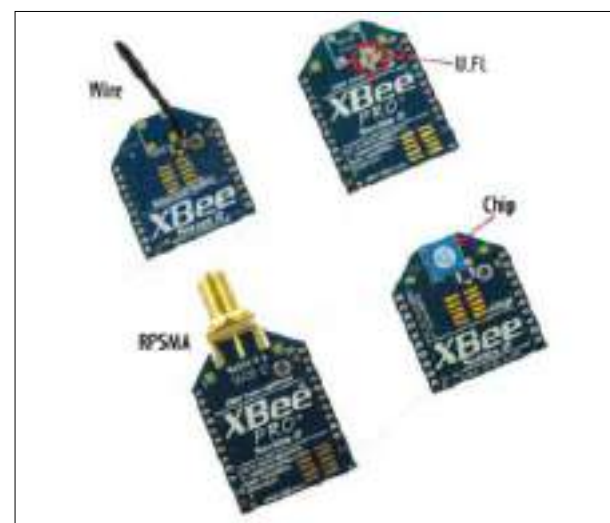


Figure 78: Antenna Types of XBees (Faludi, 2010)

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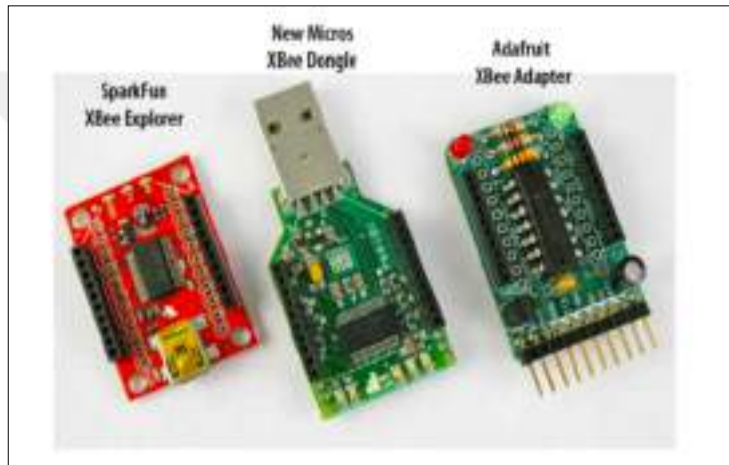


Figure 79: Adapter Types of XBees (Faludi, 2010)

In this prototype, Sparkfun Xbee Explorer Modules are used regarding to being not only an adapter but also an explorer module. By this specification, this module is used initially on the setup and exploring process, and later on as an adapter for the receiver part of the prototype, by attaching the receiver Xbee to the Explorer Module and connecting it to the Arduino Uno board. The setup is done via X-CTU Software. The X-CTU program is the official configuration program for XBee radios (Digi, 2019). For a correct connection of Xbee devices, X-CTU configuration for our Xbees must be as following;

For Xbee transmitter:

- * CH: C
- * ID: 1001
- * CE: Coordinator
- * Baud rate: 9600 bps.

For xBee receiver:

- * CH: C
- * ID: 1001
- * CE: End point
- * Baund rate: 9600 bps.



Figure 80: Prototype III – Wearable Patch // Transmitter

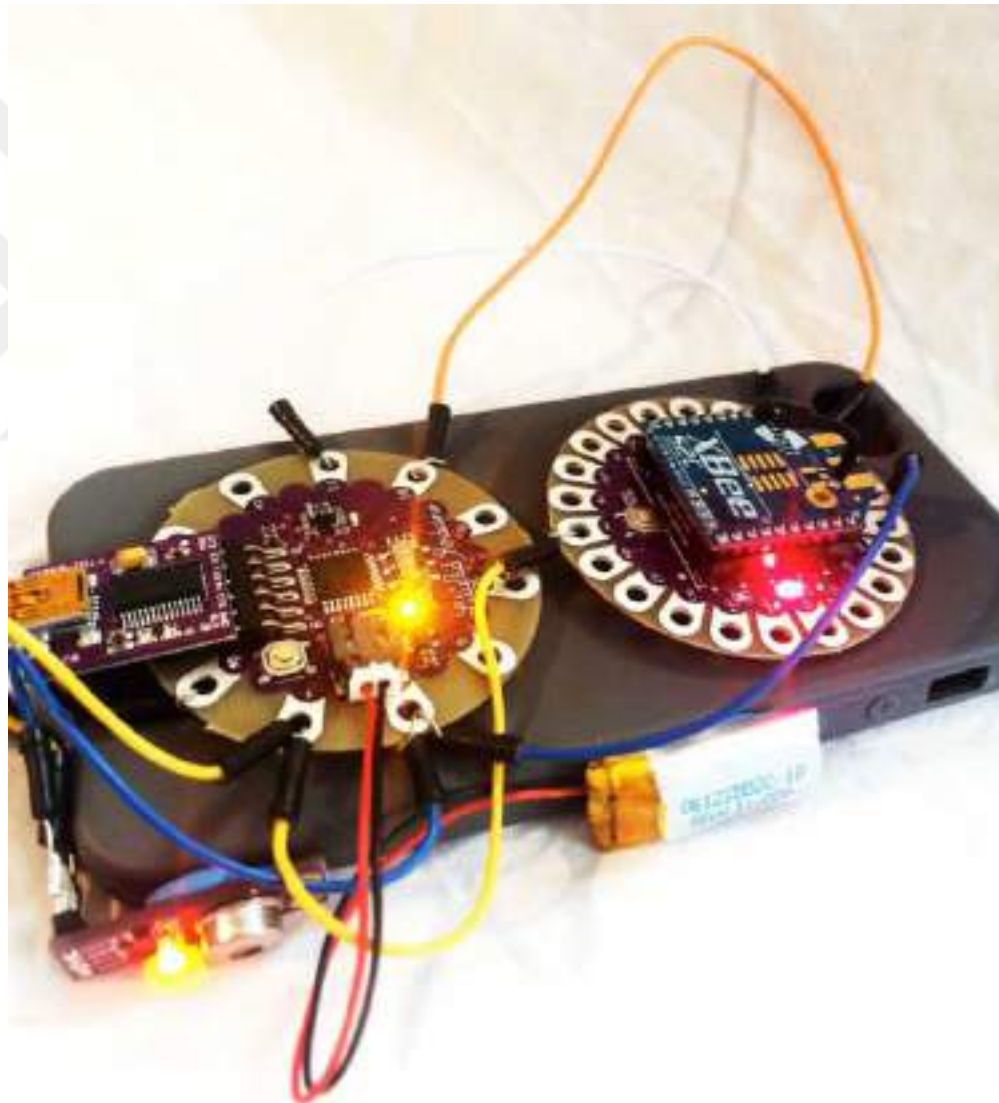


Figure 81: Prototype III – Smart Phone
Case // Transmitter

By programming the Prototype II by Arduino IDE, the following results of the interaction is successfully achieved. Apart from the IoT prototype, the BIM Integration is still on progress. Unfortunately there are some technical deficiencies of the prototype at this moment of the research; which are; the GPS Module cannot give very precise information indoors/outdoors regarding exact coordinates of the user, and it is hard to locate the user in the rooms, and the X-Bee Module is very sensitive for the everyday use and the wireless connection is generally problematic.

38C receiver will turn ON the Ventilator. Otherwise both heater and ventilator are off.

The test is done by the following steps:

Uploading the code Transmitter on the Lilypad Flora USB by testing the transmitter code for both cases:

Case1: `SoftwareSerial Xbee(10, 11);`

Case2: `SoftwareSerial Xbee(A2, A3);`

Uploading the code Receiver on the Arduino UNO and connecting the servo motors with Arduino. Lilypad sends the temperature data to the receiver after every 500 mili-seconds. If the temperature is less then 25C receiver will turn ON the Heater and if the object temperature (users hand) is greater then

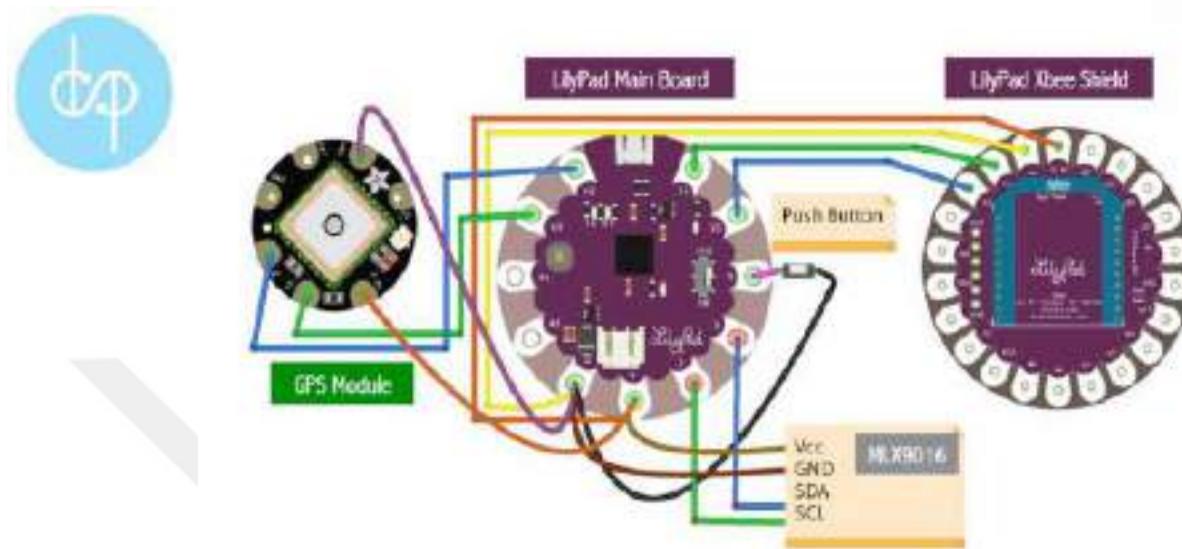


Figure 82: Prototype III – Wearable Patch // Transmitter Schematic

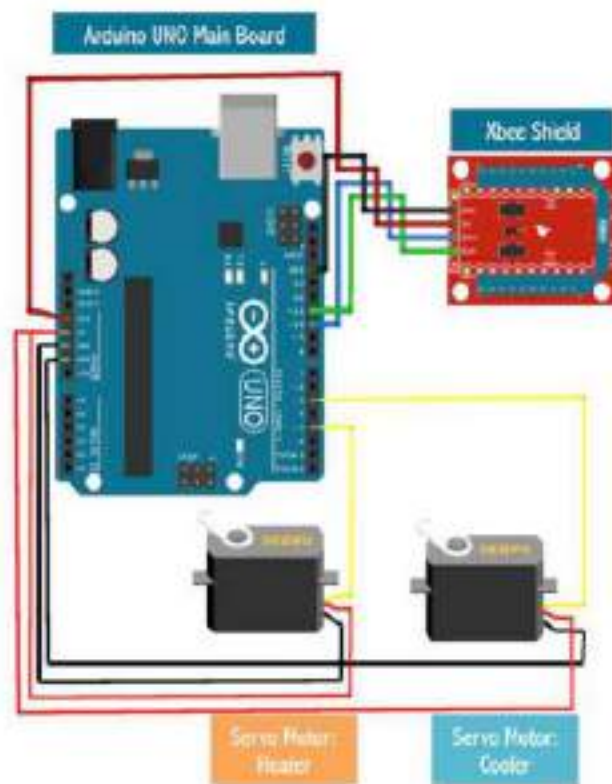


Figure 83: Prototype III – Wearable Patch // Receiver Schematic

IV
PROTOTYPE



8.4. PROTOTYPE IV

PROTOTYPE IV	Transmitter	Receiver
Time Period	September – October 2018	September – October 2018
Variables	Ambient Temperature User Body Temperature	BIM Extracted Material data
Hardware		
Micro-Controller	Arduino Pro Mini	Arduino Uno
Sensor	MLX90614 Infrared Thermometer	-
Motors	-	2 Servo Motors (Heater and Cooler)
Other Tools	FDTI Cable HC05 Bluetooth Serial Module ProtoBoard	Battery HC05 Bluetooth Serial Module
Wiring Type	Soldered	Wired
Connection Type	Bluetooth Communication	Bluetooth Communication
Software		
Processing	Arduino IDE	Arduino IDE
Purpose	Wearable Object design ~~Wireless Connection~~	Testing the connections
Function	Data accuracy Wireless connection Design improvement	Proving the material data
BIM Data	No	Yes
Errors	Wireless connection fails	-
Conclusion	The prototype is soldered, and the fragility is eliminated, yet, the Bluetooth connection is not giving desired results and the errors have to be resolved in the following prototype. Design is more compact, easier to use as a wearable device.	

Figure 84: Prototype IV – Checklist

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Figure 85: Prototype IV – Transmitter

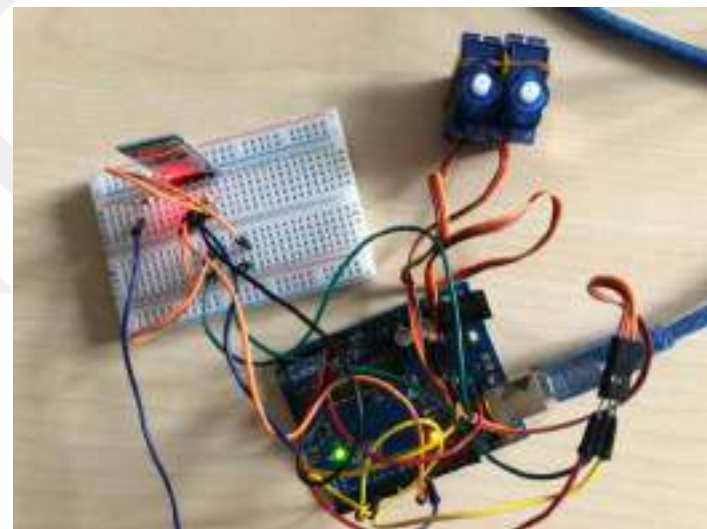
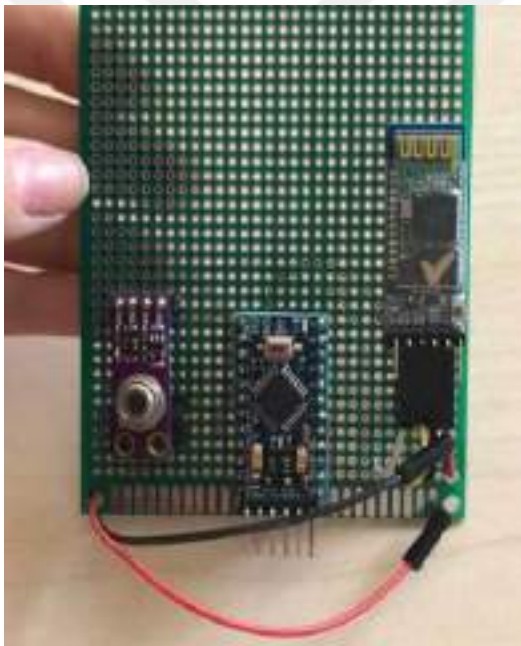
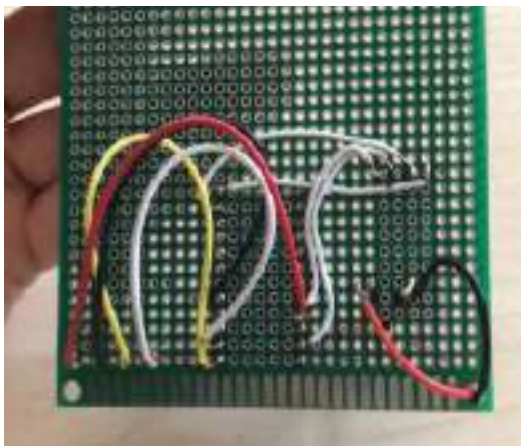


Figure 86: Prototype IV - Receiver



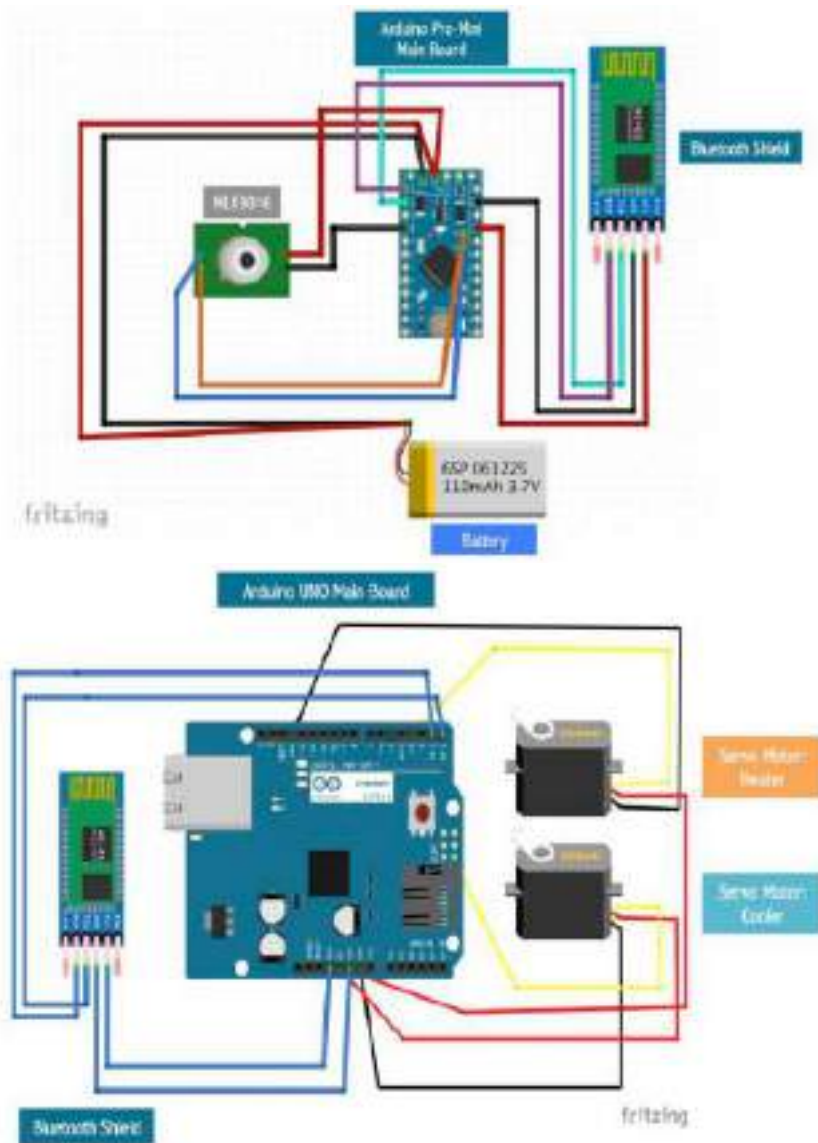


Figure 87: Prototype IV - Schematic

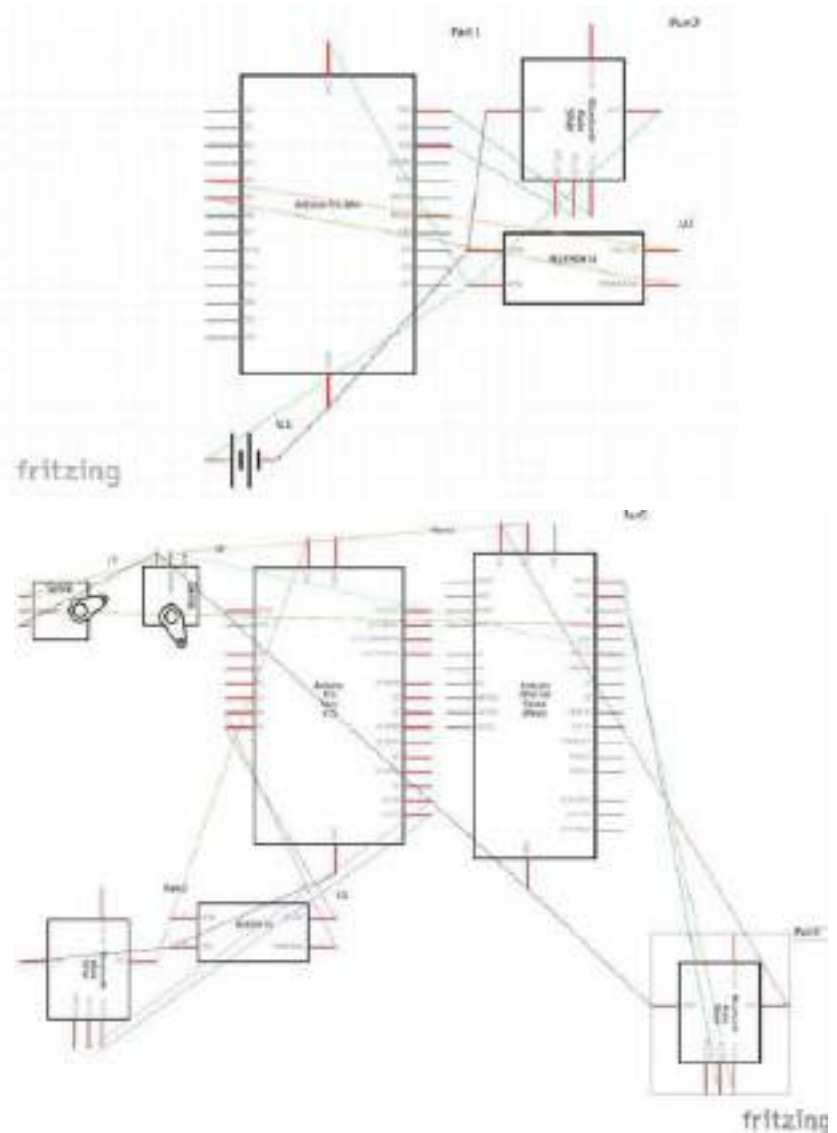


Figure 88: Prototype IV – Schematic

FTDI Cable Connection Problem:

The FTDI cable is a USB to Serial (TTL level) converter which allows for a simple way to connect TTL interface devices to USB. The I/O pins of this FTDI cable are configured to operate at 5V. The FTDI cable is designed around an FT232RQ, which is housed in a USB A connector. The other side of the cable is terminated with a 0.1" pitch, 6-pin connector with the following pinout: RTS, RX, TX, 5V, CTS, GND (RTS is the green cable and GND is black).



Figure 89: FTDI Programmer Cable (Sparkfun, 2019)

This cable has the same pinout and functionality as our FTDI Basic Breakout board; you can use it to program your Arduino Pro, Pro Mini and Lilypad. For use with those boards, align the

black and green wires of the FTDI cable with the 'BLK' and 'GRN' labels on the PCB. There are pros and cons to the FTDI Cable vs the FTDI Basic. The FTDI Basic has great LED indicators, but requires a Mini-B cable. The FTDI Cable is well protected against the elements, but is large and cannot be embedded into a project as easily. The FTDI Basic uses DTR to cause a hardware reset where the FTDI cable uses the RTS signal (Sparkfun, 2019). To use the FTDI USB devices with LabVIEW, you will need to download and install the Virtual COM Port Driver from the FTDI Chip VCP Driver Website for your specific operating system On Future Technology Devices International Ltd. Website (FTDI Chip, 2019), all the settings and phases for programming by FTDI programmer cables are explained by detail. Even though there is a huge amount of information and technical help, still, the compatibility of the devices and interface might be problematic in some cases. Also Operating System incapability is an important issue, and might create function errors in some projects depending to the used device, cable and OS variations. In the specific case of Prototype IV, uploading the code by using FTDI Programmer cable by Macintosh OS was failing, and when it is uploaded by using another device with Windows OS, it was successful. This error might be in relation with some serial port connection error or simply by the incapability of the downloaded libraries / interfaces with the OS and also with Arduino IDE.



The Hardware – Prototype IV:

The transmitter device hardware consists the Arduino Pro-mini Mainboard, a Bluetooth single module - BT Wireless HC-05 for wireless data transmittance and battery power for wireless use. The Prototype IV Transmitter is soldered for efficient and secure usage. The receiver is the same as previous, just with a single modification that is the BT Wireless HC-05 receiver agent included for the wireless communication.

The Interface – Prototype IV:

The receiver code includes the unified 'room thermal value calculation' by introducing the elements thermal values that are extracted from the Revit to an Excel sheet. The interface is tested for turning on the heater below 25C and turning on the cooler above 38C for the average of ambient and body temperature data.

```
if((u) && (data[1].toInt() < 25)){
  Serial.println("Heater ON");
  TurnOnHeater();
}else if((u) && (data[1].toInt() > 38)){
  Serial.println("Vantilator ON");
}
```

By that, the first attempt on embedding material information to the code from BIM data is done. Also blending BIM with real-time IoT is being tested. Those values are the variables to calculate a single value for each room, that defines the threshold

for the decision making too, apart from the real-time temperature data. This part of the code is explained previously on Arduino IDE Test section. The calculation is developed throughout Prototype III and IV, and tested with Prototype IV. *Note: Threshold for motors decision-making is set up as 0.5, to try if the code is working. This is a test value for further steps, to be developed.*

The Variables of the Prototype IV is as following:

1. BIM Extracted:

Construction materials, opening details, location and orientation and insulation materials coefficients' data (R-Values and Area & Dimension information)

2. Real-time ambient (interior) temperature data:

Indoor thermal information from the infrared thermometer 'Prototype IV'.

3. Real-time body temperature data of the user:

Users' body temperature data form the 'Prototype IV'.

4. Location (local - indoor):

Users' current location from 'Prototype IV'.

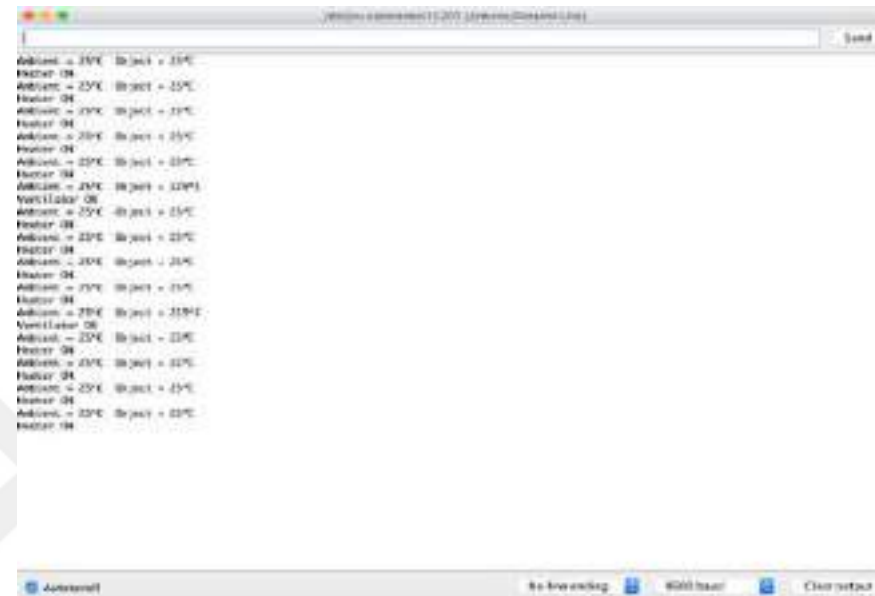


Figure 92: Serial Port Transmitter – Prototype IV

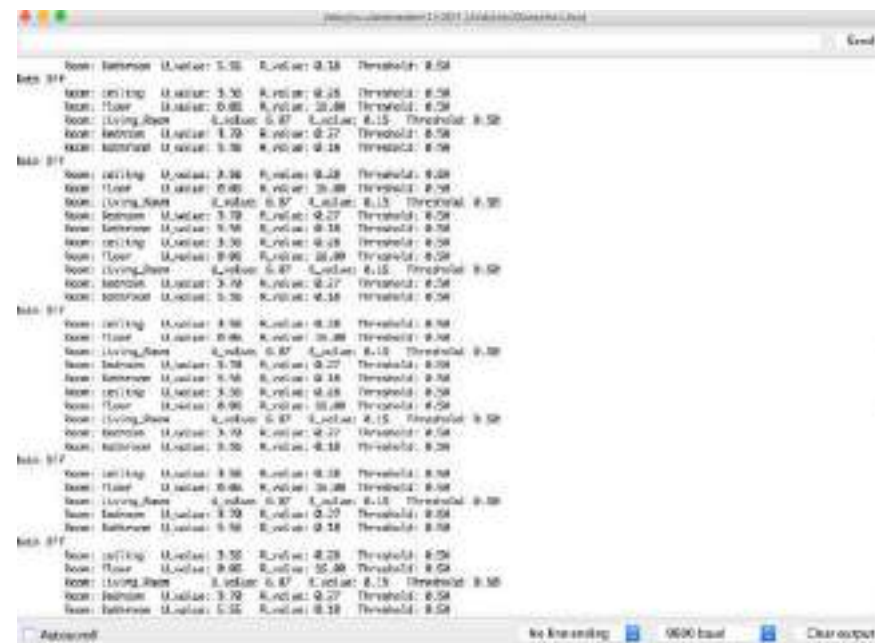


Figure 93: Serial Port Receiver – Prototype IV

PROTOTYPE



8.5. PROTOTYPE V

PROTOTYPE V	Transmitter	Receiver
Time Period	November – December 2018	November – December 2018
Variables	Ambient Temperature User Body Temperature Location (GPS)	BIM Extracted Material Data
Hardware		
Micro-Controller	2 of Arduino Pro Mini's	Arduino Mega
Sensor	MLX90614 Infrared Thermometer	-
Motors	-	2 Servo Motors (Heater and Cooler)
Other Tools	FDTI Cable ESP8266 Wi-Fi Module SIM800L GSM / GPRS Module LM7805 – 5V Regulator LM1117 – 3.3V Regulator 2 Switches Protoboard	Battery ESP8266 Wi-Fi Module SD Card Module
Wiring Type	Soldered	Soldered
Connection Type	Wireless Communication	Wireless Communication
Software		
Processing	Arduino IDE	Arduino IDE
Purpose	Wearable Object design. ~~Wireless Connection.~~	Testing the connections. ~~SD Card – Data input.~~
Function	Data accuracy. ~~Wireless connection.~~ Design improvement.	Proving the material data. ~~Reading the material data from SD Card.~~
BIM Data	No	Yes
Errors	Wireless connection fails GPS not accurate Dimension is not satisfactory	Wireless connection fails SD Card reading is challenging.
Conclusion	Received data is accurate and fast. Yet, the location tracking is not giving desired results to the system. It cannot be used as indoor location tracking. Design is not as compact as previous versions, it has to be revised. SD Card Reader is working, code has to be improved.	

Figure 94: Prototype V – Checklist

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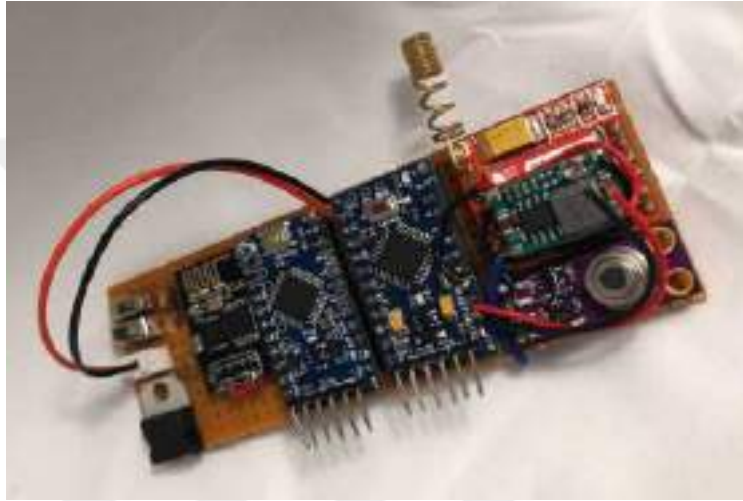


Figure 95: Prototype V – Transmitter

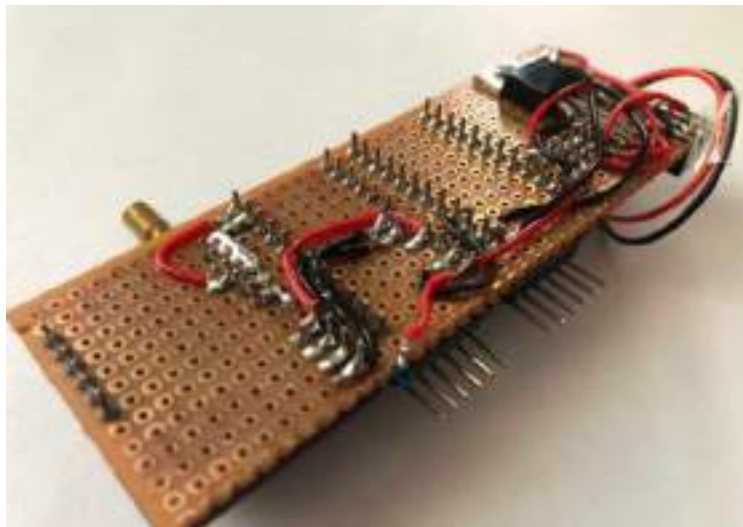


Figure 96: Prototype V - Receiver

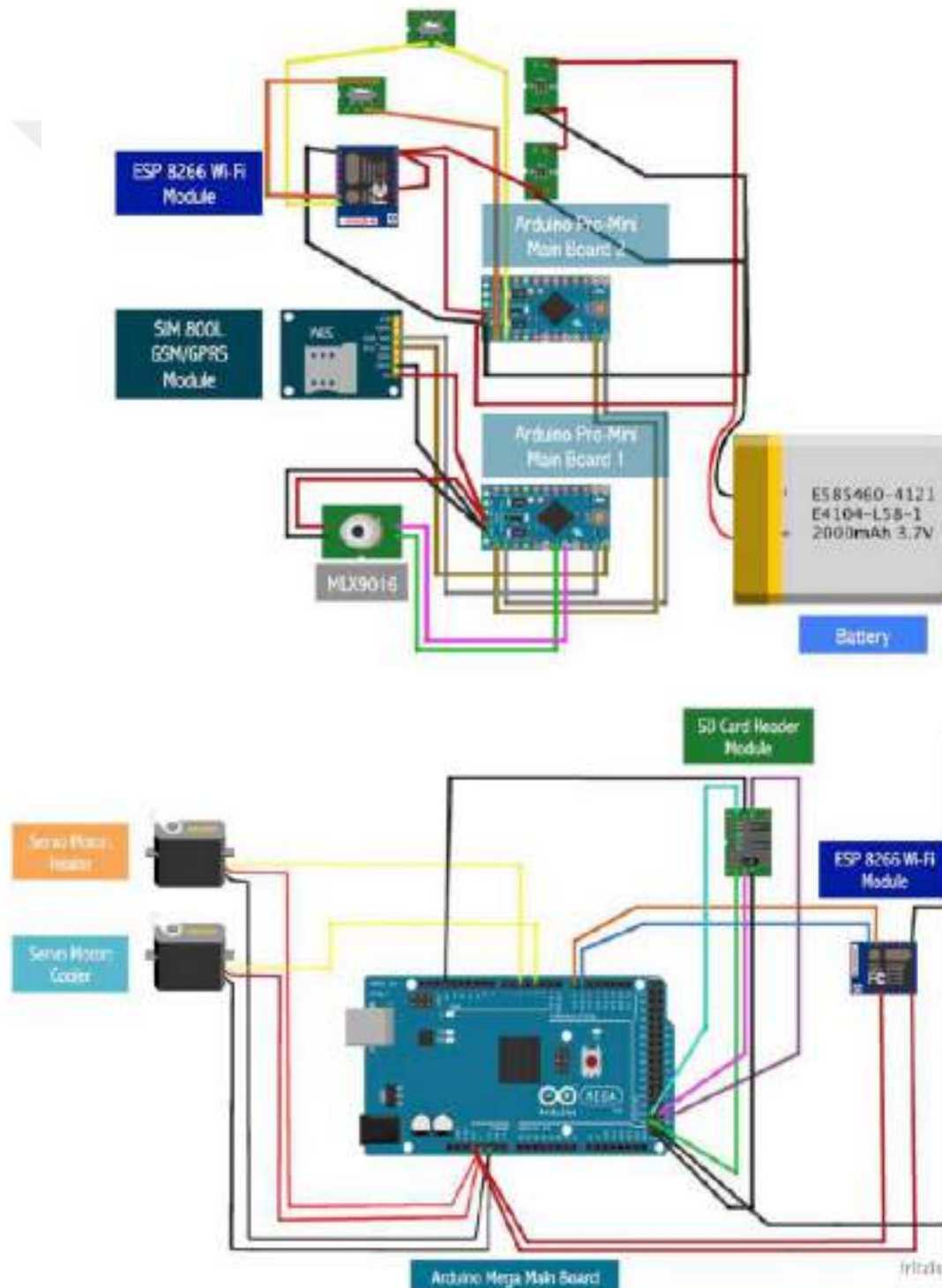


Figure 97: Prototype V – Schematic I

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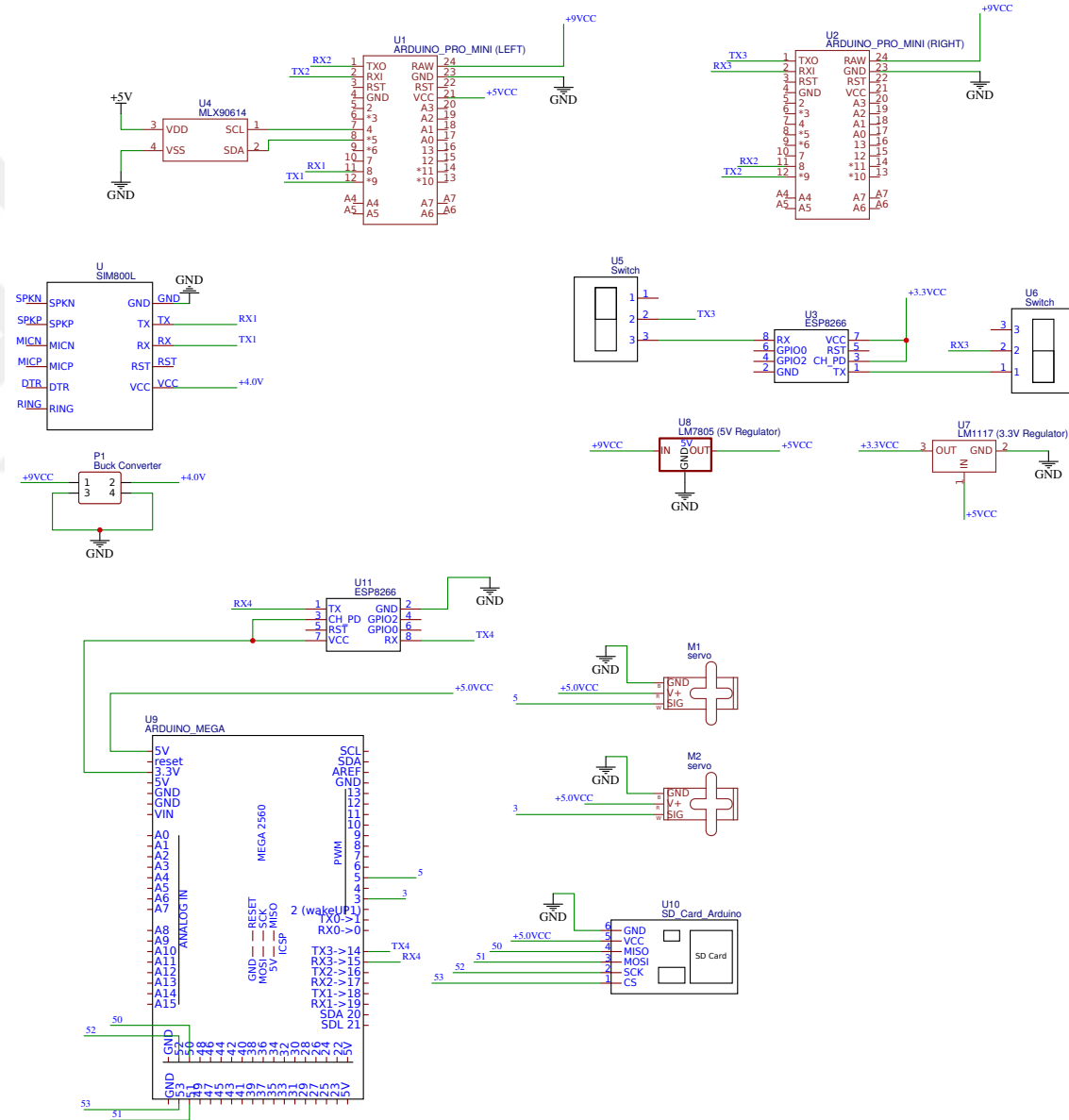


Figure 98: Prototype V – Schematic 2



ESP8266 Wi-Fi Module:

The ESP8266 Wi-Fi Module is a self contained SOC with integrated TCP/IP protocol stack that can give any microcontroller access to your Wi-Fi network. The ESP8266 is capable of either hosting an application or offloading all Wi-Fi networking functions from another application processor. Each ESP8266 module comes pre-programmed with an AT command set firmware, meaning, you can simply hook this up to your Arduino device and get about as much Wi-Fi-ability as a Wi-Fi Shield offers (and that's just out of the box)! The ESP8266 module is an extremely cost effective board with a huge, and ever growing, community.

This module has a powerful enough on-board processing and storage capability that allows it to be integrated with the sensors and other application specific devices through its GPIOs with minimal development up-front and minimal loading during runtime. Its high degree of on-chip integration allows for minimal external circuitry, including the front-end module, is designed to occupy minimal PCB area. The ESP8266 supports APSD for VoIP applications and Bluetooth co-existence interfaces, it contains a self-calibrated RF allowing it to work under all operating conditions, and requires no external RF parts.

Specifications:

- 802.11 b/g/n
- Wi-Fi Direct (P2P), soft-AP
- Integrated TCP/IP protocol stack
- Integrated TR switch, balun, LNA, power amplifier and matching network
- Integrated PLLs, regulators, DCXO and power management units
- +19.5dBm output power in 802.11b mode
- Power down leakage current of <10uA
- 1MB Flash Memory
- Integrated low power 32-bit CPU could be used as application processor
- SDIO 1.1 / 2.0, SPI, UART
- STBC, 1×1 MIMO, 2×1 MIMO
- A-MPDU & A-MSDU aggregation & 0.4ms guard interval
- Wake up and transmit packets in < 2ms
- Standby power consumption of < 1.0mW (DTIM3). (Sparkfun, 2015)

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Figure 99: ESP8266 Wi-Fi Module (Sparkfun, 2015)

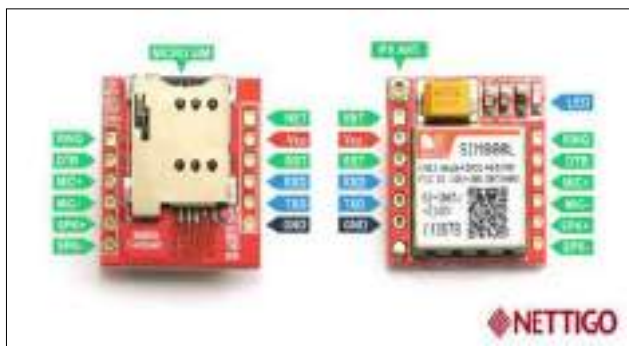


Figure 100: SIM 800L – GSM Module (Nettigo, 2019)

SIM 800-L GSM Module:

SIM800L is a quad-band GSM/GPRS module, that works on frequencies GSM850MHz, EGSM900MHz, DCS1800MHz and PCS1900MHz. SIM800L features GPRS multi-slot class 12/ classes 10 (optional) and supports the GPRS coding schemes CS-1, CS-2, CS-3 and CS-4. With a tiny configuration of 15.8*17.8*2.4mm, SIM800L can meet almost all the space requirements in user applications, such as smart phone, PDA and other mobile devices. SIM800L has 88pin pads of LGA packaging, and provides all hardware interfaces between the module and customers' boards. SIM800L is designed with power saving technique so that the current consumption is as low as 0.7mA in sleep mode (SIMCom, 2013).

Specifications:

- Supply voltage: 3.8V - 4.2V
- Recommended supply voltage: 4V
- Power consumption:
- sleep mode < 2.0mA
- idle mode < 7.0mA
- GSM transmission (avg): 350 mA
- GSM transmission (peek): 2000mA
- Module size: 25 x 23 mm



- Interface: UART (max. 2.8V) and AT commands
- SIM card socket: microSIM (bottom side)
- Supported frequencies: Quad Band (850 / 950 / 1800 / 1900 MHz)
- Antenna connector: IPX
- Status signaling: LED
- Working temperature range: -40 do + 85 ° C

SIM800L is a miniature cellular module, which allows for GPRS transmission, sending and receiving SMS and making and receiving voice calls. Low cost and small footprint and quad band frequency support make this module perfect solution for any project that require long range connectivity. After connecting power module, it searches for cellular network and login automatically (Nettigo, 2019). SIM800L is used in this prototype for receiving Location Information and calculation of proximity to the destination.

The Hardware – Prototype V:

Transmitter:

Arduino Pro-Mini 1
 Arduino Pro-Mini 2
 MLX90614 Non-Contact Infrared Thermometer
 SIM88L - SIM Card module (Location)
 Buck converter
 ESP8266 - Wi-Fi Microchip (Wireless Communication)
 LM 7805 - 5V Regulator
 LM 1117 - 3.3V Regulator
 2 Switches
 FDTI Cable
 Battery

Receiver:

Arduino Mega
 SD CARD reader (BIM data – Room Thermal Value: Read)
 ESP8266- Wi-Fi Microchip (Wireless Communication)
 2 Servo Motors (heater / cooler)

The Interface – Prototype V:

On Prototype V Transmitter and Receiver code, major modifications have been made. First of all, for the wireless communication, the setup of local Wi-Fi and Wi-Fi Password is introduced to the code. Actually, by this, then the connection is realized, the code starts to operate, which allows an automatic check-in to the Platform. Adding GIS Information by the SIM88L, gives the location information of the mobile device. This tool is introduced to the code by using 'APK' service. Adding the SD CARD reader is a solution for the further use of the Platform as well as the location tracking. This tool allows the user to insert the memory card that has a simple text file with the data of room tags and room thermal values associated, which the Receiver code automatically connects, reads and processes the data by the algorithm without requiring any other calibration or modification. Lastly, on Receiver code, the new values from Model 2 are introduced manually. The room thermal values are calculated accordingly in the code. Thresholds are defined as following:

```
void loop() {
  if (millis() - timerX > 3000) {
    check1();
    Serial.println("Temp1: " + String(temp_A) + "
temp_0: " + String(temp_0) + " Room Thermal Value: "
+ String(threshold) + " Device Status: " + device);
    timerX = millis();
  }
  if (temp_A > 27 && temp_0 > 27) {
    TurnOnVantilator();
  }
}
```

```
device = "Vantilator";
}
else if (temp_A < 25 && temp_0 < 25) {
  TurnOnHeater();
  device = "Heater";
}
else {
  device = "Off";
}
Blynk.run();
}
```

The test is done by the following steps:

Uploading the Transmitter code first to the Transmitter 1 Arduino Pro mini. This microcontroller is in charge of transmitting the temperature data and receiving and transmitting the location data from SIM Card. Then, soldering the TX and RX cables to the Transmitter 2, that is in charge of transmitting the data to the Receiver wirelessly. There are two pro mini boards because of the flash memory capacity and also because of creating a smoother connection wirelessly, between transmitter to receiver. On Receiver part, the code is uploaded directly, and the SD card that has the text file of the room thermal values is inserted to the SD Card reader.



The Variables of the 'Prototype V' is as following:

1. BIM Extracted:

Construction materials, opening details, location and orientation and insulation materials coefficients' data (R-Values and Area & Dimension information).

Read from the SD Card reader, as a text file – Dynamo calculation 'Room Thermal Value Results'

2. Global Information System (GIS) data:

Global weather data, Outdoor Thermal / Weather Information.

3. Real-time ambient (interior) temperature data:

Indoor thermal information from the infrared thermometer 'Prototype V' transmitter.

4. Real-time body temperature data of the user:

Users' body temperature data form the 'Prototype V' transmitter.

5. Location: Global location data (GSM – Sim88L).

Errors:

1. FDTI Programming Cable: Connection and setup is problematic. Different devices and the Mac and Windows OS are acting

differently. FDTI softwares versions are tested. Both cases are tested. Windows OS and the last current version of Arduino IDE is working correctly.

2. SD Card reading problem: The data cannot be reached. Error had to be resolved on following Prototype.

3. Location: Users' current location from 'Prototype V' transmitter, from SIM Card Module is not accurate. Outdoor local location tracking is successfully working, yet indoor location tracking is not accurate. The device is not giving satisfactory, gives approximate GIS information. Indoor tracking is not correctly introduced on this Prototype. This location information in real time might be used in further stages, for proximity to home; when the user is reaching the home to arrange the desired thermal condition, for machine-learning included. For this current stage, this solution is advanced and not necessary. On the following Prototype, this feature is excluded.

specificity & sensitivity



Figure 101: Prototype V - Transmitter // Pro Mini Right



Figure 102: Prototype V - Transmitter // Pro Mini Left



```
MEGA | Arduino 1.8.3  
MEGA  
68  
69 if (!IS.begin(tripleInt)) {  
70   Serial.println("I2C failed, or not answer");  
71   while (1);  
72 }  
73 Serial.println("core initialized.");  
74 File dataFile = SPI.open("data.txt");  
75  
76 // if the file is available, write to it:  
77 if (dataFile) {  
78   while (dataFile.available()) {  
79     str = dataFile.read();  
80     corridor += str;  
81     if (str == "\n")  
82     {  
83       while (dataFile.available()) {  
84         str = dataFile.read();  
85         guest += str;  
86         if (str == "\n")  
87         {  
88           while (dataFile.available()) {  
89             str = dataFile.read();  
90             kitchen += str;  
91             if (str == "\n")  
92             {  
93               while (dataFile.available()) {  
94                 str = dataFile.read();  
95                 child += str;  
96                 if (str == "\n")  
97                 {  
98                   while (dataFile.available()) {  
99                     str = dataFile.read();  
100                    school += str;  
101                    if (str == "\n")  
102                    {  
103                      while (dataFile.available()) {  
104                        str = dataFile.read();  
105                        dining += str;  
106                        if (str == "\n")
```

Figure 103: Prototype V - Receiver // Mega

VI
PROTOTYPE



8.6. PROTOTYPE VI

PROTOTYPE VI	Transmitter	Receiver
Time Period	January – March 2019	January – March 2019
Variables	Ambient Temperature User Body Temperature Outdoor Weather Indoor Location	BIM Extracted Material Data
Hardware		
Micro-Controller	Arduino Pro Mini	Arduino Mega
Sensor	MLX90614 Infrared Thermometer	-
Motors	-	2 Servo Motors (Heater and Cooler)
Other Tools	FDTI Cable ESP8266 Wi-Fi Module Protoboard	Battery ESP8266 Wi-Fi Module SD Card Module
Wiring Type	Soldered	Soldered
Connection Type	Wireless Communication	Wireless Communication
Software		
Processing	Arduino IDE Blynk App	Revit – Dynamo (BIM) Arduino IDE
Purpose	Wearable Object design. Wireless Connection.	Testing the connections. SD Card - Data input.
	Data accuracy.	Proving the material data.
Function	Wireless connection. Betterment on design.	Reading the material data from SD Card.
BIM Data	No	Yes
		Thresholds have to be calibrated.
Errors	-	BIM Values should be tested.
	Blynk App is used as control & user visualization mechanism. Indoor	
Conclusion	location is done manually by Blynk. Design is compact and efficient. SD Card data reading is successful.	

Figure 104: Prototype VI – Checklist

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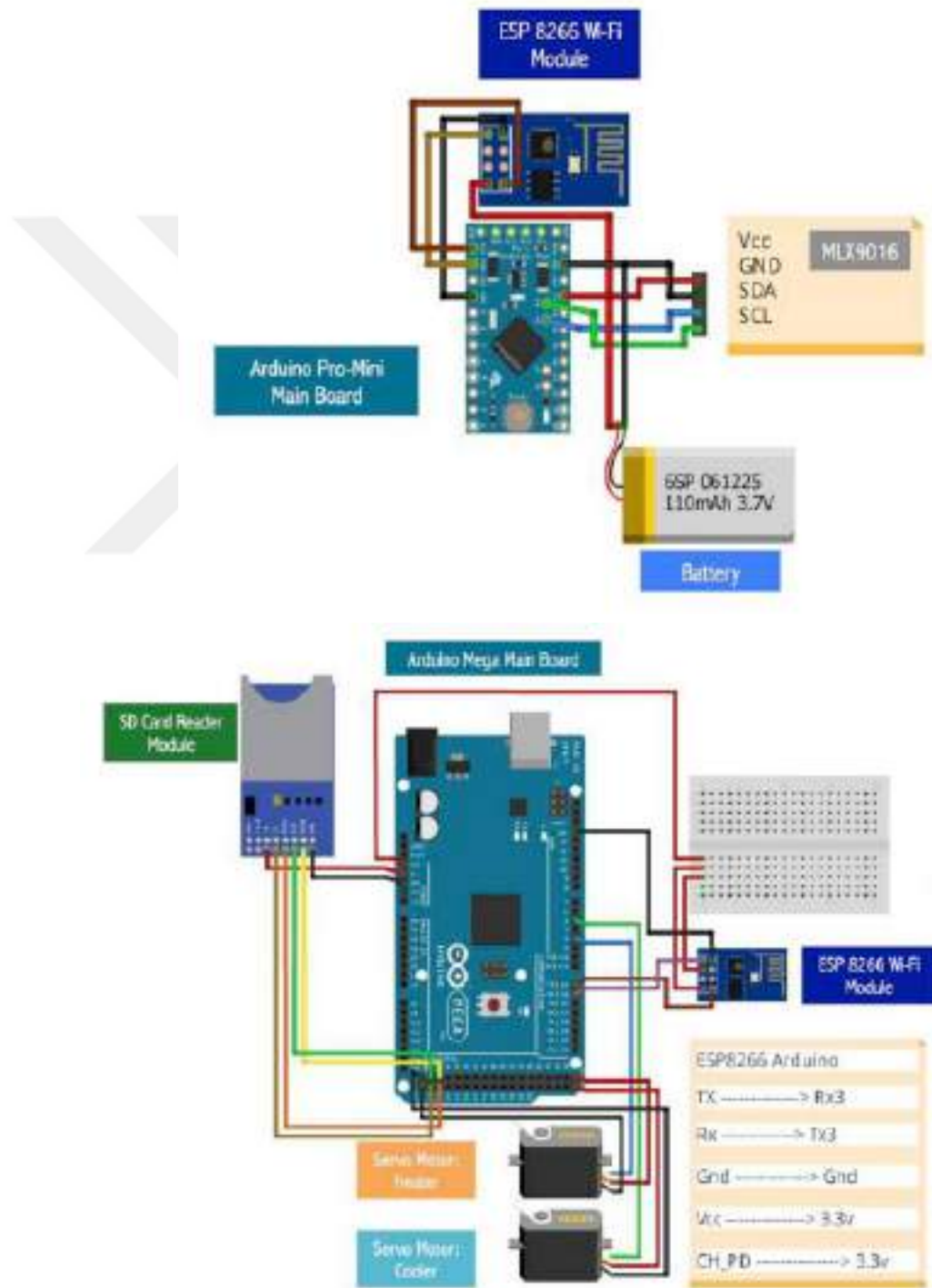


Figure 105: Prototype VI - Schematic



The Hardware Prototype VI:

Transmitter:

Arduino Pro-Mini
MLX90614 Non-Contact Infrared Thermometer
ESP8266 - Wi-Fi Microchip (Wireless Communication)
FDTI Cable
Battery

Receiver:

Arduino Mega
SD CARD reader (BIM data – Room Thermal Value: Read)
ESP8266- Wi-Fi Microchip (Wireless Communication)
2 Servo Motors (heater / cooler)

The Interface Prototype VI:

The interface has a major modification, that is the testing of the Model 2 data with the new calculation method, by Revit-Dynamo and Orchid Plug in. The code is modified accordingly. This calculation is explained previously on Dynamo Test section. Also the Blynk control app is modified accordingly, the room tags are

changed from Model 1 to Model 2. By that, the location tagging is done by the user whenever they check-in to a room.

The Variables of the 'Prototype VI' is as following:

1. BIM Extracted:

Construction materials, opening details, location and orientation and insulation materials coefficients' data (R-Values and Area & Dimension information)

Read from the SD Card reader, as a text file – Dynamo calculation 'Room Thermal Value Results'

2. Real-time ambient (interior) temperature data:

Indoor thermal information from the infrared thermometer 'Prototype VI' transmitter.

3. Real-time body temperature data of the user:

Users' body temperature data form the 'Prototype VI' transmitter.

4. Blynk App:

Indoor location, location tagging, real-time data visualization.

Errors:

SD Card reading is still challenging. The module is not working correctly, sometimes the connection gives some errors which are not software based. So that eliminating the SD Card module is not a solution, yet, the error has to be resolved on the following prototype.

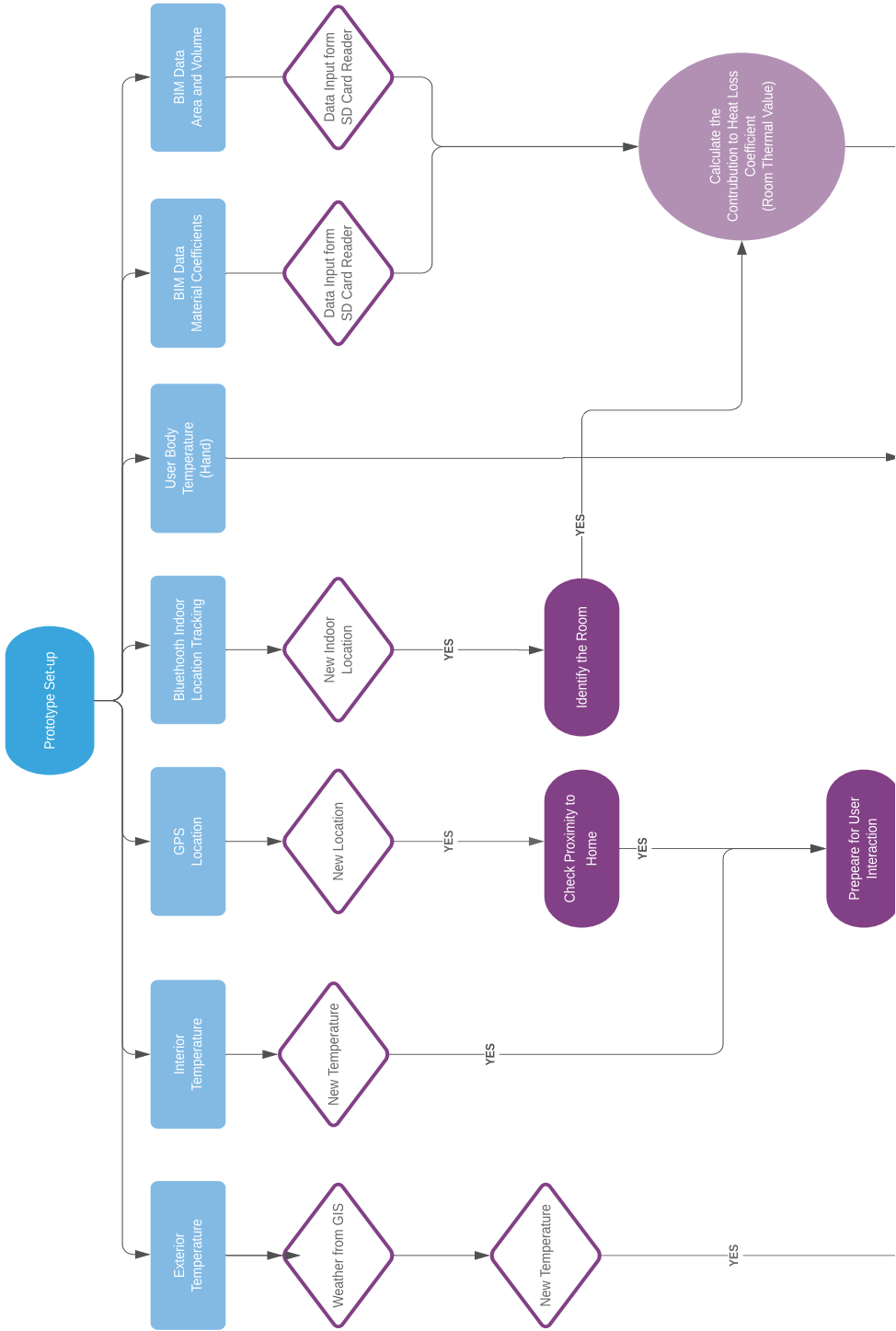
Also, definition of the thresholds have to be calibrated and tested for accuracy.

Figure 106: Prototype VI - Transmitter



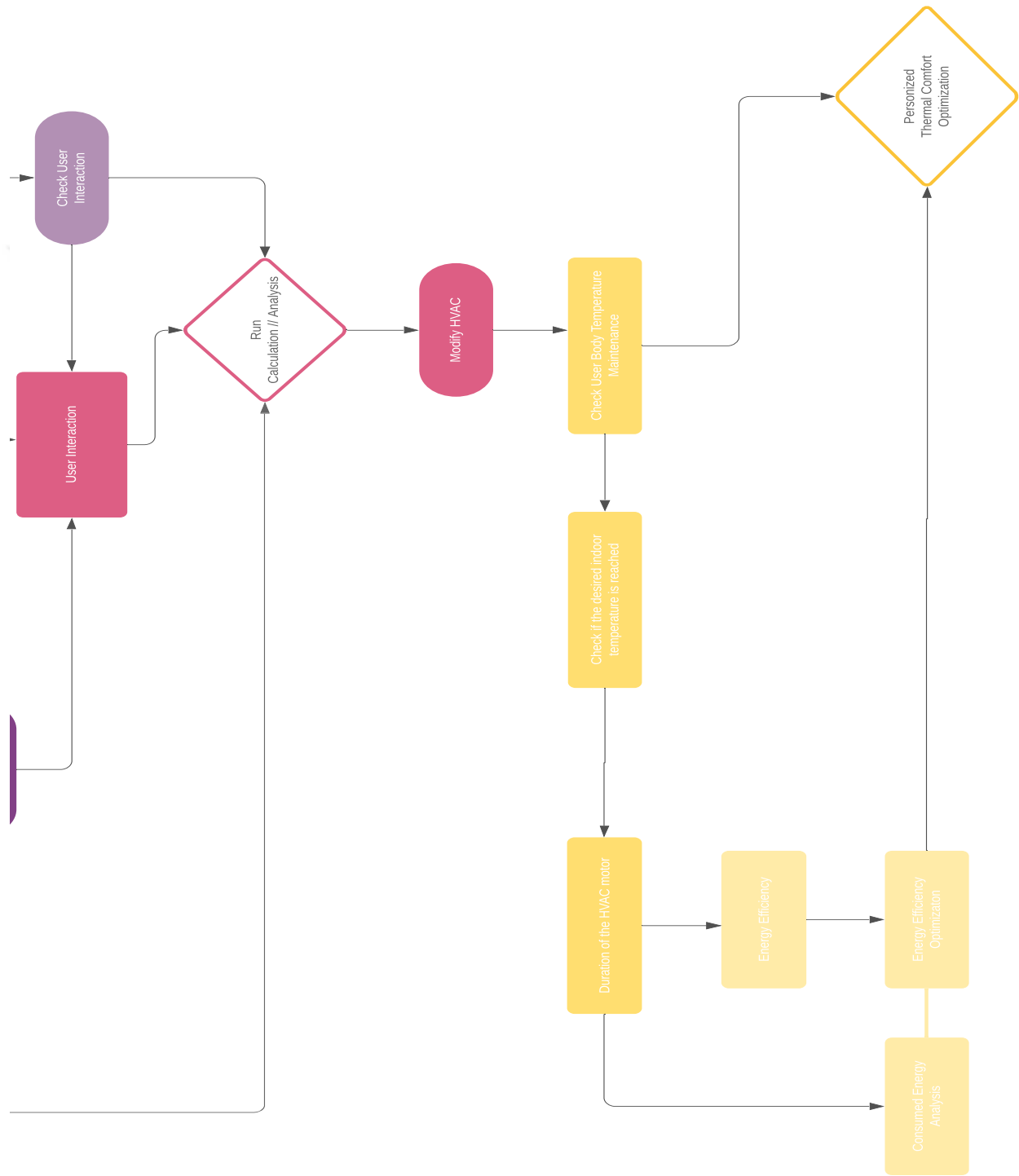


[OPERATION FLOWCHART] | June 16, 2019



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Figure 107: Prototypes' Action Flowchart

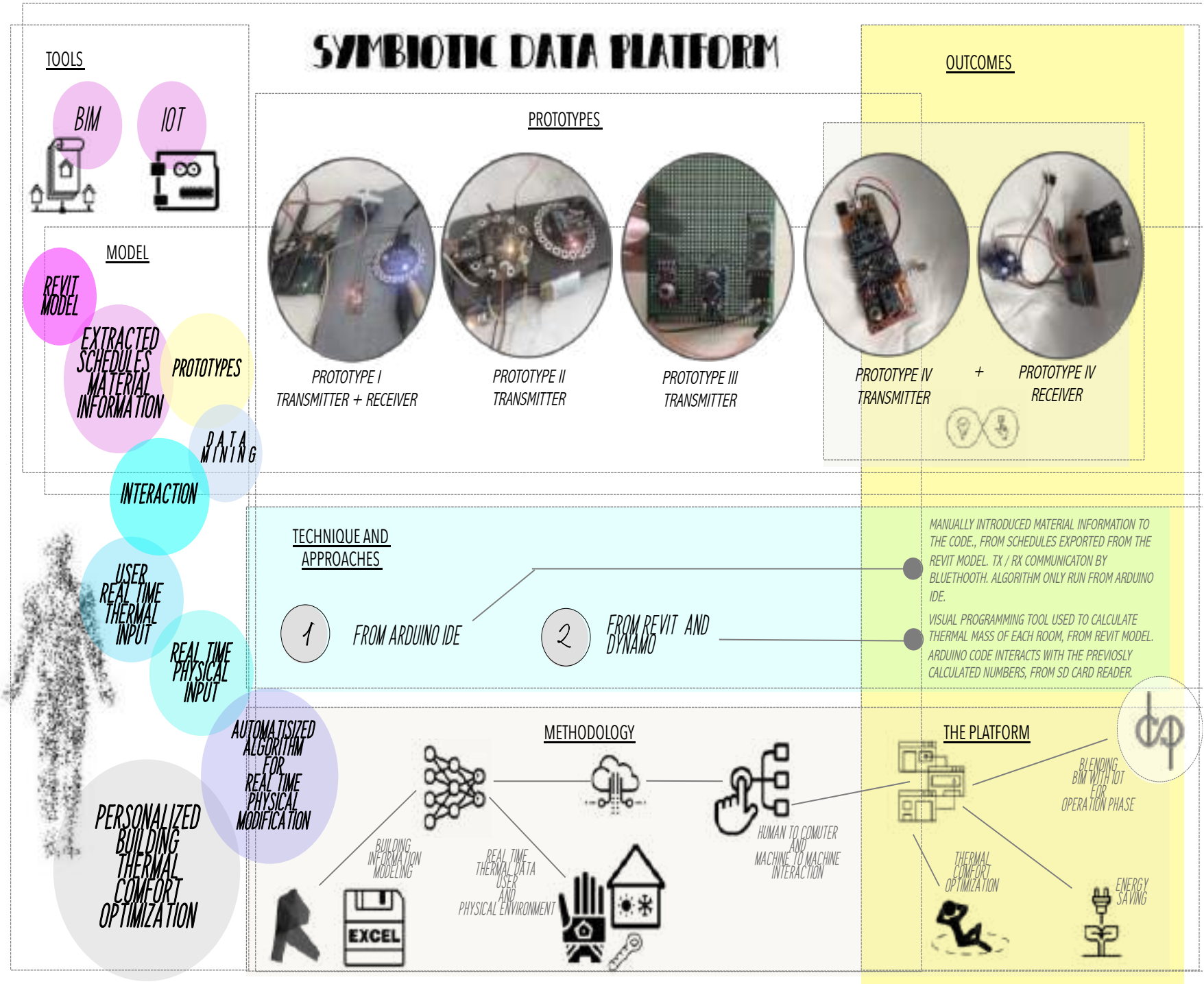


Figure 108: Design Thinking Final Schema

FINAL PROTOTYPE

PROTOTYPE

9. FINAL PROTOTYPE

9.1. PROTOTYPE VII

The final prototype is the most compact and light-weight designed version of all Prototypes of Symbiotic Data Platform. The function of the initial design thinking is completely adapted and tested by the Prototype VII. As a matter of fact, throughout the tests and attempts of blending BIM with real-time information in occupation phase of the building, and including the occupant to the BIM methodology is finally proven positively.

On this final prototype, as the micro-controller the NodemCu board is used due to its compact design and efficient use by the embedded wireless connection. Thanks to NodemCu technology, no additional connection had to be introduced neither to the hardware nor the code.

The prototype is tested only for 'single user' scenario. The tests are done according to the assumption that is the use of the rooms only by one person, yet the multiple user scenario is discussed in following sections. For the final algorithm, the variables and thresholds are calibrated and tested by using the database of the Model 2. Also, motors working duration, working power, force and energy use is analyzed during the development of the final prototype.

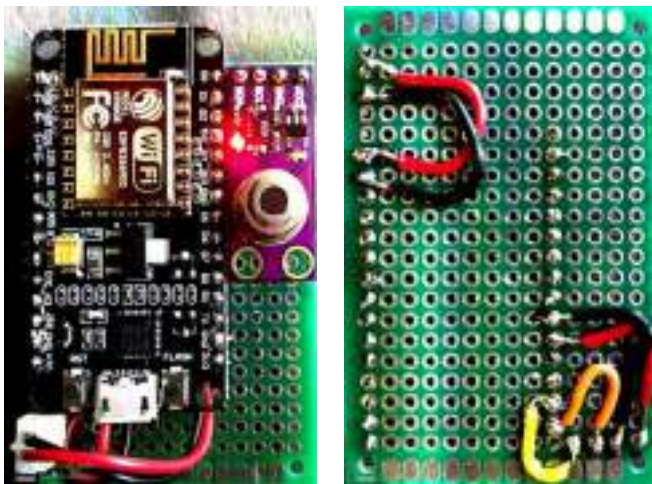


Figure 109: Prototype VII – Transmitter Device



PROTOTYPE VII Final Prototype	Transmitter	Receiver
Time Period	April – August 2019	April - August 2019
Variables	Ambient Temperature User Body Temperature Outdoor Weather Indoor Location	BIM Extracted Material Data
Hardware		
Micro-Controller	NodeMcu CP2102 - 3V Lua Amica	Arduino Mega
Sensor	MLX90614 Infrared Thermometer	-
Motors	-	2 Servo Motors (Heater and Cooler)
Other Tools	FDTI Cable Protoboard	Battery ESP8266 Wi-Fi Module SD Card Module
Wiring Type	Soldered	Soldered
Connection Type	Wireless Communication	Wireless Communication
Software		
Processing	Arduino IDE Blynk App Open Weather API	Revit – Dynamo (BIM) Arduino IDE
Purpose	Wearable Object design. Wireless Connection. Indoor location tracking. Including outdoor temperature.	Testing the connections. SD Card - Data input. Defining and testing the thresholds
Function	Real-Time visualization via Blynk app. Wireless connection. Betterment on design.	Proving the material data. Reading the material data from SD Card.
BIM Data	No	Yes
Errors	-	-
Conclusion	Design is simplified and most accurate to be used as a wearable object. Received data is correct and accurate. Algorithm is calibrated, thresholds are tested and set up. Prototype works correctly. BIM & IoT connection is completed.	

Figure 110: Prototype VII – Checklist

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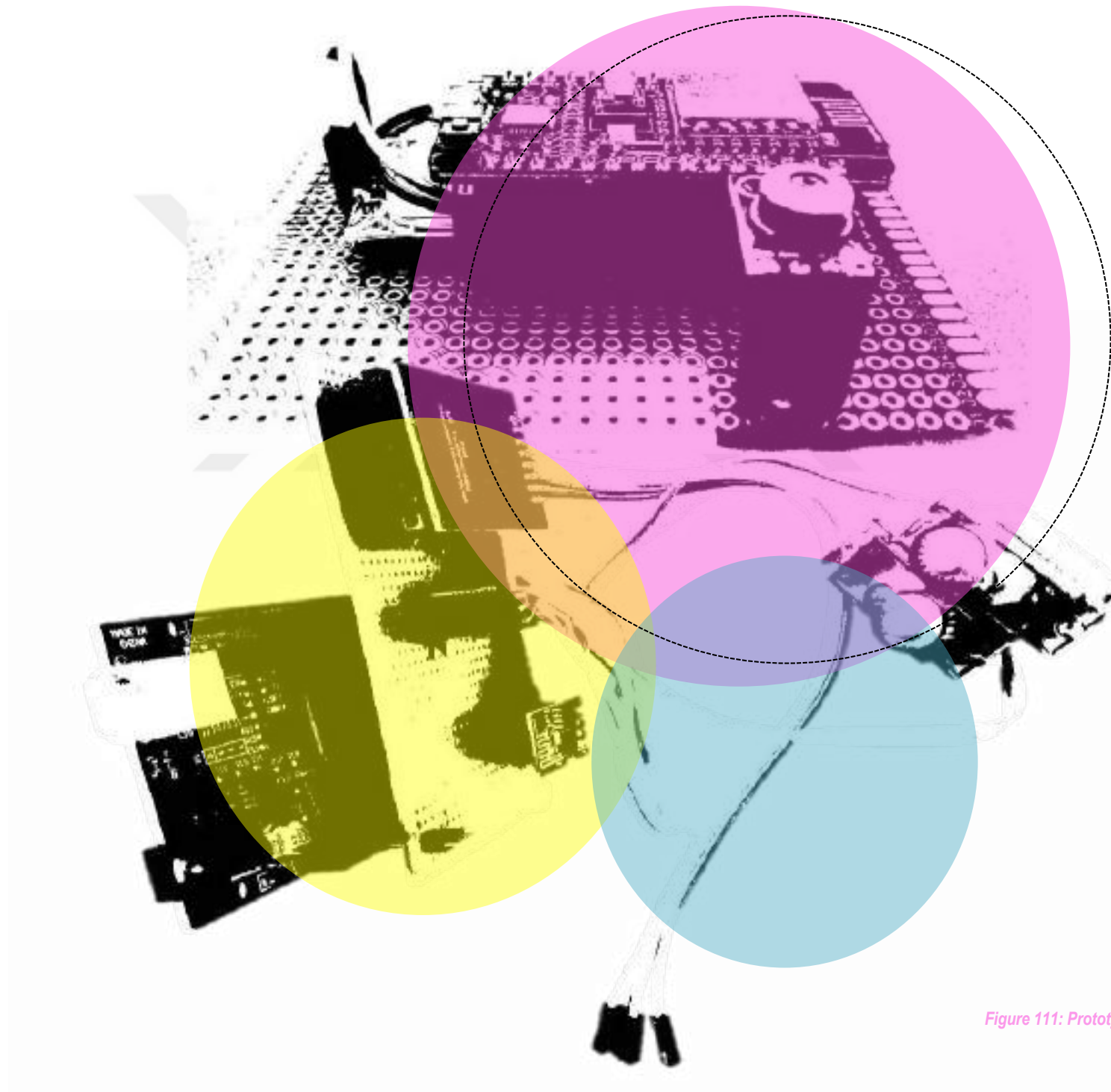


Figure 111: Prototype VII - Conceptual



Figure 112: Prototype VII – Transmitter / Option 1 Big



Figure 114: Prototype VII – Transmitter / Option 1 Big – Dimensions

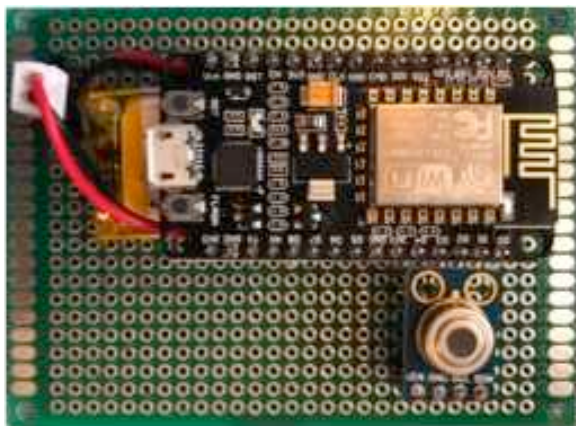


Figure 113: Prototype VII - Transmitter / Option 2 Compact



Figure 115: Prototype VII – Transmitter / Option 2 Compact – Dimensions

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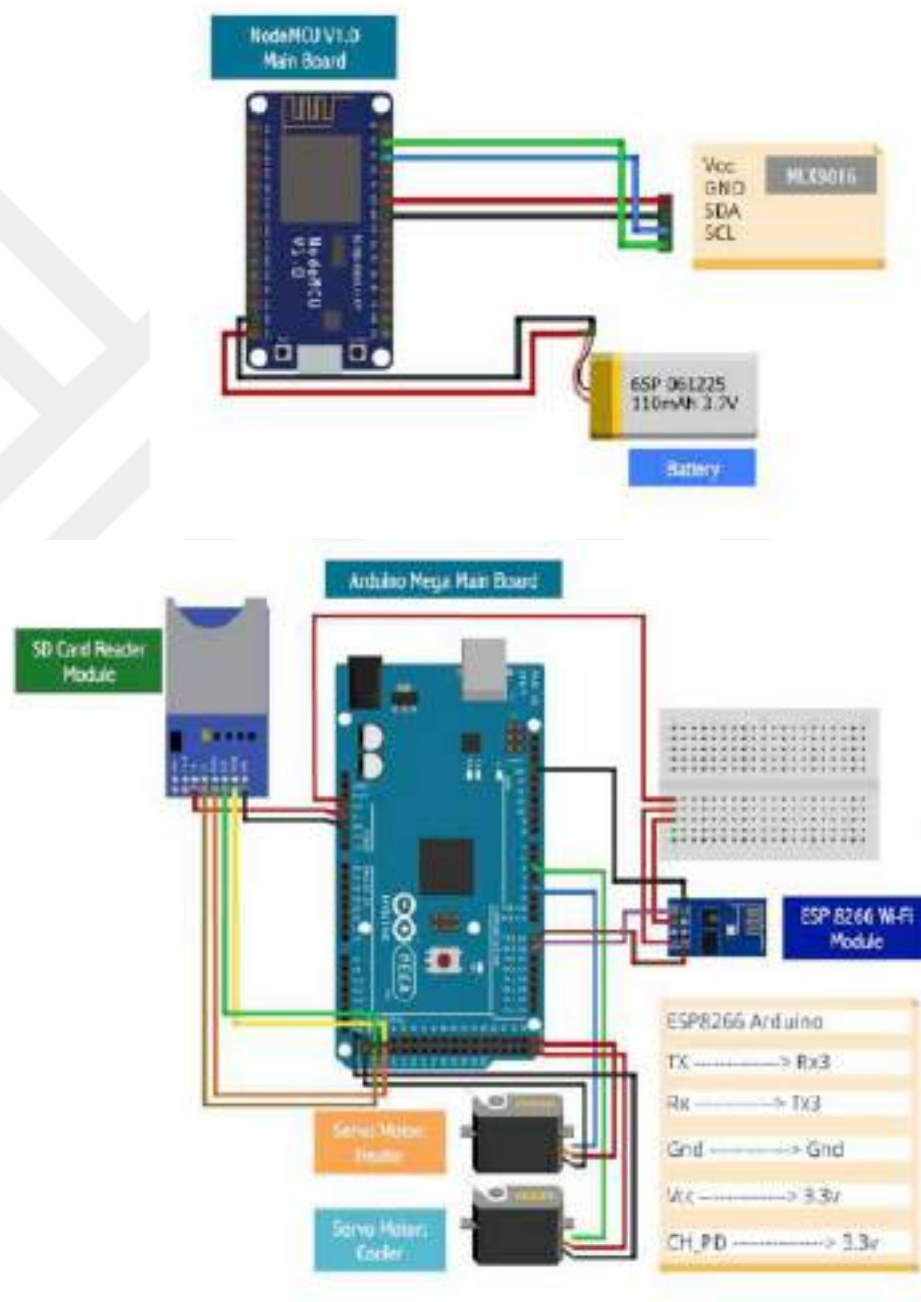


Figure 116: Prototype
VII – Schematic



NodeMCU Module:

NodeMCU is an open source IoT platform. It includes firmware that runs on the ESP8266 Wi-Fi SoC from Espressif Systems, and hardware, which is based on the ESP-12 module. The term "NodeMCU" by default refers to the firmware rather than the development kits. The firmware uses the Lua scripting language. It is based on the e-Lua project, and built on the Espressif Non-OS SDK for ESP8266 (NodeMCU, 2014).

NodeMCU Module is preferred in this Prototype regarding to eliminate the Wireless connection errors and deficiencies of communication tools, and compatibilities. Since NodeMCU has the connection module (ESP8266) embedded to the main board, this prototype's design and connection is more simple and clean. Relatively, the transmitter code is also simpler and shorter, in relation to the decreased amount of the connections.



Figure 117: NodeMCU Board (NodeMCU, 2014)

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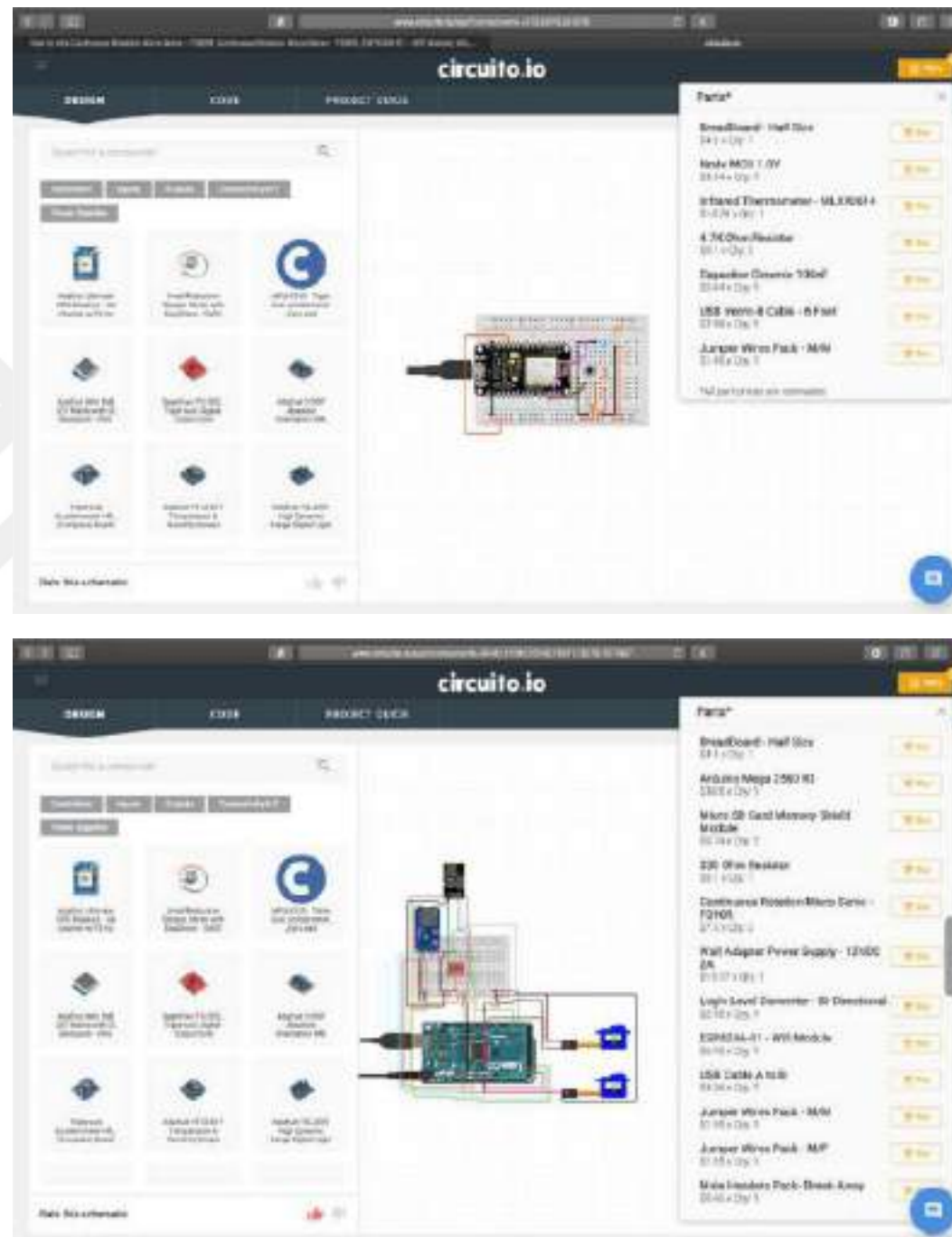


Figure 118: Prototype VII – circuit.io Schematics



Variables:

1. BIM Extracted:

Construction materials, opening details, location and orientation and insulation materials coefficients' data (R-Values and Area & Dimension information). Manually entering the data from the Dynamo calculation 'Room Thermal Value Results'

2. Global Information System (GIS) data:

Outdoor Thermal / Weather Information real-time via OpenWeather API.

3. Real-time ambient (interior) temperature data:

Indoor thermal information from the infrared thermometer 'Prototype VII' transmitter.

4. Real-time body temperature data of the user:

Users' body temperature data from the 'Prototype VII' transmitter.

5. Blynk App:

Indoor location, location tagging, real-time data visualization.

Final Code:

The modifications upon the Prototype VI code formed the last version of the interface. On transmitter code, the major change is the addition of Open Weather API for real-time local weather information to calibrate the accuracy of customization and optimizing the thermal comfort by pre-defined parameters(preferences) of the user. This addition created another variable as the Exterior Temperature. Another modification is the automatic check-in to the system. The devices (both transmitter and receiver) connect automatically when it connects the local wi-fi zone, and the data collection activates. On the Arduino IDE, when the algorithm runs, (visualized by Serial Monitor), if the room data is 0, means, the user is outside, there is no data. This makes all devices automatically OFF.

On the Receiver code part, there were 2 alternatives to be tested. First alternative was upon having a percentage calculation by the variables, transmitter from the wearable device. In this case, having the %25 of each variable (exterior temperature, interior temperature, user body temperature and the room thermal value), was tested. In conclusion, giving equal value to those variables was not correct, and the test is discarded.

The second alternative is the final one. This alternative is based on threshold definitions. The first threshold definition is introduced depending on the Room Thermal Values that was previously generated from the Dynamo definition. The results of the calculation shows that the values are between 0 to 1000, where the poorest thermal quality is 0 and the best thermal quality is 1000. In the model 2; the duplex villa example, the highest value is below 800. According to this, the threshold for motor activation is set as 350.

On the other hand, the data that is transmitted from the Transmitter device, generates the other value, which is real-time. The real-time thermal values are considered as one, and the balance is set as, %20 of Exterior Temperature, %40 Interior Temperature and %40 of User Body Temperature. According to this percentage result, the activation threshold is defined as for heater activation above 20 Celsius Degrees and for cooler (ventilator) activation 27 Celsius Degrees. For the in between temperature, there is no modification expected since the comfort level is satisfactory. Yet, this thresholds could be modified within the app, by users preference.

OpenWeather API:

The transmitter code has the API⁷³ that allows the prototype to work within an 'Application Programming Interface' that is called 'OpenWeather API'. This is an interface or communication protocol between the user and a server intended to simplify the building of client-side software.

Open Weather API is a free online interface. By including this service to the transmitter code, the prototype has access to current local weather data. By OpenWeather API, it is possible to access any locations weather information in real time, including over 200,000 cities. Google has closed their Weather and Cloud solutions since 4th of June 2015 and recommended to use OpenWeather Map with the Google Maps JavaScript API as an alternative solution (OpenWeather, 2019). This is a good solution for Symbiotic Data Platform, because the platform is not designed for a specific city, yet; the platform aims to address any location and any building that has a BIM file. By using this API, current weather is frequently updated based on global models and data from more than 40,000 weather stations. This API and its library can be used to develop applications and

⁷³ Application Programming Interface: It is a set of functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service.



services for multiple platforms, such as Windows, Mac OS X, Linux, and Android.

Additionally, with OpenWeather API, it is possible to access to various other environmental open-data, such as; weather alerts, UV index and air pollution data if necessary. Weather alerts, that have a simple syntax to create triggers that will be working upon the occurrence of specified weather conditions (temperature, humidity, pressure, etc.) in a certain period of time. The alerts will be generated in our service after performing conditions of the trigger. Current UV index (Clear Sky) and historical data are available for any geolocation (lat/lon). Interpreting of the UV Index and recommended protection are provided. And lastly, Air pollution data, for current and historical (since November 2015) data on air pollution with main indexes of CO, O3, NO2 and SO2.

The weather data is available in JSON, XML, or HTML format. In this prototype, JSON format is used. By this, the local weather data is used as an input, in only 3-5 lines of the specific code (See Figure 119).

```
15 const char server[] = "api.openweathermap.org";
16 String nameOfCity = "Barcelona,ES";
17 String apiKey = "a1487f8f9f8fcb2de0ab5883d527f7ec";
18
19 String text;
20 int jsonend = 0;
21 boolean startJson = false;
22 int status = WL_IDLE_STATUS;
23 unsigned long lastConnectionTime = 10 * 60 * 1000;
24 const unsigned long postInterval = 10 * 60 * 1000;
25
26
27 double atemp;
28 double otemp;
29 double trhsld;
30 unsigned long t;
31 float temperatureD;
32
33 WiFiClient client;
34 ADFRUIT_MLX90614 mlx = ADFRUIT_MLX90614();
35
```

Figure 119: Prototype VII – Transmitter Code – OpenWeather API and location (Barcelona, ES) setting.

9.2. BLYNK APP

Blynk is a hardware-agnostic IoT platform with white-label mobile apps, private clouds, device management, data analytics, and machine learning (Blynk Inc., 2019). The mobile application is used for controlling the IoT projects and visualizing the data on the smart phones. Not only for visualization, but also controlling the tools are possible with this mobile app. Blynk app fills the gap of Arduino platforms' real-time data visualization. The app is compatible with various IoT platforms.

There are two options to use the app; the free version and the paid version. For Prototype VII, it was necessary to use the paid version, since the project requires more buttons and an advanced connection. Additionally, there is a Demo App Package; (also paid version, monthly \$99), that exports the Blynk project as a standalone Android app. For Symbiotic Data Platform, using the pre-designed interface and using Blynk as a gadget was satisfactory, since it is a research project and validating the function was successful. It is an open source platform, compatible with around 400 hardwares. The connection is managed over Wi-Fi, LTE, 2G-4G, or Ethernet. A public host for big-scaled projects can manage the created open-source cloud environment or it also could be privately hosted on a local machine. In the case of Prototype VII, the host is private on the local machine.

The Blynk App is used on this last prototype for indoor location tagging and visualization of the real-time data on users' mobile phone. The advantage to use this platform for Prototype VII is, having a well-designed UX/UI, and without any previous knowledge, enabling the user to access the platform. It is easy to understand and use, and universally acceptable. The real-time visualized data is also clear to observe and understandable. By Blynk App, have a variety of pre-designed widgets to build native iOS and Android apps that control electronics, monitor sensor data, get notifications. Symbiotic Data Platform had an initial interface, controlled by a smartphone. The design is not unique, since it is a pre-designed app, yet; thanks to the drag-n-drop buttons, all the required functions of Symbiotic Data Platform are enabled.

The hardware could be controlled by using this app, without any location limitations. On Prototype VII, by connecting the Wi-Fi network, the transmitter could be activated, and this regulation, the necessity of having a GPS module is excluded. Yet, by adding other Wi-Fi networks to access the app, not necessarily being the house or the specified location, would enable the user to access the hardware and control the HVAC system, before arriving the house.



9.3. FINAL TEST

Sankey Diagram 1:

The final test is done by using the Model 2 data from the Revit Model. Values of the Model 2 are between 0 to 1000. Regarding to this, room thermal value thresholds definition on Symbiotic Data Platforms algorithm is made by the following values:

<350 very bad insulation
350-500 moderate condition
>500 better insulation
>750 good insulation

After many calibrations tests during summer time and winter time in the specific location, the optimum thermal comfort threshold is defined as following:

```
#define Value_V 27
#define Value_H 20
```

Those threshold values are variable for each person. On Symbiotic Data Platform usage, this thresholds would be able to modified and arrange according to the desired ambient qualities through the app.

Sankey Diagram 2:

Temperature Threshold:

The Value 1 that corresponds the thermal value that comes from the transmitter in real-time defines the first threshold. For cooler, 27C Degrees, and for heater 20C Degrees. Room Thermal Value Threshold:

<350 poor -----15 min period, full power
between 350-500 moderate ----- 7 min, normal power
>500 good ----- 3 min, normal power

After many calibrations tests, the optimum thermal comfort threshold is defined as following:

```
#define Value_V 27
#define Value_H 20
#define Time1 15
#define Time2 7
#define Time3 3
```

Those threshold values of desired temperature are variable for each person and the duration of the motors depends to the insulation quality of each building case. On Symbiotic Data Platform usage, the temperature thresholds would be able to modified and arrange according to the desired ambient qualities through the app. Even though the duration thresholds are tested only fore one case and gives accurate and satisfactory results, the function duration has to be calibrated by further research within more case studies, and on various buildings, locations & different seasons and weather.

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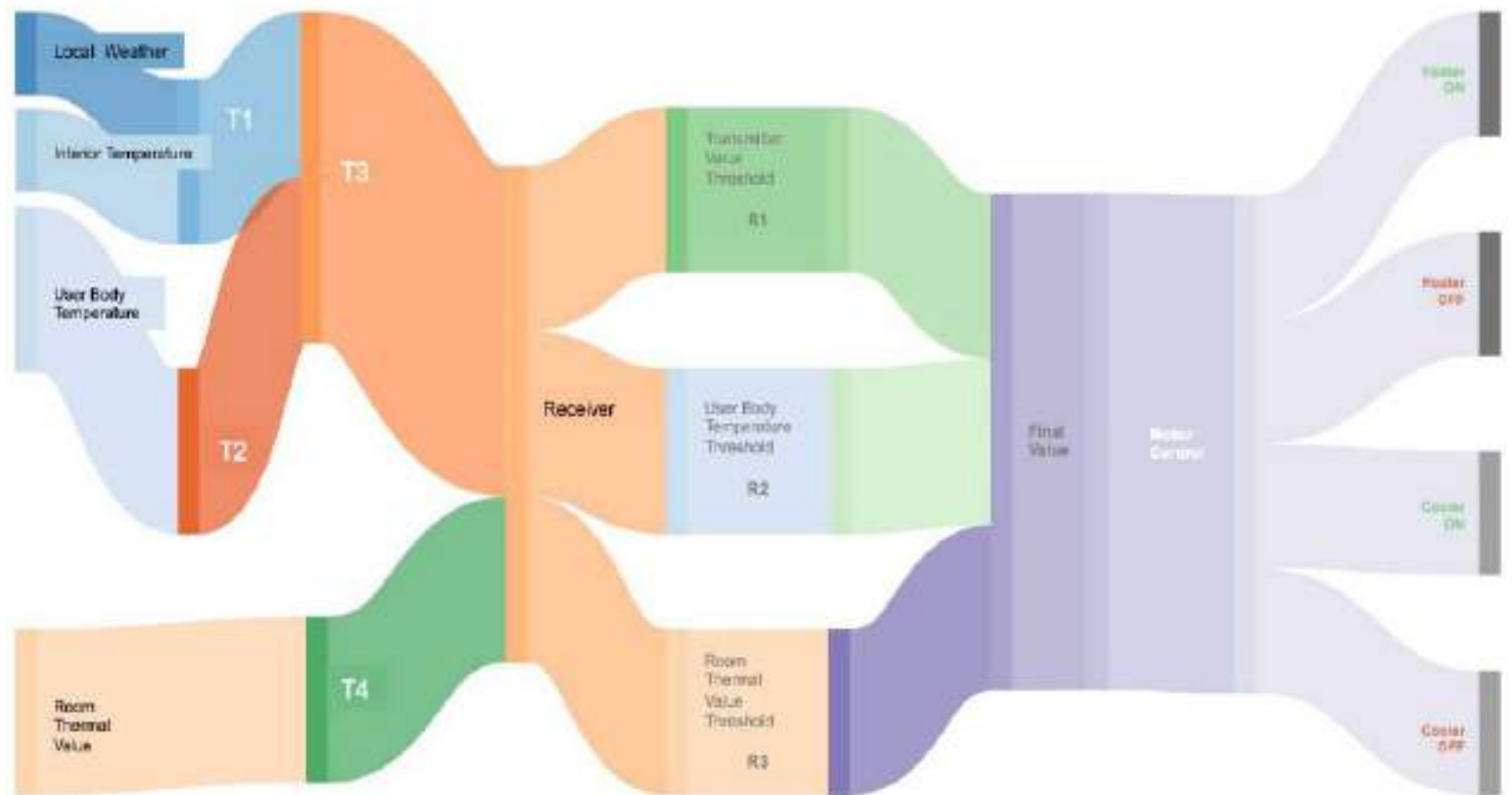


Figure 120: Sankey Diagram of Final Code – without duration

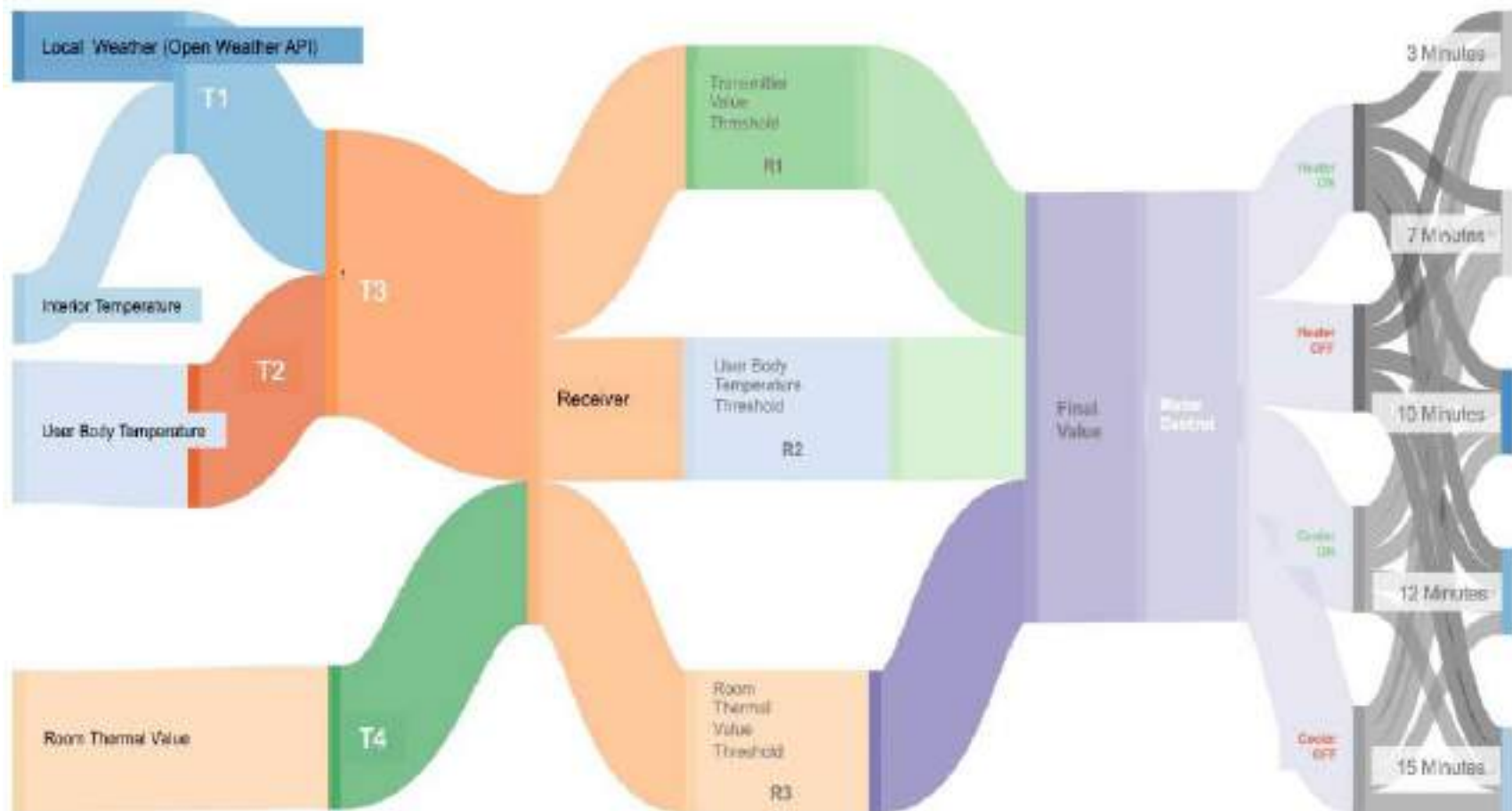


Figure 121: Sankey Diagram of Final Code – with duration

Summer Test // 30 August:

Among all the other; the two example tests are done in the extreme thermal conditions. The summer test is done on 30 August 2019, that the outdoor temperature was 33C.

For the test, Model 2 is used. The thresholds were as stated in the Sankey 2 diagram, and the test is done within the previously stated motor activity duration times. The real-time thermal values are considered as one, and the balance is set as, %20 of Exterior Temperature, %40 Interior Temperature and %40 of User Body Temperature. Since the ventilator activation threshold is 27C, whenever the average of Outdoor and Ambient temperature is equal or above this threshold, the system checks if the Object (user body) temperature is equal or above this threshold. If yes; creates the average of all, and the first milestone for motors function is active. Then, when one of the motors, in this case it is the Ventilator, is ON, the second milestone is activated. The second one is the duration thresholds, which takes the reference from the Room Thermal Values. Those values are;

<350 poor -----15 min period, full power
 between 350-500 moderate ----- 7 min, normal power
 >500 good ----- 3 min, normal power.

The 30 August 2019 test works positively to prove between those durations, the user body temperature is normalized when applied to the conditions.

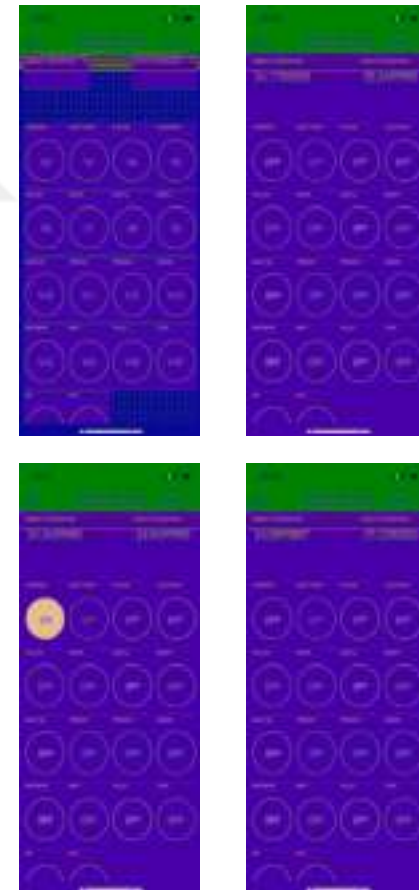
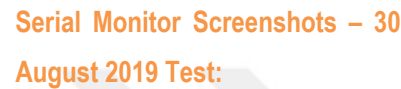
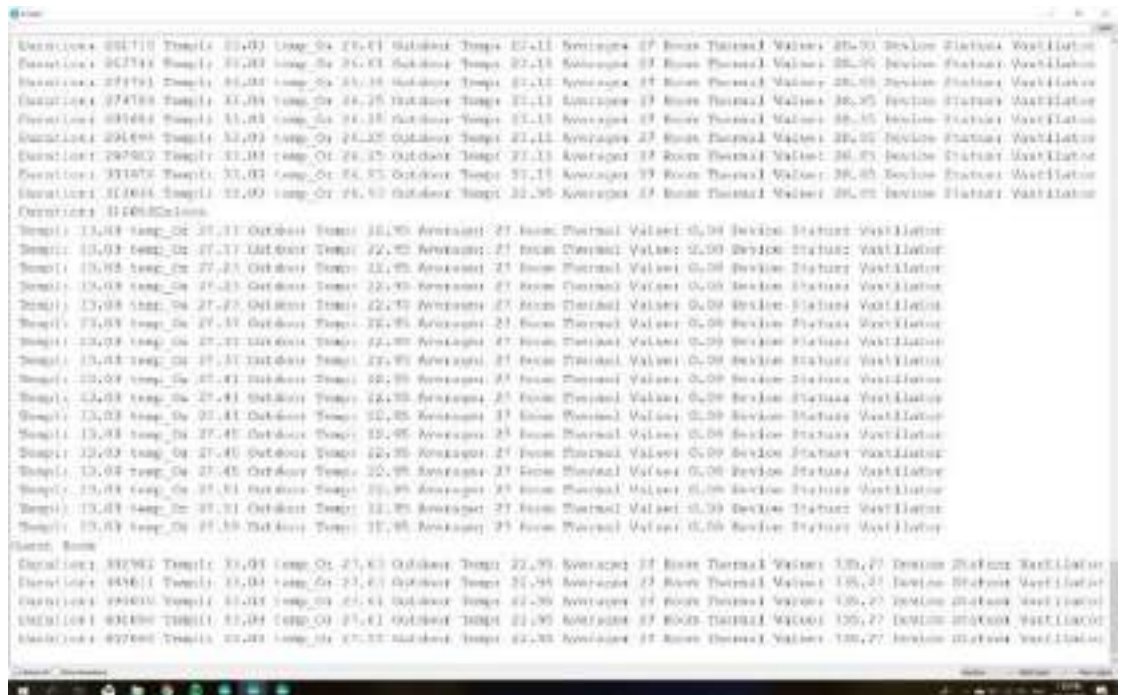


Figure 122: Prototype VII –Blynk App Screenshots - 30 August 201



sensitivity & specificity



Screenshot – Test 30 August 2019 - 4



Winter Test // 12 January:

The winter test is done on 12 January 2020, when the outdoor temperature was 9C degrees.

For the test, Model 2 is used. The thresholds were as stated in the Sankey 2 diagram, and the test is done within the previously stated motor activity duration times. The real-time thermal values are considered as one, and the balance is set as, %20 of Exterior Temperature, %40 Interior Temperature and %40 of User Body Temperature. Since the heater activation threshold is 20C, whenever the average of Outdoor and Ambient temperature is equal or below this threshold, the system checks if the Object (user body) temperature is equal or below this threshold. If yes; creates the average of all, and the first milestone for motors function is active. Then, when one of the motors, in this case it is the Heater, is ON, the second milestone is activated. The heater, is assumed to be an instant heater on this test. The second one is the duration thresholds, which takes the reference from the Room Thermal Values. The duration continues until the desired level is achieved. If not, the algorithm asks the sensor again until the comfort level is optimized. Those values are;

<350 poor -----15 min period, full power
between 350-500 moderate ----- 7 min, normal power
>500 good ----- 3 min, normal power.

Likewise the summer test on 30 August 2019, the winter test on 12 January 2020 test also works positively to prove between those durations, the user body temperature is normalized when applied to the conditions.

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Serial Monitor Screenshots – 12 January 2020 Test:

Figure 127: Prototype VII – Serial Monitor
Screenshot – Test 12 January 2020 – 1



Figure 128: Prototype VII – Serial Monitor
Screenshot – Test 12 January 2020 – 2





Figure 129: Prototype VII – Serial Monitor Screenshot – Test 12 January 2020 – 3



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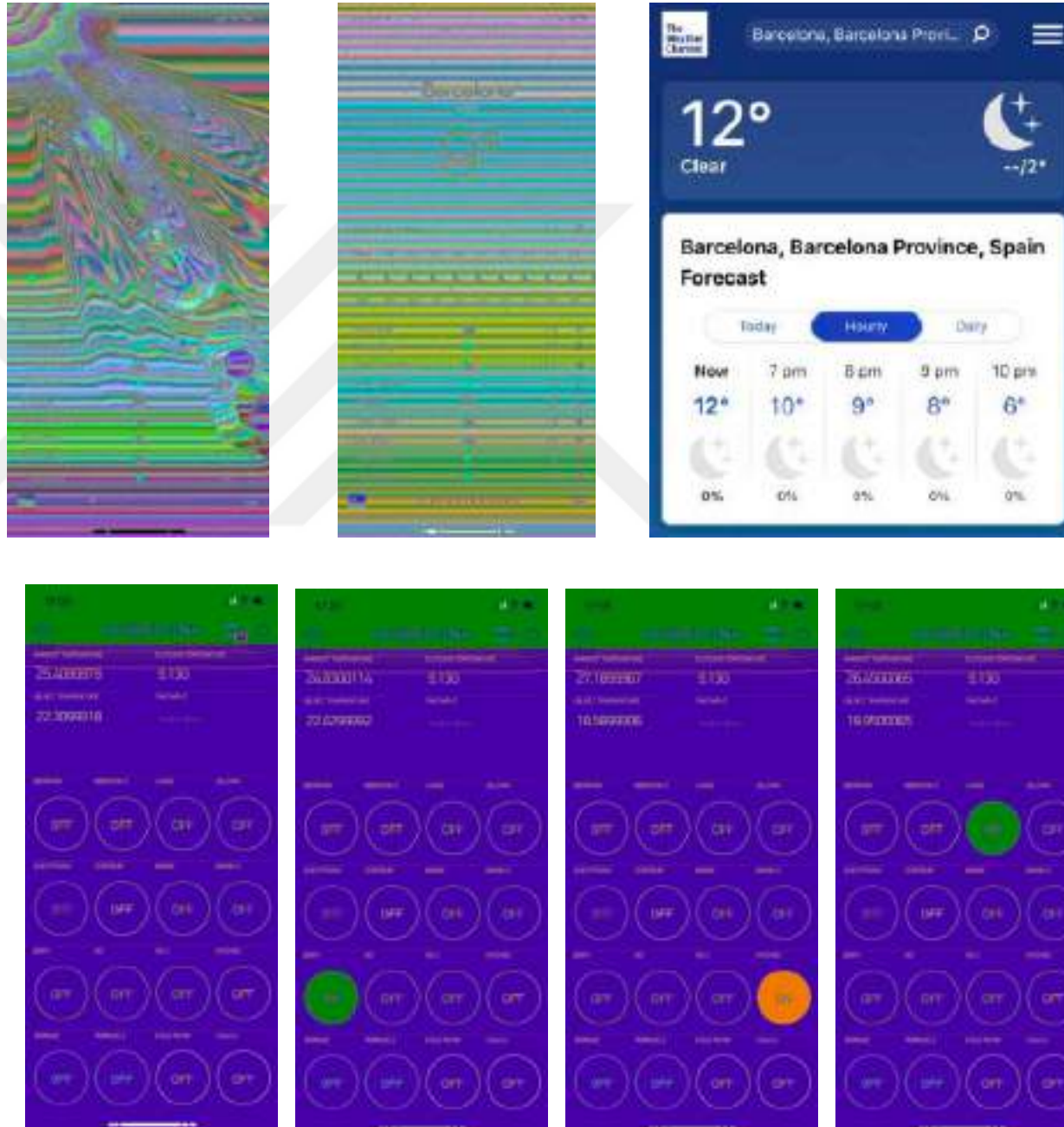


Figure 131: Prototype VII – Weather App and Blynk App Screenshots - 12 January 2020



9.4. CONCEPTUAL VISUALIZATIONS

Design Of The Case:

For the final prototype, the necessity of protection of the device is the last addition for the final Prototype. Aim is to make a designed case to enable the user to use the transmitter module as a wearable and/or attach it to the clothes to be used as a daily accessory, smartphone or a furniture.

Prototype Protective Case Description:

1. Type: Smartphone case as a base that the prototype will be attached to this. Or, used as an accessory to be attached to the clothes, used as a collar or pinned to the surrounding furniture.
2. Size of the prototype: Option 1 – Big, 8cm x 6cm or Option 2 – Compact, 6cm x 4 cm
3. Thickness of the proto-board: 1mm (3D Printed rectangular cover. It is a L-shaped section, where the photo-board will be imbedded.)
4. Total height of the prototype cover: 1,5 cm
5. Material: One-piece 3D Printed case-Transparent or Flexible Thermoplastic Elastomers (TPE), Transparent Plexi-glass.
6. Ornament: This will be the top cover of the prototype. Have one or two layers, same pattern, different orientation and sizes. It will be cover of the prototype attachment, but it shouldn't cover the infrared eye. It must have an extension attached to the case, and this

extension is with 1,5 cm margin to cover the prototype. The extension can be fitted or one-piece 3D printed. If the ornament is laser cut transparent Plexi-glass, the 'plexi' piece ornament is detachable to allow the inserting the prototype.

7. Color scheme: Baby Blue, Yellow, Hot Pink, Orange.



Figure 132: Protective Case Visuals

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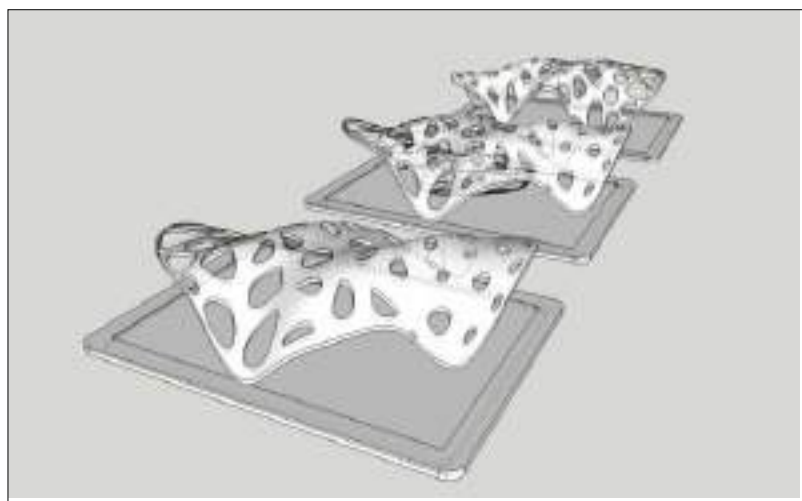
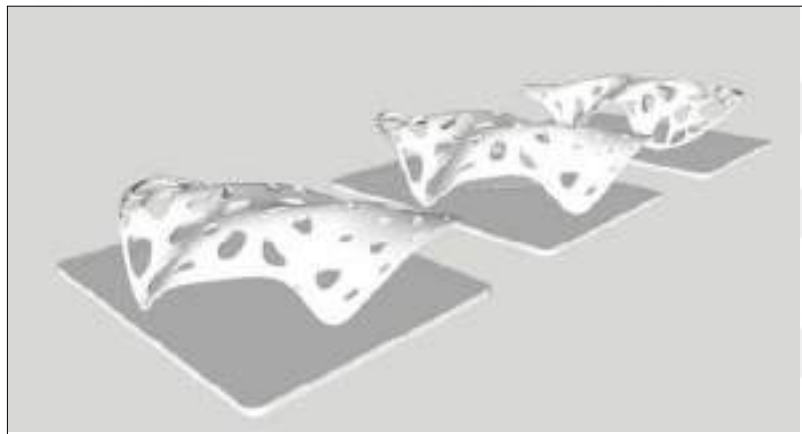


Figure 133: Protective Case Visuals

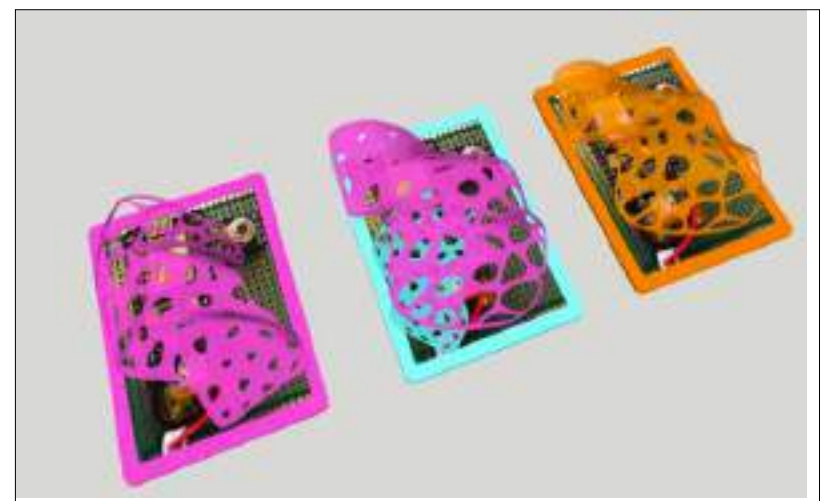


Figure 134: Protective Case Visuals



Website Visualization

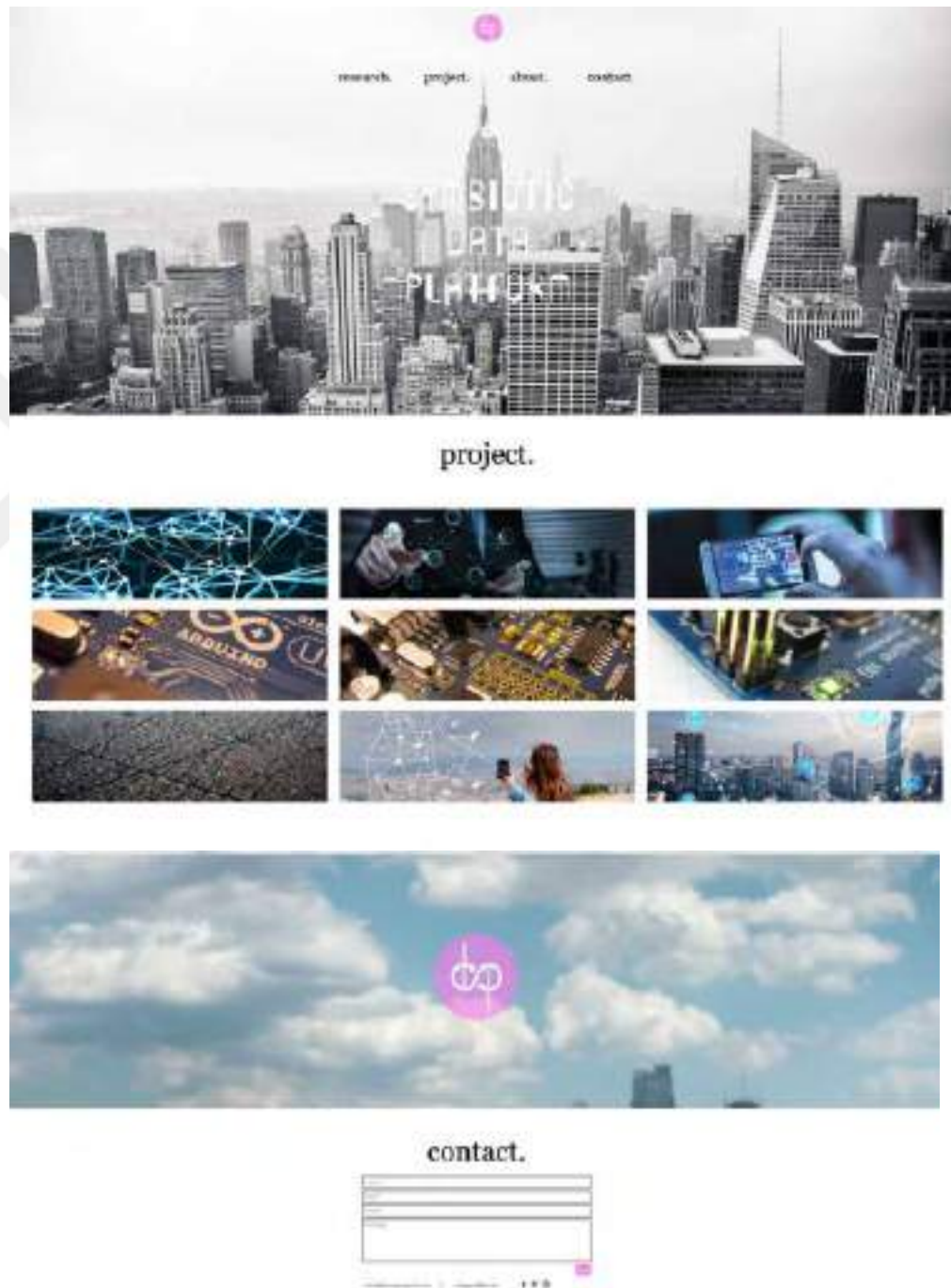
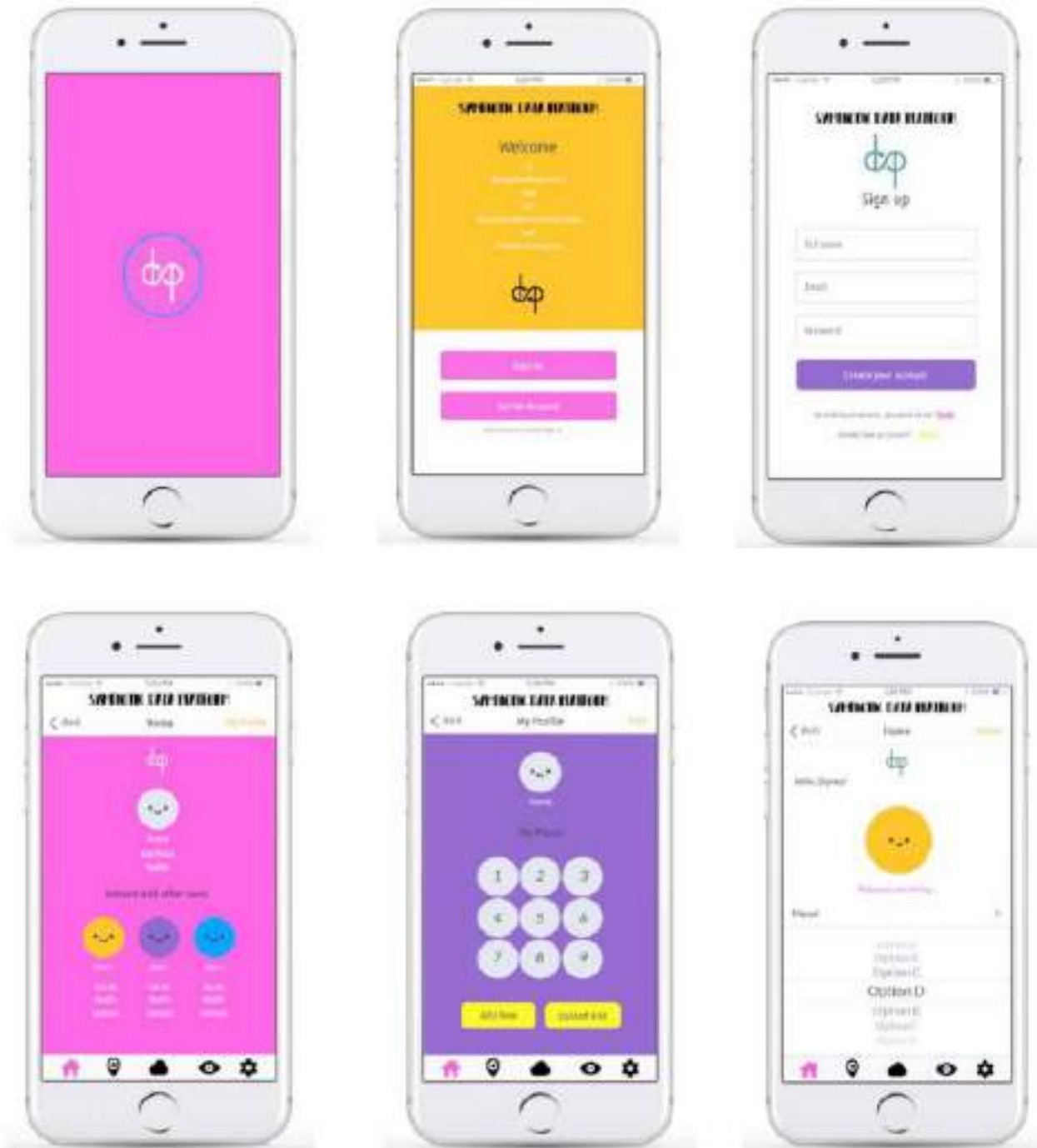


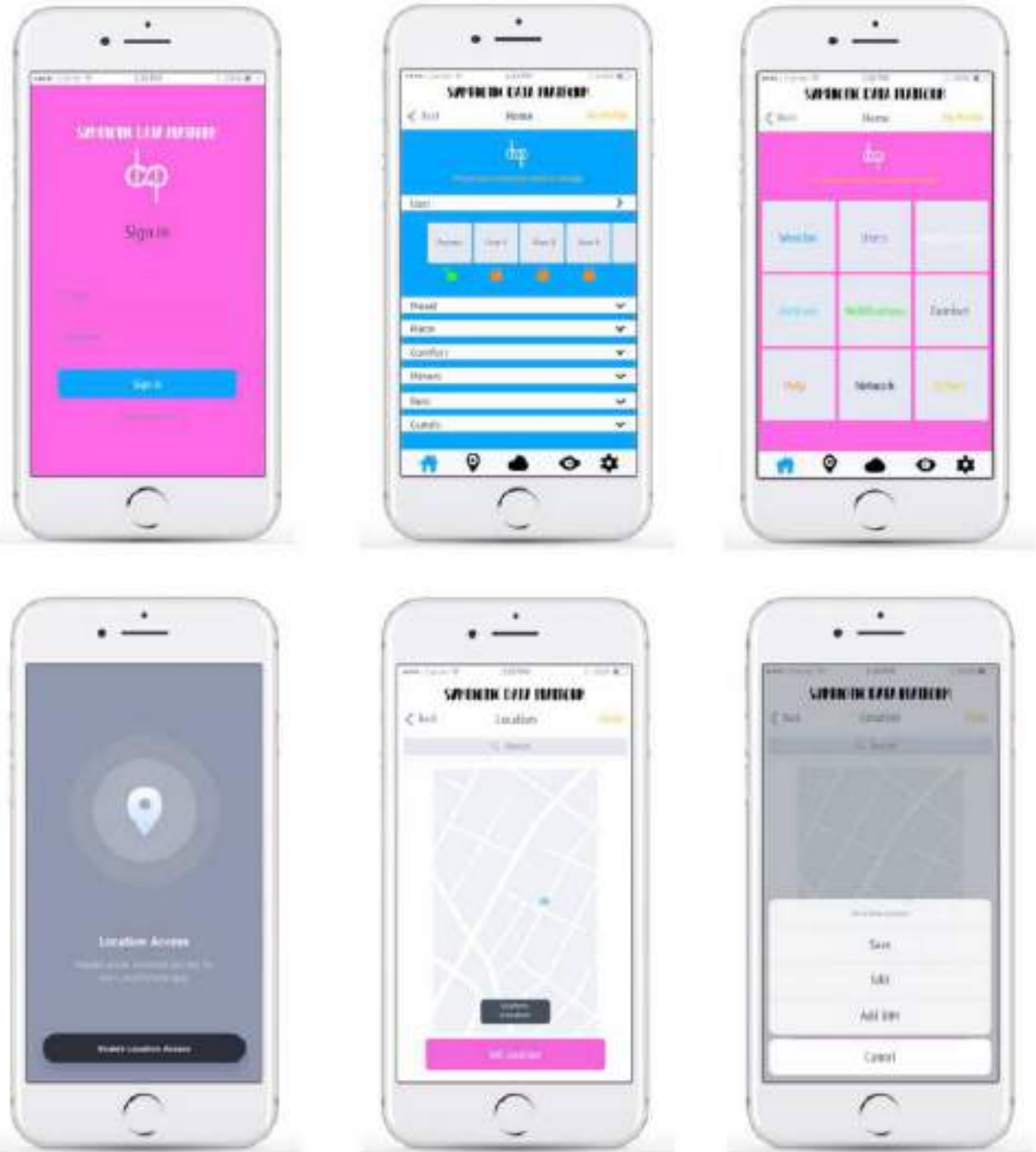
Figure 135: Website Visual

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Mobile App Mock-up:





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SYMBIOTIC DATA PLATFORM

resilibility & resigibility

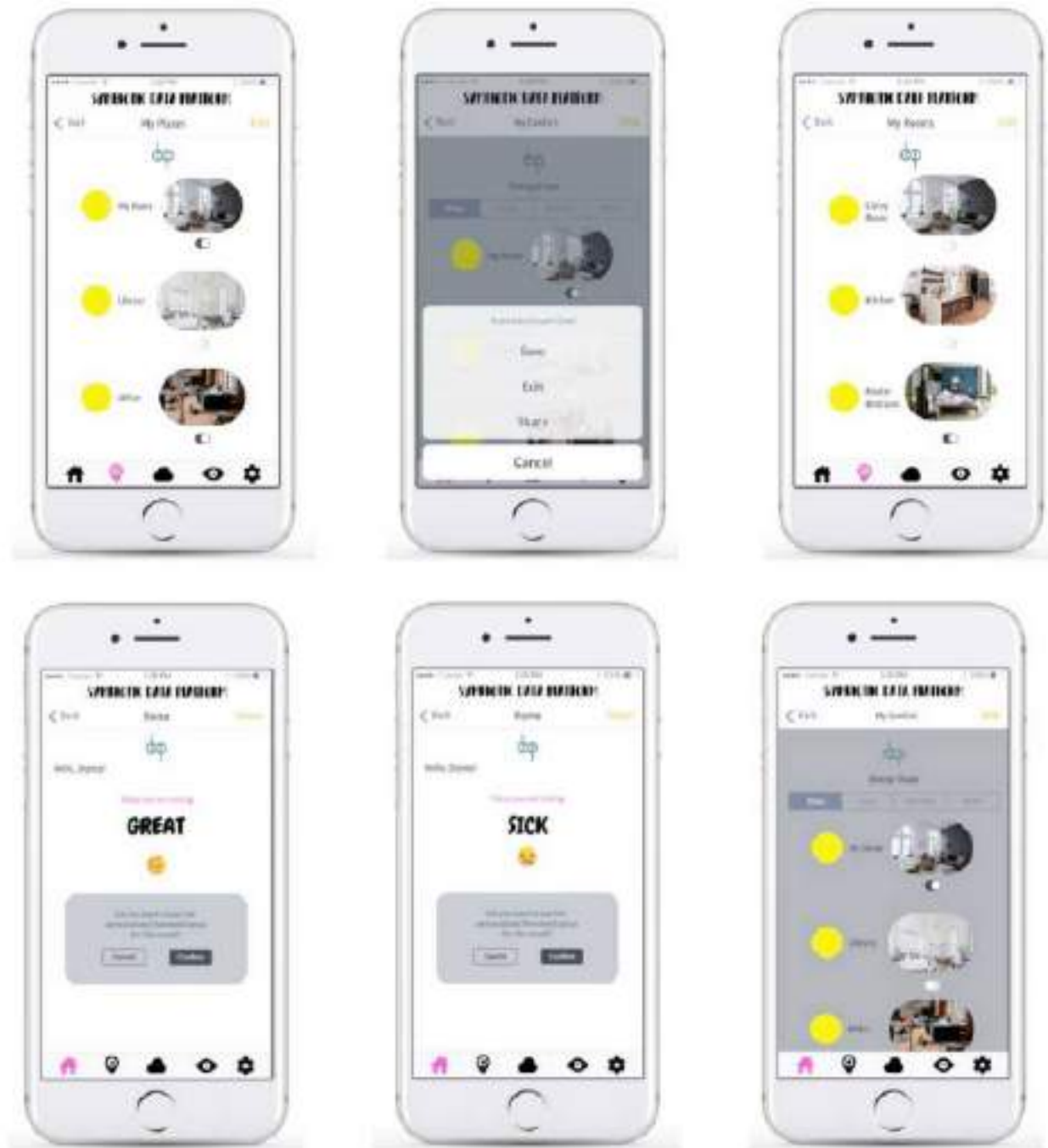


Figure 136: Symbiotic Data Platform' Mobile Application Mock-U



9.5. PROTOTYPES CONCLUSION

Prototype VII proves 'Symbiotic Data Platforms' hypothesis positively. Blending BIM data with IoT Technologies are successfully implemented to each other. The general terms of the platform are as following:

1. Symbiotic: That develops both sides benefits mutually. Apart from this metaphoric title, the platform addresses customizing and optimizing thermal comfort of the occupant by enhancing energy efficiency by reducing excess energy consumption. As a consequence, a sensible system with a sensitive approach results beneficially for the user, society and for the environment in socio-economic & natural manners.
2. Encouraging & Empowering: By showing the efficient use and optimizing the comfort level by user-centered approach, the platform creates a sustainable usage cycle that encourages for more use, while empowers the user by existing data & their own real-time data and giving satisfactory results.
3. Productive: The reduction of energy use and its economic outcomes, with personalized thermal comfort level creates a more productive and efficient living & working space.
4. Receptive-Responsive: The platform works within the continuous cycle that is receptive and response. This term also leads to have the interference of being sensible and sensitive on the way of the previously mentioned technical & theoretical literature review references.

Final Checklist of all Prototypes:

The summary and discussion upon the tests and prototypes can be seen in the following checklist that shows the all seven prototypes and their evolution throughout the research timeline. Each prototype is developed upon the previous versions' gains and errors. On the final prototype (VII), the required results for Symbiotic Data Platform is achieved. The hardware is compact, all errors are resolved and it has fluid connection with the main computer wirelessly. The software is processing BM data and real-time data through complementary applications and softwares (See Figure 137).

SYMBIOTIC DATA PLATFORM

usability & feasibility

	PROTOTYPE I	PROTOTYPE II	PROTOTYPE III	PROTOTYPE IV	PROTOTYPE IV	PROTOTYPE VI	PROTOTYPE VII
Time Period	January - February 2018	March - April 2018	May - June 2018	September - October 2018	November - December 2018	January - March 2019	April - August 2019
Variables	Ambient Temperature User Body Temperature	Ambient Temperature User Body Temperature Location (GPS) , BIM Extracted Material data	Ambient Temperature User Body Temperature Location (GPS) , BIM Extracted Material data	Ambient Temperature User Body Temperature, BIM Extracted Material data	Ambient Temperature User Body Temperature Location (GPS), BIM Extracted Material data	Ambient Temperature User Body Temperature Outdoor Weather Indoor Location, BIM Extracted Material data	Ambient Temperature User Body Temperature Outdoor Weather Indoor Location, BIM Extracted Material data
Hardware							
Micro-Controller	Arduino Lilypad Arduino Uno	Arduino Lilypad Arduino Uno	Arduino Lilypad Arduino Uno	Arduino ProMini Arduino Uno	2 of Arduino Pro Mini's, Arduino Mega	Arduino ProMini Arduino Mega	NodeMCU CP2102 - 3V Lua Amica Arduino Mega
Sensor	MLX90614 Infrared Thermometer	MLX90614 Infrared Thermometer	MLX90614 Infrared Thermometer	MLX90614 Infrared Thermometer	MLX90614 Infrared Thermometer	MLX90614 Infrared Thermometer	MLX90614 Infrared Thermometer
Motors	1 Servo Motor	2 Servo Motors (Heater and Cooler)	2 Servo Motors (Heater and Cooler)	2 Servo Motors (Heater and Cooler)	2 Servo Motors (Heater and Cooler)	2 Servo Motors (Heater and Cooler)	2 Servo Motors (Heater and Cooler)
Other Tools	FDTI Cable, Battery	FDTI Cable GPS Module Battery	FDTI Cable GPS Module XB24C ZigBee Xbee Shiled XB24C ZigBee Wireless Connection Board Push button Battery Cells, CoinBattery, Battery XB24C ZigBee Xbee Shiled XB24C ZigBee Wireless Connection Board	FDTI Cable HC05 Bluetooth Serial Module Protoboard, Battery HC05 Bluetooth Serial Module	FDTI Cable ESP8266 Wi-Fi Module SIM800L GSM / GPRS Module LM7805 - 5V Regulator LM1117 - 3.3V Regulator 2 Switches Protoboard, Battery ESP8266 Wi-Fi Module SD Card Module	FDTI Cable ESP8266 Wi-Fi Module Protoboard, Battery ESP8266 Wi-Fi Module SD Card Module	FDTI Cable Protoboard Battery ESP8266 Wi-Fi Module SD Card Module
Wiring Type	Wired	Wired	Sewed, Wired	Soldered, Wired	Soldered	Soldered	Soldered
Connection Type	Wired	Wired	Wired	Bluetooth Communication	Wireless Communication	Wireless Communication	Wireless Communication
Software							
Processing	Arduino IDE	Arduino IDE	Arduino IDE	Arduino IDE	Arduino IDE	Arduino IDE Blynk App Revit - Dynamo (BIM)	Arduino IDE Blynk App Open Weather API Revit - Dynamo (BIM)
Purpose	Testing the connections	Design and simplification Proving the location tracking Testing the location tracking Testing the connections	Wearable Patch Wireless Connection Location tracking, Testing the connections, Proving the material data	Wearable Object design Wireless Connection Testing the connections	Wearable Object design. Wireless Connection, Testing the connections. SD Card - Data input.	Wearable Object design. Wireless Connection, Testing the connections. SD Card - Data input.	Wearable Object design. Wireless Connection. Indoor location tracking. Including outdoor temperature. Testing the connections. SD Card - Data input. Defining and testing the thresholds
Function	Proving the connection	Sensing the real-time object temperature Proving the material data	Proving the location tracking Testing the location tracking	Data accuracy Wireless connection Design improvement Proving the material data	Data accuracy. Wireless connection. Design improvement. Proving the material data. Reading the material data from SD Card.	Data accuracy. Wireless connection. Betterment on design. Proving the material data. Reading the material data from SD Card.	Real-Time visualization via Blynk app. Wireless connection. Betterment on design. Proving the material data. Reading the material data from SD Card.
BIM Data	✗	✓	✓	✓	✓	✓	✓
Errors	✗	Location accuracy Connectivity Material quality	Location accuracy Connectivity Material quality	Wireless connection fails	Wireless connection fails GPS not accurate Dimension is not satisfactory. Wireless connection fails SD Card reading is challenging.	Thresholds have to be calibrated. BIM Values should be tested.	✗

Figure 137: The Final Checklist for all prototypes



	PROTOTYPE I	PROTOTYPE II	PROTOTYPE III
Time Period	January - February 2018	March - April 2018	May – June 2018
Variables	Ambient Temperature User Body Temperature	Ambient Temperature User Body Temperature Location (GPS) , BIM Extracted Material data	Ambient Temperature User Body Temperature Location (GPS) , BIM Extracted Material data
<u>Hardware</u>			
Micro-Controller	Arduino Lilypad Arduino Uno	Arduino Lilypad Arduino Uno	Arduino Lilypad Arduino Uno
Sensor	MLX90614 Infrared Thermometer	MLX90614 Infrared Thermometer	MLX90614 Infrared Thermometer
Motors	1 Servo Motor	2 Servo Motors (Heater and Cooler)	2 Servo Motors (Heater and Cooler)
Other Tools	FDTI Cable, Battery	FDTI Cable GPS Module Battery	FDTI Cable GPS Module XB24C ZigBee Xbee Shiled XB24C ZigBee Wireless Connection Board Push button Battery Cells, CoinBattery, Battery XB24C ZigBee Xbee Shiled XB24C ZigBee Wireless Connection Board
Wiring Type	Wired	Wired	Sewed, Wired
Connection Type	Wired	Wired	Wired
<u>Software</u>			
Processing	Arduino IDE	Arduino IDE	Arduino IDE
Purpose	Testing the connections	Design and simplification Proving the location tracking Testing the location tracking Testing the connections	Wearable Patch Wireless Connection Location tracking, Testing the connections, Proving the material data
Function	Proving the connection	Sensing the real-time object temperature Proving the material data	Proving the location tracking Testing the location tracking
BIM Data	✗	✓	✓
Errors	✗	Location accuracy Connectivity Material quality	Location accuracy Connectivity Material quality

PROTOTYPE IV	PROTOTYPE IV	PROTOTYPE VI	PROTOTYPE VII
September – October 2018	November – December 2018	January – March 2019	April – August 2019
Ambient Temperature User Body Temperature, BIM Extracted Material data	Ambient Temperature User Body Temperature Location (GPS), BIM Extracted Material data	Ambient Temperature User Body Temperature Outdoor Weather Indoor Location, BIM Extracted Material data	Ambient Temperature User Body Temperature Outdoor Weather Indoor Location, BIM Extracted Material data
Arduino ProMini Arduino Uno	2 of Arduino Pro Mini's, Arduino Mega	Arduino ProMini Arduino Mega	NodeMcu CP2102 - 3V Lua Amica Arduino Mega
MLX90614 Infrared Thermometer	MLX90614 Infrared Thermometer	MLX90614 Infrared Thermometer	MLX90614 Infrared Thermometer
2 Servo Motors (Heater and Cooler)	2 Servo Motors (Heater and Cooler)	2 Servo Motors (Heater and Cooler)	2 Servo Motors (Heater and Cooler)
FDTI Cable HC05 Bluetooth Serial Module Protoboard, Battery HC05 Bluetooth Serial Module	FDTI Cable ESP8266 Wi-Fi Module SIM800L GSM / GPRS Module LM7805 – 5V Regulator LM1117 – 3.3V Regulator 2 Switches Protoboard, Battery ESP8266 Wi-Fi Module SD Card Module	FDTI Cable ESP8266 Wi-Fi Module Protoboard, Battery ESP8266 Wi-Fi Module SD Card Module	FDTI Cable Protoboard Battery ESP8266 Wi-Fi Module SD Card Module
Soldered, Wired	Soldered	Soldered	Soldered
Bluetooth Communication	Wireless Communication	Wireless Communication	Wireless Communication
Arduino IDE	Arduino IDE	Arduino IDE Blynk App Revit – Dynamo (BIM)	Arduino IDE Blynk App Open Weather API Revit – Dynamo (BIM)
Wearable Object design Wireless Connection Testing the connections	Wearable Object design. Wireless Connection, Testing the connections. SD Card - Data input.	Wearable Object design. Wireless Connection. Testing the connections. SD Card - Data input.	Wearable Object design. Wireless Connection. Indoor location tracking. Including outdoor temperature. Testing the connections. SD Card - Data input. Defining and testing the thresholds
Data accuracy Wireless connection Design improvement Proving the material data	Data accuracy. Wireless connection. Design improvement. Proving the material data. Reading the material data from SD Card.	Data accuracy. Wireless connection. Betterment on design. Proving the material data. Reading the material data from SD Card.	Real-Time visualization via Blynk app. Wireless connection. Betterment on design. Proving the material data. Reading the material data from SD Card.
✓	✓	✓	✓
Wireless connection fails	Wireless connection fails GPS not accurate Dimension is not satisfactory, Wireless connection fails SD Card reading is challenging.	Thresholds have to be calibrated. BIM Values should be tested.	✗

10

CONCLUSIONS

10. CONCLUSIONS

Building Information Modeling is a comprehensive tool for AEC industry, and those models hold all the information of a structure, while creating an interoperable working & operation environment, from cradle to grave. On the other hand, Internet of Things and related technologies are the tools that enables the technical research & development to move forward with advanced solutions. Combining the potentials of those two technologies create pioneering projects, such as Symbiotic Data Platform.

The dissertation of Symbiotic Data Platform project raised the following research question; *“How to use the existing BIM data and constantly produced real-time data together; during the operational phase of the building, to upgrade the energy efficiency and enhance sustainability while addressing optimizing thermal comfort?”*

The first milestone of the project is set up as the platform should address the ‘occupant of the building’ in the first position. The

platform is designed to create and automated tool for ‘customizing and optimizing occupants thermal comfort’ decision-making. As the main objective of the project is to achieve personalized comfort optimization while enhancing energy efficiency, the roadmap to accomplish the goal was passing from taking benefit of existing data and combining existing technologies with an adequate way. Consequently, following the design science research methodology and developing prototypes, leads the results positively.

The approach of research was quite different from the previous literature review, that most of the projects intended to create an additional feature for BIM for visualization, energy analysis or upon other concerns, yet, on Symbiotic Data Platform, the perspective was a bit alternative. To search possible ways to implement the existing BIM data and real-time data together; the scope of application is chosen as physical computation; and the database is chosen as existing BIM data, and real-time data that is collected constantly. The platform is thought to be a life-cycle operation tool for the built environment rather than being a design tool, differently from other BIM and IoT projects.

Following the research question, re-stating the hypothesis as;



“BIM is the digital twin of the real building, so it holds all the information of it. Occupants are the end users of the building, whom use the building actively, and they must have access to the existing information of their built environment in the digital era. Smart users require smarter systems from the built environment. With current technology, existing softwares, devices and tools are capable of capture, process, analyze, blend and interact with the big data and real-time information together. So, the existing information and real-time data could be used for further benefit of the occupants, such as comfort optimization and/or energy efficiency.”

The results achieved from development of Prototype VII, the hypothesis is proven positively. BIM data is used as a decision making criteria for betterment of thermal comfort in existing spaces, and it is blended with the relevant real-time information. Thanks to IoT, all the data collection and human-to-computer, computer-to-computer and computer-to-human interaction are made possible. BIM data is processed by an interactive platform for real conditions' optimization. Moreover, occupants; as users of the platform, are empowered by their own data.

In current stage, Symbiotic Data Platform is developed and tested as a prototype. The possibility of integrating 'Machine Learning', for further configurations of the platform; such as

regular arrival and leaving time, sleeping loops, eating and bathroom habits opens another door for developing the project. The platform; when the further research for programming is conducted; can be more accurate, and more personalized, and as a result, the comfort optimization could make a peak-up. To conclude the general outcomes of the research through the results of the prototypes and their algorithm, the research question is answered. Thanks to BIM data, the existing information could be used for further benefit of the occupants.

Correspondingly, regarding to the fact that prototypes function, the platform could be applied to greater scales, and also to other comfort areas, energy and natural resources consumption (such as water and gas) with various sustainability concerns. In further research Symbiotic Data Platform could be a building, neighborhood, district or city network, that allows a collaborative data exchange, that leads a holistic betterment for all.

As it was stated in a key paper upon the specific research area that integrates BIM and IoT together, by Attar et.al; it is stated that; one of the important concerns is the 'building performance and comfort optimization in balance'. Since comfort and energy savings are often inversely related, understanding a balanced bound between those contexts are often complicated and inversely related. By performance related factors, that might be

simulated by BIM softwares, are challenging without an accurate post-occupancy evaluation with real feedback. It is stated that; the augmented approach upon two main factors are crucial, which are; firstly an effective capture of the occupant's requirements (data collection), secondly, more effective and intelligent means of visualizing the collected data are needed (data representation). On the research project, taking into account the results of the studies, the key challenge is documented as, an occupant-centric approach is required to address better qualified performance analysis & improvements of the project. The conclusion of the research was; *"To increase the accuracy and ongoing validity of performance analysis, the building science community has come to understand the value of extending the focus beyond design to include the full building life-cycle"* (Attar, Hailemariam, Breslav, Khan, & Kurtenbach, 2011). Regarding to the elaborate documentation of the project and the well-described results, Symbiotic Data Platform's design thinking and project outcomes are aligning with the Attar et.al's results.

Ultimately; regarding the to the 'new architectural design understanding' that is coined in the State of the Art of this dissertation, requires a sensible framework with a sensitive & responsible approach. **'Form + Function + Interaction'** is a necessity for tomorrows' built environment.

The new generation is already have been denominated as the 'knowledge generation', where todays world gives the access to massive amount of possibilities to communicate, contact, get inspired, develop intelligence and sophistication. As a matter of fact, the society have developed a sensitive and intellectual cognition & conscience, that could be defined as 'responsible and respectful'. The new generation applied those newly developed skills and expectations to all fields of life, including the built environment. We, as the new generation, expect efficient, beautiful, ethical, sustainable and sophisticated spaces to live in. We; as the society; are a part of this actually by having the leading role and the biggest responsibility, to shape the future.

Discussion:

Symbiotic Data Platform is developed by 7 prototypes. The final prototype is the Prototype VII that has the most compact design and the final version of the code among others. The tests to prove the hypothesis is done by 2 servo motors symbolizing the heater and cooler devices. Likewise, the model that was used for the final test is a hypothetical building. Since it is extremely challenging to test the platform with real heating and cooling devices regarding economic and technical reasons, the



prototype is designed and tested only for the function and for its algorithm. When applied to the required real cases, the algorithm would give desired results, thanks to the adaptability of the thresholds. Regarding the thresholds in the algorithm for decision making, the default values are set up by taking researchers personal preference. Those values are particular to each and every user, reflecting their personal comfort level. To do so, Symbiotic Data Platform should have a user friendly interface (such as a mobile app) to be able to control the values in real practice⁷⁴.

The values that are included in the algorithm, give a clear description of the thermal condition to the system. Exterior temperature (weather), indoor temperature, users, body temperature (hands) are the real time values that sets up the principal control value. The room thermal value, that is calculated from the values extracted from the BIM file gives the secondary threshold, regarding the thermal insulation quality of the specific space. As a result, whenever the users optimum thermal comfort value changes, the platform gets activated and modifies the current situation by turning ON/OFF the required devices.

As another discussion point, the prototype is tested and designed only for single user scenario, for simplifying the code. Yet, for further stages, the platform could be developed for multiple user scenarios, as well as public buildings, that interacts with surrounding spaces⁷⁵.

Symbiotic Data Platform is currently a prototype. It could be developed further by interdisciplinary collaboration, by adding machine learning for learning users habits, augmenting the experience by being more automatized. Also adding an advanced location tracking feature for calculating the proximity to home, pre-preparation and indoor location tracking technologies would give better results in order to eliminate the manual 'check-in' by Blynk (or similarly; Symbiotic Data Platform App).

Symbiotic Data Platform is '*sensible*' by using existing BIM data, collecting real-time information, by processing the collected and existing data together and ultimately by being interactive.

It is '*sensitive*' on the way of concerning 'energy efficiency', 'sustainability', 'creation of livable ambient qualities', and it is

⁷⁴ See Symbiotic Data Platform Mobile App Mock-Up visuals.

⁷⁵ See Symbiotic Data Platform Chapter for single and multiple user scenario explanations.

SYMBIOTIC DATA PLATFORM

sensibility & sensitivity

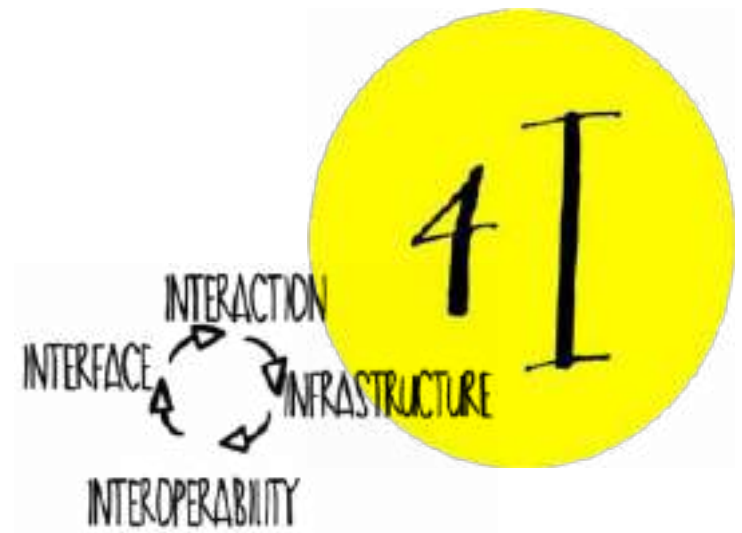
used by the 'responsible users with cognition of knowledge generation'. Over and above, this platform is meant to be a collective interface in a building scale, that the neighbors could take benefit of each others data and energy by sharing their private spaces thermal condition data through the app. The platform is a 'receptive & responsive' tool, which makes it 'sensible and sensitive'. It is an interactive agent on the way of creation of responsive environments.

Summary of Added Values:

1. Dynamo definition for the calculation of room thermal value; that could apply to all cases, to export the data. This may apply to Works with every model, by the unique dynamo definition.
2. Wearable transmitter with lots of potential to be developed, that creates human-computer, computer –computer, computer –human interaction. Allowing the wireless connection for mobile use and for data collection accuracy.
3. Possibility to add machine learning and AI in further research & development. On further stages, proximity to home while the user is approaching the location; the future decision-making criteria could be applied to the system.

4. Using existing technology for energy efficiency. Gives personalized and optimized solutions for buildings' *thermal comfort* in real-time, applicable to all existing buildings. It is a easy, simple and economic solution for taking benefit of the existing condition.
5. Socio-economic and environmental outcomes. Using the sensible tools with a sensitive & responsible approach.

The outcomes as '4I':



The results of the project have 4 outcomes; also can be called the 4I. The points are as follows;



1. The Infrastructure,
2. The Interface,
3. The Interaction of the User,
4. The Interoperability.

1 and 2. Interface that works as an Infrastructure:

Symbiotic Data Platform could be developed for further commercial use as an interface or an mobile app that also could be applied as a building or city infrastructure. This would upgrade the 'smart home' concept to become a 'responsive house / environment' concept.

3. Human-Computer, Computer -Human and Computer-Computer Interaction:

The platform creates three ways of interaction, that maintains the mutual benefit for all parties.

4. Interoperable, easy to use, problem solver:

The platform is designed and tested only for single user scenario. Yet, in further research & development, the project could be upgraded by its algorithm to give access to multiple users. The future development of the platform is aimed to have a

open-source cloud network that users could collaborate and anonymously share their thermal data, through the cloud of the platform. This mutual collaboration is the main idea of Symbiotic Data Platform that empowers the neighbors and the society by their own data. The platform's operation could be done through a mobile app and/or via the website by creating a personal account. The mobile app mock-ups could be seen in the conceptual visualizations section. The UX/UI design is important on the way of facilitating easy to use and efficient access to the platform. Also, *"The access to Cloud services has to be easy, direct, open and interoperable. That is, the provided communication means and programming interfaces (APIs) shall be easy to implement on every platform and developing environment"* (Piyare & Ro Lee, 2013).

To sum up; under the title of 'Symbiotic Data Platform: A Receptive-Responsive Tool For Customizing Thermal Comfort & Optimizing Energy Efficiency'; the project covered up concepts such as 'sensitivity and sensibility', 'interaction', 'customization & optimization', 'responsiveness and interaction' and 'users' comfort level adjustments'. The design thinking objective of the Platform is aimed to be an 'Interactive Infrastructure that works Interoperable by its' unique Interface".

The 8 Pillars of Symbiotic Data Platform:

- 1. Data Detection:** The data that is collected from the transmitter is the first milestone to the access of the control mechanism.
- 2. Data Collection and Analyze:** Following the data collection, the algorithm analyzes if a modification is required regarding to the previously set-up thresholds referring to the users personal preferences for their personalized thermal comfort level.
- 3. Perception and Visualization:** Through the serial monitor and by the 'proposed' app, the collected data could be visualized, for decision making of the system.
- 4. Cognition:** The algorithm has the virtual cognition for automatized decision making. Regarding to the preferences, the necessary modification could be made. On the other hand, within time; the user will also gain cognition and a more responsible manner by realizing the efficient use of the platform, while having the comfort level optimized.
- 5. User Emotion:** Users senses and emotion is the reference for the threshold setup. Optimizing the physical conditions will regenerates or regulates the emotional wellbeing and stability too. As a matter of fact of the usage, realizing the beneficial use of the platform encourages the user to collaborate with the self-sustainable operation cycle.

- 6. Action:** Users interaction with the system on the first step requires a physical action, yet later on the system functions automatically depending to the interaction between the human and the devices.
- 7. Interaction:** Human to Computer interaction leads the computer to computer interaction, and lastly, by the physical modification, the computer to human interaction is realized. This creates a continuous input-feedback cycle.
- 8. Reflection:** The feedback of the modification (user body temperature reaction) out of the operation cycle continues until there is a new input.

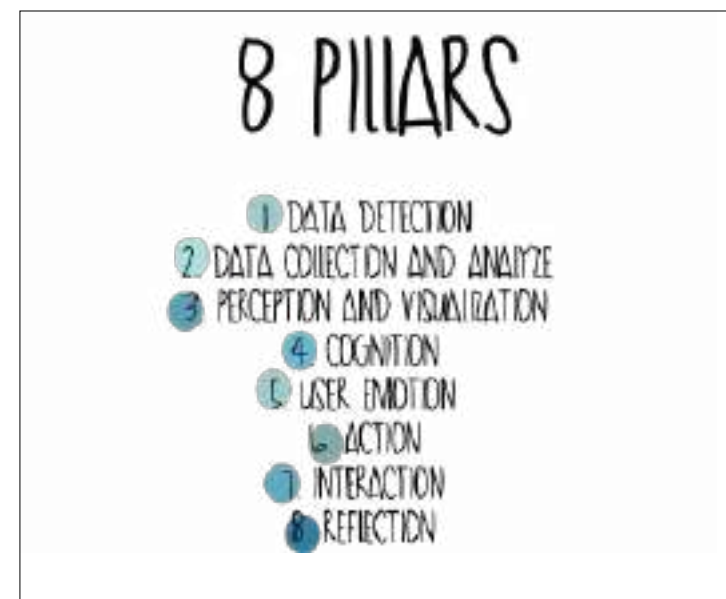


Figure 138: Symbiotic Data Platform' s 8 Pillars

FURTHER RESEARCH

11

11. FURTHER RESEARCH

Taking reference from the results achieved from the Prototype tests, it is possible to say that the connection of BIM data and real-time data is positive. Implication of BIM databases to real-time data can be used to upgrade energy efficiency in the built environment while upgrading the thermal comfort of the occupants. As the prototype test prove the connection is successful, the new horizon for the research could be the expansion of the scale of the prototypes. Even though the Symbiotic Data Platform focuses on the building scale, the further research could be upon expanding the scale through the neighborhood scale and the city scale.

On a greater scale, the project can be developed further as an urban interface, to create an information cycle/network between the smart homes to the smart cities by a new understanding of citizen participation. That project has a bottom-up theory, which is “not making the city ‘smarter’ but making the user more active and the environment ‘responsive’”.

Within ‘Responsive City’⁷⁶ context, the Symbiotic Data Platform is explained by its possibilities of future research. The extension of this platform is explained in a symposium proceeding, under the title of ‘Active Public Space’ (Birgonul, Cocho-Bermejo, & Sarrablo, 2018). The objective of the proposed platform in urban level, is to create intelligence in the society regarding urban values and empower the citizen with collective values. Sharing data by the platform will create a stronger community network depending on the increase in productivity and efficiency in daily life of the citizens and will also upgrade the citizen participation in urban field. It is a promising project on the way of introducing a responsive city system by multi-ended outcomes. Simplifying and monitoring the existing data by the platform, will be the new solution for productivity, efficiency and sustainability in urban development.

Regarding the current definition and structure of smart cities, the forthcoming development proposals should be ‘Sensible’ and ‘Sensitive’⁷⁷. According to this statement, the ‘smart city’ context is not only the latest urban phenomena but also the optimal approach for the urban development plans since it offers progress in several disciplines. By ‘sensibility & sensitivity’

⁷⁶ See Responsive Cities Section.

⁷⁷ See chapters ‘Sensibility’ and ‘Sensitivity’.



concept, the further research would like to converge the smart city concept to an upgraded perspective that is a concrete manner of data collection, processing, analyzing and monitoring theory; which is a data platform that addresses sustainable urban development.

11.1. THE IMAGE AND FUNCTION OF THE CITY

The image and function of the city, and how these terms should be are being discussed until centuries. Recently, the city became a term much more complex just than the infrastructure, spaces, places and buildings. Rising up the concept of smart cities; which corresponds to an urban development vision to integrate infrastructure technologies with information and communication technology (ICT) and Internet of Things (IoT) to upgrade the urban structure in efficiency, productivity and sustainability. This definition broadens up all these concepts one-step further than the classical understanding of architecture and urbanism and introduced new terminologies to the contemporary understanding.

The smart city assets covers up, buildings, infrastructures, citizen platforms, information systems, public services, transportation systems, health-care systems, power plants, water supply networks, waste management, law enforcement, and other community services. The goal of building a smart city is to

improve quality of life by using urban informatics and technology to improve the efficiency of services and meet residents' needs. Moreover, as time progressed, architecture became a compilation of digital means, structural design and dynamics, and user interaction. Recently, it won't be a mistake to say, digital era⁷⁸ created a new definition of architecture, which is a mutual adaptation of structures, infrastructures, systems, networks, interaction and development. In today's world, city has infinite layers depends on what which dimension you are looking through. Michael Batty⁷⁹ mentioned the bottom-up evolution of defining the 'city' as, in the 50 years decade, the city was first defined as a 'system', then as a 'machine', and finally nowadays, the understanding change and it is defined as an 'organism' (Batty, 2011). This clearly shows that, the cognition of the society changed by the last 50 years. Moreover, the society got a concern on future, also, the expectation from the city evolved to be a responsive organization, rather than just being a space to live in. A city as an 'organism' stands for, the city is a self-sustainable fact, which also can sense and response to the

⁷⁸ The Digital Era, (also known as the Information Age, Computer Age, Digital Age, or New Media Age) is a period in human history characterized by the shift from traditional industry that the Industrial Revolution brought through industrialization, to an economy based on information computerization. The onset of the Digital Era is associated with the Digital Revolution, just as the Industrial Revolution marked the onset of the Industrial Age.

⁷⁹ Prof. Michael Batty's is lecturer in Bartlett, UCL, Chairman of CASA - the Centre for Advanced Spatial Analysis - and Editor of the journal Environment and Planning B.



instances. The science and technology are developing various systems to make the cities self-sufficient; also, we can say that all these developments and studies are a part of 'smart city' progress.

A city can be both self-sustainable organism and smart, but this fact does not mean that, a self-sufficient city is always can be considered as a smart-city. Self sufficient city or sustainable city, which applies upgraded energy cycle, preserving natural sources and applying re-cycling has one step to be a smart city, but on the other hand, a smart city stands for a more complex term, that is multilayered, and a sensitive evolution of a traditional city. Sustainability can be applied to economy, socio-cultural aspects and environment simultaneously. The more the city evolves to be self-sufficient, the better 'sustainable urban development' is achieved. Consequently, city as a self-sustainable organism theory guides the urban approaches to propose more sensitive projects and more delicate solutions. If we take one step further from the sustainable cities, and add on mote responsibility to the urban form, we achieve the 'smart city' concept. The smart city is addressing various factors that organize a city, such as energy efficiency, sustainable economy, mobility, public transport, contemporary expectations, services, and smart governance. To be smart does not mean only to get operated more functionally, but also to address social and

economic and contemporary values as well. Besides, the first objective of transforming a traditional city to a smart city is upgrading it to be more 'livable'.



11.2. THE STRUCTURE, COMPLEXITY & THE SCIENCE OF CITIES

Spatial, Organizational And Functional Aspects in Relation with Smartness Of Cities & Science of Cities⁸⁰

Regarding the spatial design and the layout analysis for networks, Alexander⁸¹, in his famous article “A city is not a Tree”, wrote:

“The tree of my title is not a green tree with leaves. It is the name of an abstract structure. I shall contrast it with another, more complex abstract structure called a semilattice. In order to relate these abstract structures to the nature of the city, I must first make a simple distinction. I want to call those cities which have arisen more or less spontaneously over many, many years natural cities. And I shall call those cities and parts of cities, which have been deliberately created by designers, and planners’ artificial cities. Siena, Liverpool, Kyoto, Manhattan are examples of natural cities. Levittown, Chandigarh and the British New Towns are examples of artificial cities” (Alexander, 1965).

⁸⁰ Science of Cities, the term is coined by Michael Batty. (Batty, Building a Science of Cities, 2011)

⁸¹ Christopher Wolfgang Alexander is a widely influential architect and design theorist, and currently emeritus professor at the University of California, Berkeley. His theories about the nature of human-centered design have affected fields beyond architecture, including urban design, software, sociology and others.

Alexander criticizes the designed cities, with his words “When compared with ancient cities that have acquired the patina of life, our modern attempts to create cities artificially are, from a human point of view, entirely unsuccessful” (Alexander, 1965).

The networks of the cities can be analyzed according to the base of Baran's⁸² network graph that explains “centralized, decentralized and distributed” networks (Baran, 1964); See Figure 139. In connection with Alexander and Baran, from trees to nets, the functionality develops. For example, a city that could be defined as a tree, could be illustrated as a centralized graph of Baran, and a city, which can be considered as ‘not’ a tree, could be illustrated as a distributed graph, which has greater connection and nets of values, See Figure 139 & Figure 140.

⁸² Paul Baran was an engineer who was a pioneer in the development of computer networks. He was one of the two independent inventors of packet switched computer networking, and developed other technologies that are an essential part of modern digital communication. He was a founder of the Institute for the Future, and was then involved in other networking technologies developed in Silicon Valley. He invented Packet Switching.

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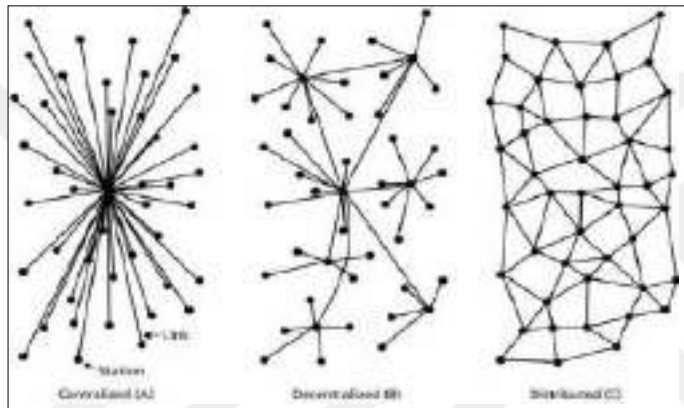


Figure 139: Paul Baran “Centralized, Decentralized and Distributed Networks” (Baran, 1964)

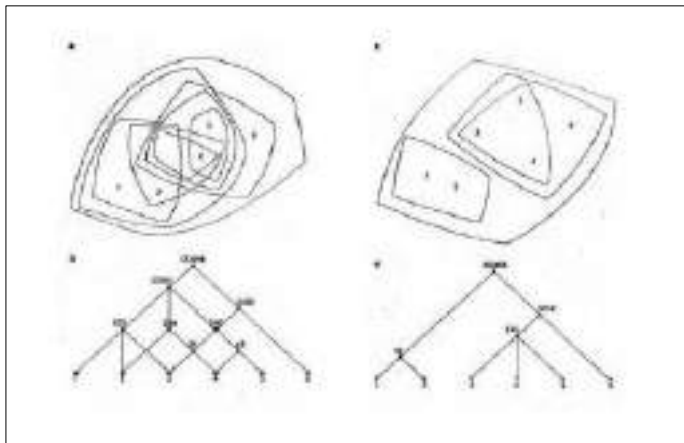


Figure 140: Christopher Alexander, “Diagrams a and b :Tree and Diagrams c and d: not a Tree “ (Alexander, 1965)

With respect to the theoretical organization diagrams of Baran and Alexander, Karimi wrote about he organizational patters as following: “Perhaps the primary concept which distinguishes organic cities from the other types is the notion of ‘irregularity’. Unlike regular patterns, organic forms do not follow geometrical orders. They cannot be easily measured, since they lack basic properties such as repetition, symmetry, parallel elements, alignment and so on. However, the notion of irregularity has not been conceived equal to ‘disorder’, ‘chaos’ or ‘disorganization’ by recent urban theorists” (Karimi, 1997).

Also after Karimi’s organizational perspective, another the urban definition is coined by Bill Hillier⁸³. He mentioned centrality as a process, in his research, in relation with function; “The term ‘center’ applied to settlements has functional and spatial elements. Functionally, it means a distinctive concentration and mix of activities in a certain area, spatially a certain position for that area in the settlement as a whole.” and “the pattern of centers and sub-centers can be explained through the movement economy process, and can therefore justify the axiom: configuration generates attraction” (Hillier, 1999).

⁸³ Bill Hillier is Professor of Architectural and Urban Morphology in the University of London, Chairman of the Bartlett School of Graduate Studies and Director of the Space Syntax Laboratory in University College London. He is the original pioneer of the methods for the analysis of spatial patterns known as ‘Space Syntax’.



The city structures could be defined particularly in each case, as well as creating a science out of these definitions, since Batty introduced. Without doubt, there are endless variations of the city structures and its' functions but the consequence of the complexity of the urban structures, the significance of these researches is to determine the possibilities of better functionality. To understand the emergence of new territories, new structures, and needs are the keys to create better solutions for the 21st century cities.

As well as the structure could be precise and clear, and the organization could be defined explicitly, as it is defined in Baran's or Alexander's diagrams. Yet, on the other hand, the new structures of the cities do not allow such precise definitions and organizations. As Hillier coined the term 'fuzzy boundaries': *"Such boundaries can be effective in supporting functional differentiation of areas or the growth of areal identities and characters, but do not depend on the area being either spatially self contained or geometrically differentiated, or having clear spatial limits. It is the relation of urban areas and their further surroundings that determine fuzzy boundaries of these urban areas"* (Hillier & Yang, 2007).

For example, a city that has blocks or superblocks, such as Chicago, New York, Brasilia and Barcelona, has the tree like

structure in the blocks, and the network could be illustrated with centralized graph. In other respects, a mega-city⁸⁴ such as London, Paris or Istanbul, has a greater network of interaction and activities, so the illustration of these cities could be symbolized with a decentralized graph. In both cases, the connectivity increase could upgrade the graphs as distributed, if the nodes are mutually interconnected. Even though, at 1965, Alexander defined London as a 'tree structure' regarding there is no overlapping units in the system, in 2017, it could be more convenient to say the structure evolved and could be considered as a distributed territory. *"This enormously greater variety is an index of the great structural complexity a semi-lattice can have when compared with the structural simplicity of a tree. It is this lack of structural complexity, characteristic of trees, which is crippling our conceptions of the city"* (Alexander, 1965)

Upon the theory of Alexander; Kittler⁸⁵ replied in his article ' A City is a Medium': *"Modern city planners doubtlessly have tried to model the networks in Chandigarh, Brasilia, and other new*

⁸⁴ A megacity is usually defined as a metropolitan area with a total population in excess of ten million people

⁸⁵ Friedrich A. Kittler was a literary scholar and a media theorist. His works relate to media, technology, and the military. He had several stints as a Visiting Assistant Professor or Visiting Professor at universities such as the University of California, Berkeley, the University of California, Santa Barbara and Stanford University.

cities using a tree graph whose branches and stems do not intersect and can thus be conflated. However, "a city is not a tree," rather "half-grid" whose overlapping themselves belong to the system" (Kittler, 1996). Regarding the overlapping's and increased connectivity, the cities become more and more distributed, hereby more global and yet more smart. Connection brings interaction, thus creates emergent progress. Moreover Batty wrote; "In terms of size and scale, we do not yet have a clear view of how big a city is in terms of the density of its activities, the volume of its built and natural space, and the way in which materials, information, and people interact to sustain such forms" (Batty, 2008).

During his research on 1997 regarding to the structure, growth and organizational patterns of cities, Kayvan Karimi ⁸⁶ mentioned;

"It is difficult to say how many years or what situations provide the conditions necessary for natural growth, but the key point

⁸⁶ Dr. Kayvan Karimi is an architectural and urban designer with more than twenty years of professional and international experience. He maintains his research and lecturing activities as a Senior Lecturer. His research focuses on strategic city planning, city centre redevelopment, urban conservation and urban regeneration, large-scale urban master planning, 'slum' upgrading and regeneration, large-scale commercial/retail development, public realm design, pedestrian movement planning and complex building projects.

here lies between two modes of the dominant nature of urban structure: the city as a product of limited ideas based on a preconceived organization, or the city as a product of numerous thoughts operating more randomly and over a long period of time. Perhaps the primary concept, which distinguishes organic cities from the other types, is the notion of 'irregularity'. Unlike regular patterns, organic forms do not follow geometrical orders. They cannot be easily measured, since they lack basic properties such as repetition, symmetry, parallel elements, alignment and so on" (Karimi, 1997).

10 years within Karimi's definition, the structure of the cities got more complex, yet the understanding of its' organization became simpler. Carlo Ratti ⁸⁷ wrote upon the terms as "Cities are clearly more complex than regularly structured systems; their geometry is variable and irregular" (Ratti, 2004) and Michael Batty wrote, "Our understanding of cities is being transformed by new approaches from the complexity sciences" (Batty, 2008), In relation between the structure and functionality of the cities, the arguments of the complexity and irregularity led the researchers through discovering the logic behind the urban forms. About the

⁸⁷ Carlo Ratti is professor in MIT and director of MIT Senseable City Lab, a research group that explores how new technologies are changing the way we understand, design and ultimately live in cities.



interpretations upon the complexity of the urban structure, *'The Science of Cities'*, which is the term coined by Michael Batty on 2011, explains the logic of the irregularity and building a science regarding to the existence and emergence of urban fabric. The 'science of cities' takes the root from the interaction. *"The idea of interactions between different individuals rooted in time and space defines the nature of what a city is all about"* (Batty, 2011).

Development of cities is a crucial aspect on understanding the emergence of the new structures, and social networks. This is an important concern on complexity of cities, and which is also included in the 'science of cities'. *"An integrated theory of how cities evolve, linking urban economics and transportation behavior to developments in network science, allometric growth, and fractal geometry, is being slowly developed. This science provides new insights into the resource limits facing cities in terms of the meaning of density, compactness, and sprawl, and related questions of sustainability"* (Batty, 2008). Also, according to the inclusion of the data, he wrote: *"In the study of cities, there are many competing paradigms. This science has the potential not only to join some of these together but also to improve theories to the point where city planners can develop operational tools grounded in extensive empirical data"* (Batty, 2008).

In relation with the smart cities, the context of science of cities by Batty, is explained as following:

"In terms of theory, new data sets are coming on stream very rapidly and are enabling new theories to be tested. Much of this data is dynamic at the level of the individual and new techniques of model building, estimation, data mining, and pattern recognition not to say new ways of storing, retrieving and analyzing massive data sets, are changing the context to the field. In one sense, cities are slowly beginning to be subject to the methods and approaches of 'big science' as data sets get ever larger and as teams of different experts are required to put together requisite models to engender this new science....This is but a mere beginning and in a decade, it is likely given the present rate of development, new and more powerful but also more pluralistic theories of how cities function and change will be with us" (Batty, 2011).

Upon Batty's new term, Ratti commented *"As Michael Batty reminds us with fascinating historical excursus, the idea of developing a 'science of cities' is not new. However, today's explosion of measurements in the urban field—the so-called big data phenomenon—is opening up possibilities that were unthinkable just a few years ago. New research territories are*

looming, to which this book is a compelling and perfectly timed guide” (The MIT Press, 2017).

The Context of Cities:

Recently, in Europe, most of the countries are competing to develop the cities as the smartest and the most sustainable. No doubts that, this urban phenomena is the future that we are going to leave as a heritage for the new generations. According to the collaborative research definition done by URENIO⁸⁸ Research Group, Inria, ESoCE Net, CDT Luleå University of Technology and Alfamicro Lda; the four concepts of urban spatiality is as following: “*Cyber cities, from cyberspace, cybernetics, governance and control spaces based on information feedback, city governance; but also meaning the negative / dark sides of cyberspace, cybercrime, tracking, identification, military control over cities. Digital cities, from digital representation of cities, virtual cities, digital metaphor of cities, cities of avatars, second life cities, simulation (sim) city. Intelligent cities, from the new intelligence of cities, collective*

intelligence of citizens, distributed intelligence, crowdsourcing, online collaboration, broadband for innovation, social capital of cities, collaborative learning and innovation, people-driven innovation. Smart cities, from smart phones, mobile devices, sensors, embedded systems, smart environments, smart meters, and instrumentation sustaining the intelligence of cities” (Schaffers, Komninos, Pallot, Trousse, Nilsson, & Oliveira, 2011).

After being smart / intelligent, the city gets more and more computerized as a consequence of the computer era. Nicos Komninos⁸⁹ coined the term ‘digital cities’ in 2006, referring to the theories aligned with the concepts that Negroponte have introduced to literature. “The digital city is the dominant form of community space corresponding to a territory” (Komninos, 2006). The digital city is the emergent layer of the physical city, which comprises a wide network of digital systems, social and economic variables and the user. Besides from the digital city, the term ‘intelligent city’ constitutes various descriptions such as, being innovative, facilitating the smart community, and having an embedded information & communication technology.

⁸⁸ URENIO Research Group: The URBAN AND REGIONAL INNOVATION Research (URENIO) is a university laboratory for the promotion of research and supply of scientific and technological services in the field of innovation systems and intelligent cities. URENIO is part of the Department of Urban and Regional Planning, Faculty of Engineering, Aristotle University of Thessaloniki, Greece.

⁸⁹ Nicos Komninos is currently a professor of Urban Development and Innovation Policy at the Aristotle University of Thessaloniki. He is editor of several journals and director of the Urban and Regional Innovation Research (URENIO) and his research interests are on intelligent cities (cyber-physical systems of innovation, architectures of intelligence, strategies and applications).



Intelligent city is a broader definition for digital city, but on the other hand a digital city always have to be intelligent so as to be a digitalized system. Moreover, there are more alternative names to explain the context, but on this part, the literature review will take the 'smart city' definition as, the name itself stands for the context clear enough and involves the broadest definition.⁹⁰ Mitchell⁹¹ explains in his article, this cycle quite well: *"The new intelligence of cities, then, resides in the increasingly effective combination of digital telecommunication networks (the nerves), ubiquitously embedded intelligence (the brains), sensors and tags (the sensory organs), and software (the knowledge and cognitive competence)"* (Mitchell, 2007). The network, embedded intelligence and sensibility is the basis for the software systems that are implemented to the intelligent – digital cities spine. These technologies are the new-generation infrastructures that our cities just started to have. A new era of

digital urbanism have arrived. As well as it's said by Bélissent⁹²; *"smart city solutions must start with the city not the smart"* (Bélissent, 2010). *"Cities admit innovation, indeed they are the crucibles of innovation, they generate surprise, they display catastrophes"* (Batty, 2008), summarizing the development of urban definitions and evolvement of the terms, the concentration point of this research is the last decade of the architectural and urban form. At the present time, to be a 'system', or a 'machine', neither just an 'organism' is not enough for architecture. Nowadays, 'systems', 'machines' and 'organisms' are reinterpreted to for complementary platforms to upgrade city systems.

Ratti and Claudel⁹³ define recently *"Architecture should become an integral and responsive part of human life. Architecture must do more than just look like a living organism: it should perform as a living system"* (Ratti & Claudel, 2016). Importance of the shift from the 'organism' to a living system is; to be able to create upgraded systems and set up more serviceable functions in the city structure. The concept of 'living system' is an

⁹⁰ While addressing the sustainable and digitally assisted cities, this research, I will use 'smart' regarding the definition had been stated previously since it is more frequently used in architectural and urban literature.

⁹¹ William J. Mitchell is an architect and urban theorist who envisioned the modern city as an electronically interconnected network of systems and who, while serving as dean of the school of architecture and planning at the Massachusetts Institute of Technology. He led the Smart Cities research group at the MIT Media Lab and was a professor of architecture and media arts and sciences.

⁹² Jennifer Bélissent is political science from Stanford University and her research spans open data initiatives, citizen engagement, and governance tools, as well as the Internet of Things and connected urban infrastructure.

⁹³ Matthew Claudel is researcher in MIT Senseable City Lab.

upgraded value; yet more, it connects the contemporary era with the contemporary life of today's world, and its demands with digital features, with a clear foresight. The contemporary city is not just a place to live in anymore: It is a place to interact with the system and with each other, while live together with upgraded values.

11.3. CASE EXAMPLE: LEARNING FROM BARCELONA

Cerdàs' Smart City Phenomena:

In the 1850's as Ildefons Cerdà⁹⁴ envisioned a new Barcelona, he wasn't on the railroad or the telegraph company's payroll. He was merely trying to craft a better city by exploiting new technologies. But today, big technology companies have usurped a leading role in shaping our visions for future cities (Townsend, 2013) Cerdà was intelligently created the city of Barcelona, with a collective sense of geography, infrastructure, social and cultural sensitivity and 1850's contemporary technology. At that time when Barcelona got a new planning strategy, Cerdà was the head of this development. Nowadays, Barcelona became one of the smartest cities in the world, by the well-designed heritage of Cerdà, and with cooperation of uncountable mentors, designers, researchers and companies. Technology is the first supplement today, for the cities of the past for a sustainable development. In one of the most popular

⁹⁴ Ildefons Cerdà is a civil engineer and urban planner who designed the 19th-century "extension" of Barcelona called the Eixample. Cerdà focused on key needs: chiefly, the need for sunlight, natural lighting and ventilation in homes (he was heavily influenced by the sanitarian movement), the need for greenery in people's surroundings, the need for effective waste disposal including good sewerage, and the need for seamless movement of people, goods, energy, and information.



urban blogs in Internet, CityLab, once pointed out how Cerdà approached Barcelona while planning. *“Don't think like a city planner, architect or engineer. Think like a citizen... With a more holistic view of disciplines, planners live less in silos, and their results show it. This might stem from the continued reverence for Ildefons Cerdà, who certainly wasn't limited by his civil engineering training. Cerdà functioned as city planner, architect, even health specialist - in other words, as a holistic city-builder”* (Toderian, 2012). Additionally to my personal admire to Cerdà's approach, to begin with why Barcelona is chosen as the case study example is because, Barcelona has been named **'Global Smart City 2015'**, by Juniper Research, prevailing over New York (USA), London (UK), Nice (France) and Singapore, recently in 2015, regarding to the ongoing projects and urban attempts (Smith, 2015). Apart from the most recent award, there are various projects ongoing in Spain's' smart city, Barcelona. Moreover, it is the worlds' mobile phone capital, and European capital of innovation.

Moreover, Barcelona is chosen as the case example to fit in the research due to the developed and aligned with recent technologies and smart city applications. Day by day, new progressions are introduced the smart city Barcelona program. Apart from the individual companies and designers intention, there is two main projects going on recently in Barcelona, on the

way of reaching the smart city level. These projects are, Smart City BCN, which has various interesting and progressive projects included to the project. It is the general title that gathers all the developments and projects under the same title. Similar to Smart City BCN project, there is @22BCN that gathers various programs together within the same aim, to reach the knowledge capital and an innovative hub. When it is compared, @22BCN is an urban development and regenerating project that aims a technologic and design upgrading. While Smart City BCN is considering the whole city metropolitan area, @22BCN is located in the Poblenou, Sant Marti district, which was the industrial outskirt of Barcelona City. Both two projects are addressing the same community by different concerns. Smart City BCN is filling the technologic and infrastructural gap of the main goal, while @22BCN is constructing a developed society and a knowledge based development.

Even though the projects are quite particular in character and content, the objective strikes the same mission. Since Cerdà planned and constructed the city of Barcelona, the possibilities and objectives were already set. Today, the new era arrived, and the development is now. The technology is in our hands, and as the practitioners, we are shaping the future. The attempts on this way to the intelligence are the new reality, and it brings the quality to the future. This is the reason why, all fields are

aligned to these attempts, and also, this is why the smart city project of Barcelona are taken as examples to research upon, to understand what future is expecting from us.

Smart City Bcn:

Since 1992 Olympics, Barcelona had the evolution from a middle scale Mediterranean city, to one of the Europe's biggest cities, and a global tourist attraction. *"Barcelona has continued to enjoy an uninterrupted heyday of national and international prestige, as well as practically unanimous consensus with regard to the quality and beauty of its urban developments and habitability of a city seen as Mediterranean as well as 'human'"* (Paz Balibrea, 2004) The urban development was planned so detailed and with a very intelligent manner, so that, right after 20 years, in 2010's Barcelona became the Europe Capital of knowledge and innovation, by contribution of various urban and social programs. Smart City BCN Project is the most recent progress of Barcelona Metropolitan Municipality, which aims to convert the city into an urban phenomenon, corresponds to a sustainable and self-sufficient city nourished by innovation and new technology. In addition, one of the main desires of this project is to have a strong the branding of the city image. *"City branding provides, on the one hand, the basis for developing policy to pursue economic development and, at the same time, it*

serves as a conduit for city residents to identify with their city" (Kavaratzis, 2004).

In the programs official web page, this explained as "A city that wishes to aspire to being a truly smart city must develop all of its key areas; (transport, energy, education, health, waste management, security, economy...); simultaneously and transversally" (Ajuntament de Barcelona, 2015). The project is the collective approach for all the innovative proposals regarding the Smart City objectives for the city of Barcelona.

The 3 essential points to establish the criteria that differentiate a Smart City, according to the project context are: "1. *Efficient management of services and resources,*
2. *New tools and places for people, groups and institutions to interact with each other,*
3. *Use and integration of new technologies (ICT)"* (Ajuntament de Barcelona, 2015).

The list of the projects are s following:

1. Apps4bcn Portal
2. New Bus Network
3. Wearable Telecare Service
4. Open Data



5. Electric Vehicles
6. Smart Traffic Lights
7. School Routes
8. Apparkb
9. Mobile Id
10. Barcelona Wi-Fi
11. Fabrication Laboratories
12. Ovac: Officina Virtual
13. Mschools
14. Bcn Contactless
15. Radars Project
16. +Sustainable Barcelona Map
17. Bicing
18. Procedurs Portal
19. Smart City Campus
20. Smart Allotment
21. Smartquesina
22. Superblocks
23. Telemanaging Irrigation
24. Vincles Bcn
25. City Os
26. Barcelona Open Government
27. Sentillo
28. Buits Plan
29. Citizens' Postbox

30. Barcelona Negocis
31. @22 BCN – Poblenou Area

To explain among all the projects, the @22 BCN project is the proposal for the urban renovation plan for Barcelona's old industrial neighborhood Poblenou, Sant Marti Area. The 22@BCN model is being applied since the beginning of 2000's in the area, and it already became a benchmark in urban, economic and social transformation. The objective of the project is to have an "innovation District" which is located in the compact and the diverse city of Barcelona and has 3 phases that leads this goal such as; phase 1 is physical environment renovation that includes town planning, building & construction and infrastructure, phase 2 is the cooperate environment construction, that is shaping the economic and knowledge based projects, phase 3 is personal environment which corresponds to the community led design and capacity building.

The main task of the project is to achieve a sustainable urban and economic development. It is both a practical and theoretical plan that has been implied to the city and affected the community. The pillars on the way of achieving the success of the project are to provide, spaces and infrastructures, art and culture interest, rehabilitation and restoration, knowledge based development, innovation and technology clusters and market

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access, public financing, talent appraising, private networking, branding promotion.

@22 Barcelona project is basically an urban renovation and revitalization plan, but what is significant about the project is, it includes the knowledge and economic development to the upgrading plan as well. The project has several branches such as promoting new businesses, supporting knowledge-based investments, having cultural associations, and organizing events for social innovation. Additionally the program has an 'urban lab' that deals with urban innovative solutions. The art and technic schools has branches and some faculties in the @22 zone to get involved to the knowledge innovation. Moreover, Torre Agbar⁹⁵ and Media TIC⁹⁶ buildings have been built related with the program and various refurbishments have been done such as of the industrial zone and old factories & warehouses had been renovated for new functionalities.

⁹⁵ Torre Agbar 38-story skyscraper/tower located between Avinguda Diagonal and Carrer Badajoz, which marks the gateway to the new technological district of Barcelona, Catalonia, Spain. It was designed by French architect Jean Nouvel in association with the Spanish firm b720 Fermín Vázquez Arquitectos and built by Dragados.

⁹⁶ Media TIC also known as Media ICT, located at Carrer Roc Boronat, 11, Barcelona, is a performative building, designed by Enric Ruiz-Geli from Cloud-9 studio. 'The performative' elements in the Media-TIC building are found in two of the four façades, which are made of the eco-efficient material ethylene tetrafluoroethylene (ETFE) cladding.

The collective approach is depending on the values that regards to society, culture and governance. Humanity decided centuries ago, the best system to live together and be governed is democracy. After arising of democracy, we can clearly observe the evolution of urban structure, life change and the shift of interest of the people. Regarding the increasing intelligence and demand, the mankind constructed cities, constitutions and rules & rights. Within this change the term 'society' appeared simultaneously. The society defines the shift of human kind, from the primitive phase to the democratized status. *"The challenge is to reconstruct society through the practice of living together, in the process of communicating with each other in the urban civilization"* (Castells, 2002). In the recent time, the society became an upgraded term, which is highly connected and depended on each other. Society invented networks and preferred to be more and more connected in case all and each person is incredibly different and specific to their own. The new rule is to be able to live together with collective values in developed circumstances.

Smart Citizen Barcelona:

Smart Citizen is a platform which offers an alternative to the centralized data production and management systems used by the large corporations that constitute the driving force behind the



smart city concept. The project empowers ordinary citizens to gather information on their environment and make it available to the public. Started in 2012 in Fab Lab Barcelona at laaC, the project develops tools for citizen action in environmental monitoring and accompanying methodologies for community engagement and co-creation (laaC, 2016). The Smart Citizen Kit is an open-source platform that comprises 3 technological layers: a hardware device, a website and online API, and a mobile app. The interface is Arduino compatible.

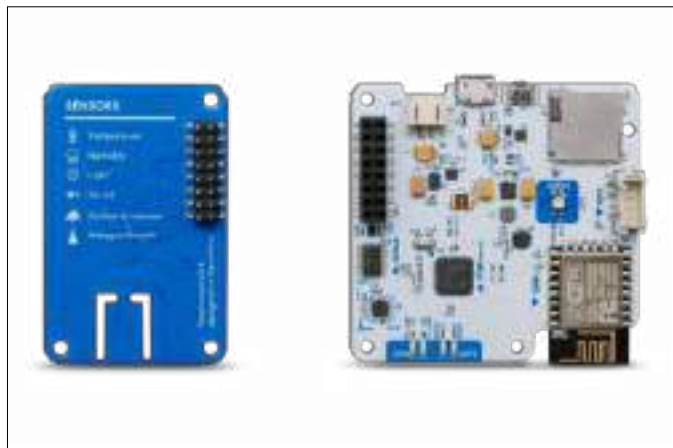


Figure 141: Smart Citizen Kit (Fab Lab Bcn, 2016)

The Smart Citizen project is based data collection and sharing by geolocation, internet and hardware & software, and later on with this data, the production of objects; it connects people with

their environment and their city to create more effective and optimized relationships between resources, technology, communities, services and events in the urban environment (Fab Lab Bcn, 2016). The project uses open source technologies such as Arduino to enable ordinary citizens to gather information on their environment and make it available to the public on the Smart Citizen platform (Smart Citizen, 2013).



Figure 142: Smart Citizen Project (Smart Citizen, 2013)

City Protocol :

The City Protocol is a Sustainable Urban Development project by City Protocol Society from Barcelona, and defined as; *“A common communications vehicle and a collaborative innovation framework that fosters city-centric solutions that benefit citizens and their quality of life. It also seeks to better define a common systems view for cities of any size or type, and then embraces or develops protocols that will help innovators create – and modern cities deploy – cross-sectorial solutions that can connect and/or break city silos. As a consequence, innovators enjoy a robust market for their solutions, and cities enjoy solution choice, reduced cost and risk, and increased collaboration and learning – all while supporting the development of a Science of Cities”* (City Protocol Society, 2015).

The City Protocol has five fundamental goals:

- *To facilitate and foster a new science of cities.*
- *To establish a cooperation framework among the city council, academia, companies, organizations and people/society.*
- *To lead and pave cities' futures.*

- *To understand the common driving forces of urban evolution and find common game-changing solutions.*
- *To find innovative economical opportunities and synergies: and deliver value adding products and services* (City Protocol Society, 2012).

City Protocol use knowledge and experience in cities around the world to accelerate their transformation, providing reliable guidance and opportunities for collaboration in research and in the development of cities (Smart Catalonia, 2016). Principal mission is creating a platform that collects and uses the information of cities and citizens for creating collaboration to accelerate the transformation of cities. City Protocol has a forthcoming of urban connectivity and globalism by interconnecting the smart cities and ultimately creating the Internet of Cities.

The City Protocol approaches the emergent new generation solutions by Sustainable City norms. *“City-centric solutions facilitated by the City Protocol should aim at providing and maintaining a high quality of life to citizens over time. According to sustainable development principles, these solutions should meet the needs of the present without compromising the ability*

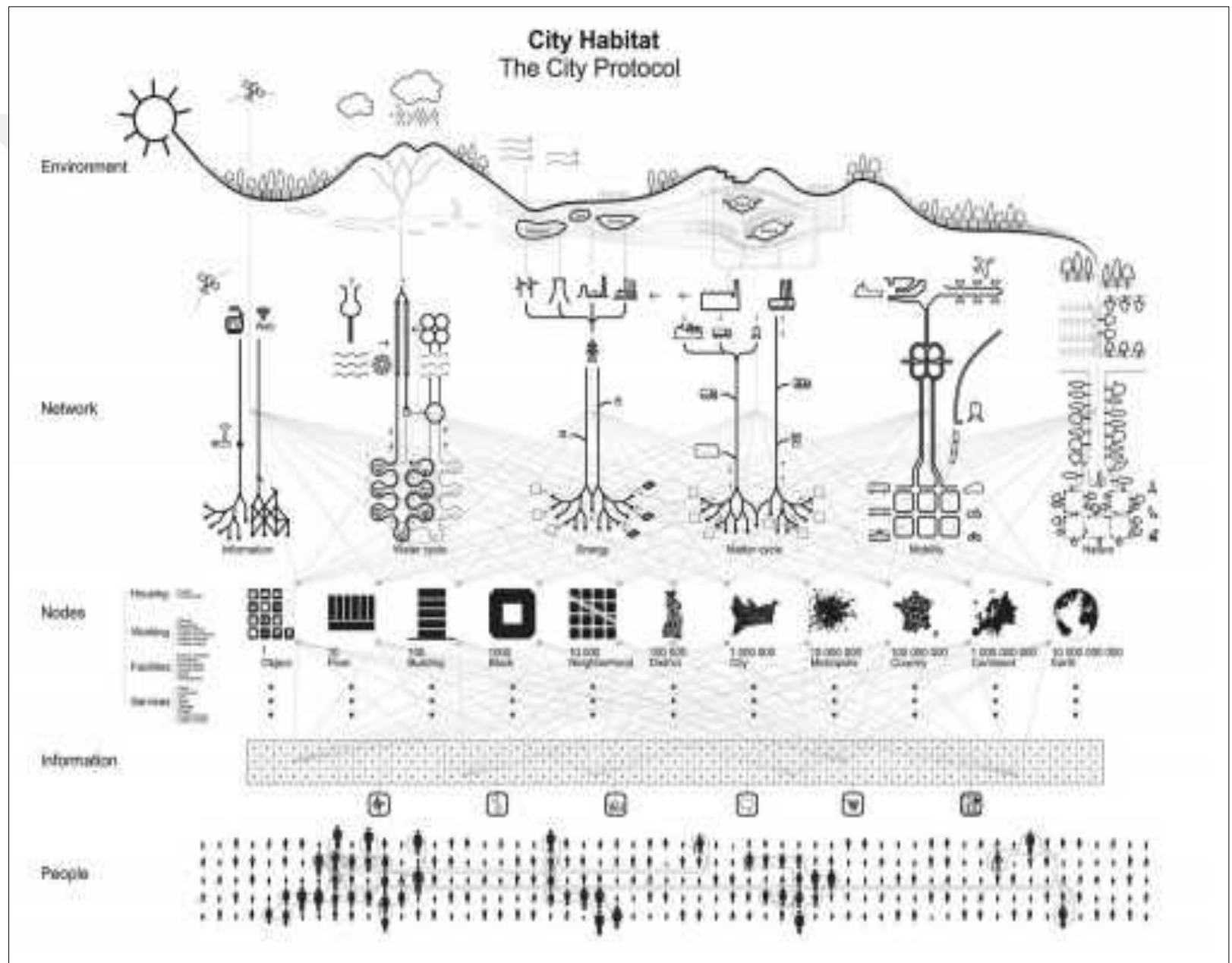


of future generations to meet their own needs” (City Protocol Society, 2015). This protocol aims to create and accelerate the livability of cities, thanks to the research & development in technology, environmental studies, social sciences, architecture, urbanism and politics.

According to the City Protocol, the definition of the city anatomy is as following:

“The City Anatomy, is an analogy to the human anatomy and its dynamic physiology, is an organizing framework for the City Protocol. It creates a foundation upon which to build a collaborative platform and tools to support effective city governance, evaluation and transformation. It offers a common language describing the city ecosystem as three key system elements: a set of physical structures (Structure); the living entities that make up a city’s society (Society); and the flow of interactions between them (Interactions). In so doing, City Anatomy helps understanding and mapping interconnections between city systems” (City Protocol Society, 2015); (See Figure 143).

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11.4. WHAT IS A RESPONSIVE CITY?

Taking the reference from the previous chapters, the definition of 'smart city' mainly focuses on the technologic upgrading, efficiency and the connectivity of the traditional city structures. Thinking upon the contemporary understanding of architecture and urban structures, betterment of 'function' of the systems are nor satisfactory.

If we take the example of Kyoto City, Japan, the city has 3 dissections as Ishida explains. *"First, an 'information layer' that contains all the data that is produced by the activity, second, an 'interface layer' which contains the 3-dimentional modeling of the city, what corresponds to what we call City Information Modeling (CIM) today. And lastly, the third one, the 'interaction layer', which the user gets involved to the network"* (Ishida, 2000). Where the user gets involved to the network, it is not possible to keep the systematic and technologic definition as 'smart'. On this very point, a new discipline arises. Information and Interface layers might be enough to explain the smartness of a system, yet, the Interactivity is a new concept and it has to be given more attention to create further possibilities.

Ishida's theory and definition are very interesting due to the fact that, it is combining a model that has the data, and by recent input of activity, the city is interacting with its user, by

understanding what is happening. Inspiration from what Ishida pointed out, that leads this chapter through the contemporaneusness of the 'network society'. The city is both producing and absorbing the great mass of data. As a result, the citizens proceed the desires, reality and the possibilities for proposing better options. Responsive Cities were defined by Sarah Williams⁹⁷ at a book chapter, as *'Techno-Utopia'* that involves embedded sensors, command centers, mobile and web-based service applications, and analysis of Big Data (Williams, 2016). The new generation cities by her vision would be providing the citizens the 'public good' by using the fruits of the technology. She also points out the importance of citizen participation on Responsive City context by stating *'DIY Cities: Bottom-up Technology Cities'*, which stands for the re-invention of the city by the citizens needs, participatory design⁹⁸ and by the power of open-source data and augmented knowledge of network society.

Consequently, Responsive Cities are the next stage that is currently emerging, from the shift of Smart Cities. Those cities

⁹⁷ Sarah Williams is currently an Associate Professor of Technology and Urban Planning. She also is Director of the Civic Data Design Lab at MIT's School of Architecture and Planning.

⁹⁸ Participatory Design is explained in the next section with Citizen Design Science methodology.

would be responsive by the active interaction and inclusion of the citizen; in governance, environmental facts, organizational themes, socio-cultural events, community networking, data management and sharing, 'interactive' and participatory. Moreover, Responsive Cities aims to attain the Sustainable Urban Development. The three pillars of Sustainable Development promoted by the United Nations, defined as; "economic development, social development – social justice, opportunities and equality - and environmental protection". On Responsive City structures, those three pillars *"are dissected and the parts incorporated in the taxonomy of the proposed City Anatomy (by City Protocol), together with other relevant city systems, elements and concepts"* (City Protocol Society, 2015).

Citizen Design Science And Participatory Design:

Future Cities Lab from ETX Zurich coined the term Citizen Design Science; which is *"a new strategy for cities to integrate citizens' design ideas and wishes in the urban planning and management process. Multiple opinions and thoughts by citizens should be combined with active design tools, enabled through information and communication technology. The active design contribution and feedback from a city's inhabitants is a still missing but essential step towards a responsive city"* (ETH Zürich, 2017). This methodology constitutes the guideline of the

Responsive Cities. The research on this context is established on a base of an interdisciplinary research line, including architecture, urbanism, technology, industry, ICT, big data & data management, social sciences, environmental sciences, and economy. As Responsive Cities have the holistic vision of an urban area by the built environment, the citizen and information layer together, the research covers up a scale of diverse disciplines.

Relatively, Participatory Design is, *"Participatory design entails user participation in design for work practice. Participatory design is a democratic process for design (social and technological) of systems involving human work, based on the argument that users should be involved in designs they will be using, and that all stakeholders, including and especially users, have equal inputs into interaction design"* (Muller & Kuhn, 1993). Or simply, is an approach where all stakeholders are involved in the design process. Responsive Cities, on the way of place-making, democratization and sustainable urban development; use Participatory Design via technologic features.

When the participatory methodologies are used in urban decision making, the results would be more productive and

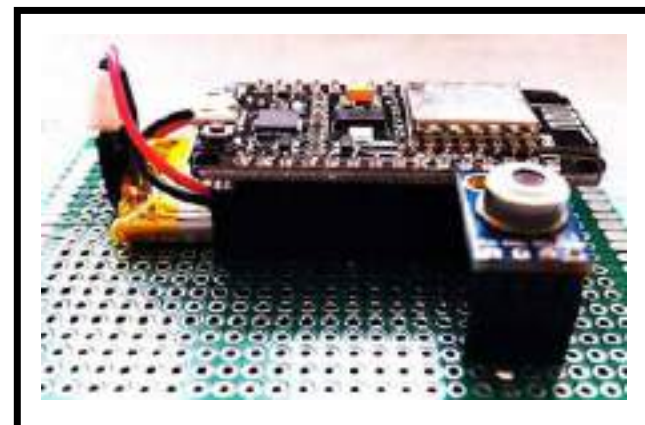


sustainable.⁹⁹ Such as in Smart Citizen Project, and The future phases of Symbiotic Data Platform; the citizens are enabled to access to data collection and decision-making by the existing data by open source tools.

Figure 144: Smart Citizen Kit (Smart Citizen, 2013)



Figure 145: Symbiotic Data Platform Prototype VII



⁹⁹ The online course taken by the researcher on 2017, from the ETH Zürich, under the title of 'Responsive Cities' mainly focuses on the Participatory Design and Citizen Design Science Research Methodologies.

11.5. LIVABLE CITIES WITH COLLECTIVE VALUES

The critical and emergent approach for the future urban formation can be embraced as 'sensitivity'. "Livable Cities with Collective Values" is a motto that inspires this research on the way of feeding the theories behind the project.

Livability is the set of key elements in urban ecology that recognize and measure how quality of life in a district or city develops and can be improved by:

"(i) developing, changing and/or transforming the city structure (natural and built environments, landscape, public spaces and the 6 infrastructures – communication, energy, water, matter, mobility and nature) to optimize performance (resilience, reliable and equitable delivery of city services, self-sufficiency, resource efficiency, etc.);

(ii) maximizing interactions by assuring universal accessibility (affordable, convenient and equitable) to all city functions (housing, jobs, education, health, security, leisure, culture, etc.) and utility infrastructures, and by fostering economic prosperity and opportunities, with an ICT-enabled environment; and

(iii) promoting participative governance, i.e., empowering citizens and engaging them in all decision-making concerning

societal issues, including urban planning and management" (City Protocol Contribution, 2015).

The city is a composite organization of layers. These layers can vary between the most physical elements - such as nature, infrastructure, streets, buildings and the other man-made places - and the nonmaterial factors – such as activity & use, history, interaction, territoriality, space and life -. We, as the user, interact with the cities that we build, just in this intersection point of the material and nonmaterial reality, and this interaction as well; is the beginning point of the sustainable urban development. What makes us call this very well organized network as a "city"? Imagine a city, with the highest skyscrapers and the most effectively functioning infrastructures. In this picture, it is necessary to include the interaction of the user and moreover the users cognition. The cognition that makes us understand and define the 'city' as it is.

The 'city' and the 'life' are two concepts that are inseparable. A city without life cannot be defined as it is meant today. The most important factor of the urban formula is the 'life' that fulfills the space and renders the system; yet, the livability of the city is the essentiality of the urban structure. Apart from the created infrastructure and the built environment of the cities, the invisible layer of action and life indicates the quality of life that is



happening in the specific urban fabric. Anthony Townsend¹⁰⁰ defines the urban system as: *“Cities and their infrastructure are already the most complex structures humankind has ever created”* (Townsend, 2013) and correspondingly, Carlo Ratti and Matthew Claudel¹⁰¹ in their book, defines the urban structure as clear enough as it could be: *“Cities are, by definition, plural, public and productive. They are created by society itself, and they function as culture’s petri dish for progress. Living in space and creating space can go hand in hand”* (Ratti & Claudel, 2016).

Livable Cities:

The Global Liveability Index of 140, ranks the cities by the livability factors. Each city is assigned a score for over 30 qualitative and quantitative factors across five broad categories of Stability, Healthcare, Culture and environment, Education and Infrastructure. Intelligence Unit describes the term liveability as following: *“The concept of liveability is simple: it assesses which*

locations around the world provide the best or the worst living conditions” (The Economist, 2019).

According to The Economists’ Intelligence Unit (EIU), for the second year in a row, Vienna, Austria has been ranked the most liveable city in the world. Austrian capital had almost perfect scores for stability, culture and environment, education and infrastructure and health care (Locke, 2019). On the article published by CNBC, the most livable cities are as following;

1. Vienna, Austria (99.1)
2. Melbourne, Australia (98.4)
3. Sydney, Australia (98.1)
4. Osaka, Japan (97.7)
5. Calgary, Canada (97.5)
6. Vancouver, Canada (97.3)
7. Tokyo, Japan (97.2 tie)
7. Toronto, Canada (97.2 tie)
9. Copenhagen, Denmark (96.8)
10. Adelaide, Australia (96.6)

Aligning with the ‘*Sensitivity and Sensibility*’ concept, livability is a very essential theme in order to create an optimized environment by every sense. As one can see, all the cities ranked in top 10, have a well-developed Sustainable Urban Development plan, meanwhile each of them are classified as

¹⁰⁰ Anthony M. Townsend is an American technology consultant. Townsend specializes in research on the implications of technology on cities and public institutions. His interests span numerous topics including; mobility and urbanization, innovation systems and innovation strategy, science and technology parks and economic development, and sustainability and telework.

¹⁰¹ Researcher from Senseable City Labs at MIT.

Smart Cities. In current day, one of the essential factors of a city with high livability is the smartness. Smartness of the cities is not only an efficient and productive infrastructure, but also a current necessity and a requirement from society.

Civil society by their personal live, uses the digital tools on their everyday life, from education to professional life, additionally, from social life to governmental and bureaucratic tasks. Consequently, the citizens of the city, who are the users of the cyberspace, requires the city to be upgraded to be intelligent too. In a short span of time, likewise the built environment, for the city infrastructures, being smart and digitalized will not be enough. Regarding to the current development in technology will create smarter devices with more and more connection. The cities will evolve through being interactive and responsive environments, while the data cloud get expended every second. The next phase for our cities is to adapt to the necessities and requirements of the present day.

Responsiveness of the cities are defined by ETH Zurich, Future Cities Lab as following;

“Responsive cities define the future of urbanization. They evolve from smart cities, with a fundamental difference: The citizens move from the center of attention to the center of action.

Responsive citizens use smart technology to contribute to planning, design and management of their cities. Responsive cities are about bringing cities back to their citizens. Responsive cities change the way the technology of a smart city is used” (Schmitt, 2017).

Moreover, Responsive Cities are the next level of the Smart Cities, by using the big data’s power. *“Harnessing the power of information technology to support an integrated, trans-disciplinary planning approach that engages the large scale and complexity of future city systems” (Future Cities Lab, 2017).* Additionally, By IGI Global, Responsive Cities concept is defined as, *“Responsive cities refer to more dynamic, adaptive, and open urban formations that are attentive, in-the-moment, to people and the broader ecosystem” (IGI Global, 2019).*

The power source of Responsive Cities is data. It requires the main gear; citizen; to activate its’ entity. *“With more than half of the world’s population currently living in cities, and 70% expected to by 2050, urban areas face huge pressure to meet their residents’ needs” (BAW, 2019).* As the population of the cities increase, the produced data grows. The future cities have to have the adequate and efficient infrastructure to manage the massive data. Taking benefit of the data by managing it, creates new horizons for optimizing the living environment.



Responsive City phenomena can be defined as a decision-making catalyzer for citizens, as soon as the citizen interacts with the provided systems & the current technology, then it exists. It does not only collect data, but also it makes good use of it by the act of the citizen. It creates a holistic movement by data-driven technologies, so as to upgrade livability of the shared environment, and address the collective values.

According to these above-mentioned statements, the 'Responsive City' context is not only the latest urban phenomena but also the optimal approach for the urban development plans since it offers progress in several disciplines, such as urban resilience, sustainability, energy efficiency & socio-economically enhanced and mutually respectful – democratic and transparent environments. Does not matter which discipline that the research belongs, all researchers aim and work for a better world with better solutions, such as we are looking for *'livable cities with collective values'*.

The Fine Line Between Smart And Responsive:

Urban form could be allocated by layers, such as buildings, infrastructure, natural & environmental elements, services, data 'invisible' cloud, activities etc. Since the urban fabric is made of uncountable factors, actors and physical means, the most important element in this network is the layer of life. This multidimensional diversity of elements could be beneficiary for each other if they somehow could connect and give feedback to each other. Within the current technology, cities are maintained by intelligent technologies which makes a urban space 'Smart'. Yet, the multidimensional functioning of the current urban morphology requires more than just being assisted by smart technologies. The next step for the smart cities is the generation of the responsiveness. Upgrading the smart to responsive means; including interactivity occurrence between the factors that compose the 'urban life', such as the physical reality, the user as citizen, real-time data, surrounding factors and the feedback, activity networks, services and so on.

Into the bargain, Anthony Townsend wrote about his own definition upon smart cities and upgrading the urban definition to the contemporary vision: *"People often ask me, 'What is a smart city?' It's a hard question to answer. 'Smart' is a problematic word that has come to mean a million things. Soon, it may take*

its place alongside the handful of international cognates — vaguely evocative terms like “sustainability” and “globalization” (Townsend, 2013). He pointed out in his book that, when people mention smart cities, the digital infrastructures are meant, such as bike sharing, real-time transportation information etc. Anyways, the smart city phenomena is not only the implication of those infrastructures to a city, but also pointing the citizen out, to be smarter to use and interact with those technologies. The vision of smart cities has to be broaden up to a next level, and viewed holistically. On this section, predicating the smart city structures a base and taking the research further through the holistic vision. That vision takes a more focused view upon the definition in literature and defines smart cities as places where information technology is combined with infrastructure, architecture, everyday objects, and even our bodies to address social, economic, and environmental problems. As Townsend also mentioned, a more important and interesting question is, *“What do you want a smart city to be? We need to focus on how we shape the technology we employ in future cities. There are many different visions of what the opportunity is”* (Townsend, 2013). To be specific, the fine line between the smart cities and the responsive cities is the interaction and the inclusion of the ‘smart citizen’ to take the principal role by using the technologies to define and shape their own environment & future.

Upgrading Smart Cities To Responsive Cities:

The emerging context; ‘Responsive City’, is taking the context of ‘Smart City’ one step further and adds up the interaction into city scale. It is a reciprocate system between the citizens and the living environment / neighborhood (Birgonul, Cocho-Bermejo, & Sarrablo, 2018). Community exists apart of spatial environments; specifically cyberspace, which is the virtual space generated by computer networks. The interaction generated by physical human activities in offline reality is the basis of the online social interaction to cyberspace. The social interactions consists functions, economy, (socio-economic facts), culture and information exchange. The interaction is in between of the physical structure and the society, where a virtual layer emerges (See Figure 146).

While a Smart City already has the digital infrastructure, including the interaction of the user, adds the value ‘Responsiveness’ to the urban definition. Likewise, in the smart homes to responsive homes, cities also could be understood within the same context. When the environment is considered ‘smart’, the basis of digital tools, ICT facilities and embedded intelligence of the built environment requires a more sophisticated development plan to be upgraded as ‘Responsive’.



The lack of users' engagement in active participation in decision-making, as well as customization of cities are the concepts that are lacking in the Smart City definitions and added in the Responsive City context. The citizen become the main actuator of the urban metabolism. They actively interact with the built environment, social structure and organization and city infrastructures. In order to customize, optimize and humanize the urban space, smart citizens moderate the urban tools.

Responsive Cities empower its citizen by the open-source data sharing. The collaborative digital enablers, such as mobile apps, devices, wearables, digital city infrastructure, and similar tools create the digital environment for citizen engagement in cyber space with collective values, socio-cultural & economic aspects and sustainable concerns.

Not only organizational or participatory, Responsive Cities would provide interactive public and private environments to its citizens, that are responding to the society and environment in real-time. Those spaces would be designed as urban infrastructure interfaces, which would be developed upon capturing, analyzing and managing the local Big Data, to achieve a responsive level for socio-cultural outcomes & public activation.

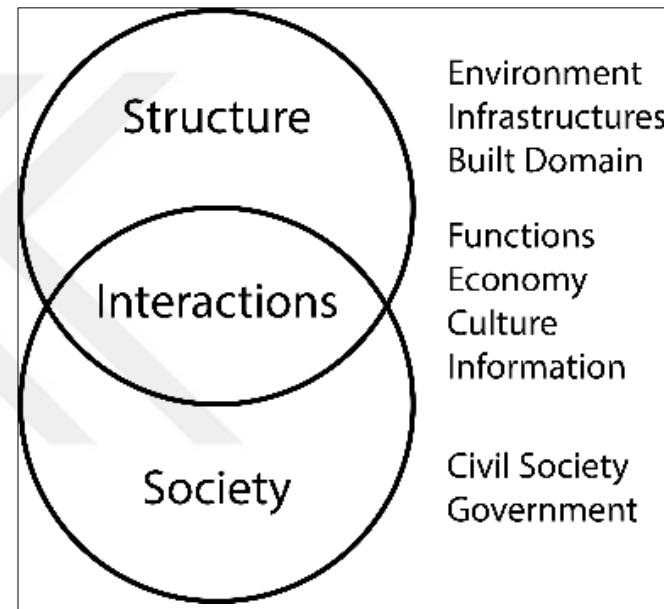


Figure 146: City Structure, The City Protocol (City Protocol Society, 2015)

11.6. SYMBIOTIC DATA PLATFORM IN RESPONSIVE CITIES

CONTEXT

Regarding to the responsiveness of design, Negroponte defined architecture 'as a machine', previously. Yet, Negroponte's vision was not only limited to the architectural design, being a more industrialized space, but also, to upgrade the quality and outcomes of it by added values, such as being participatory. "Negroponte's larger aim was to democratize and localize the control over the design of the built environment, developing 'humanistic' machines that could respond to user requirements, analyze user behavior, and even anticipate possible future problems and solutions" (Van Ameijde, 2019).

The absolute design principle of Symbiotic Data Platform is to enhance the life quality while optimizing the energy efficiency. Even though its' function is tested and proven in the building scale, it could be developed further to a greater scale, to be applied as an information exchange and energy efficiency network, by Sustainable Urban Development frame.

Information Model Databases, by their nature creates collaborative and multidisciplinary solutions. And information technologies, and IoT enables the data and real-time information

to be collected, analyzed and used for further concerns. The association of those two terms creates efficient and productive results from smaller scale to greater scale. Symbiotic Data Platform is a product that is born from the unity of those two terms, as a new artifact.

Referring to the literature upon upgrading BIM software to a more complex urban modeling systems, it have been concluded as following: "BIM can be extended to an urban scale by extending the concept of "site" to include a collection of individual cadastral lots, each one geospatially located and defined both geometrically (with different representations to suit different purposes) and with a full set of defined properties and relationships" (Plume & Mitchell, 2011). In the same research it is also commented that the term 'urban information model approach' that will manage the bigger scale built environment elements construction and maintenance. Moreover; "This allows us to manage the urban information model as a database, integrate with traditional GIS analysis tools and better support collaborative built environment design processes" (Plume & Mitchell, 2011).

Apart from expanding the scale of BIM usage, regarding this research project outcomes, BIM and IoT interaction could also applied to a greater scale, within the Symbiotic Data Platforms'



potential. Aligning with Responsive Cities context, Symbiotic Data Platform could be extended as an infrastructure, and could create building networks, as a big cloud of the neighborhood, the district, and the city.

Referring again, to Negroponete's vision upon *developing 'humanistic' machines*; Responsive Cities also address *'humanization'* of the cities, by using the fruits of digitalization. The great conflict of mega-cities of network societies could be solved by upgrading the cities to be responsive. As a matter of fact, pursuant to Negroponete, *developing 'humanistic' machines* for livable built environments, corresponds to the Responsive Cities phenomena, as well as Symbiotic Data Platforms' objectives in building scale.

As Hamilton et.al. stated on their research, the scales might vary but the main idea guides the design thinking through the contexts. They wrote;

"Although focusing on different scales of built and human environment, building design and urban planning have some similar characteristics; they are, for example, multi-dimensional and complex. Therefore they face similar challenges in their decision-making process which is the integration of multi-dimensional information and comparisons of different

design/planning alternatives" (Hamilton, Wang, Tanyer, Zhang , Arayıcı, & Song, 2005).

Due to this similarity, it would be adequate to imply Symbiotic Data Platform functions in a city scale, where the smart city would be converted to a Responsive City by the participatory features and interactive facilities of the tool.

Lastly, implying the recent technologies to the urban infrastructures, converting smart cities to responsive cities, and developing Symbiotic Data Platform as a data sharing and collaboration platform in city scale would bring **'City Excellence'** to the cities, that refers to a good development plan, betterment strategies and upgraded life values.

Recently, we are dealing with an advanced topic of this 3-layered architecture equation, which consists, 'Structure, Life and Data'. The added value of this new equation is the 'real-time data'. The interaction layer of the digitalized cities is operated by the real activity driven data input. In 'Symbiotic Data Platform', the real-time data is implemented on the existing BIM projects, and by this, a **'Real -Time Information Model'** would be achieved. To summarize, under the title of 'Blending BIM with IoT', this dissertation gives an innovative approach to the literature. Both Building Information Modeling and Internet of Things are contemporary concepts of architectural and

SYMBIOTIC DATA PLATFORM

sensibility & sensitivity

engineering fields. The project proposes the possibility to develop and it gives an incontrovertible value to interdisciplinary practices in science and progression in collective sense.

Mainly, by 'Symbiotic Data Platform' it is possible to accomplish a new approach on BIM System with an interactive monitoring, that can gather more data and gives more control upon the spaces and the buildings. Starting from a very basic idea of combining two disciplines might be a solution for a sustainable urban cycle. The main importance of the research is to focus on the users' intelligence, more than the proposed project as an outcome. The vision is, to create a smarter community by empowering them with introducing a smarter decision-making tool.

'Sensible' data and 'Sensitive' users of the smarter technologies and the urban emergent territories are the ultimate desire for the future visions. To achieve the goal is lying on the way of creating delicate tools for the user, by offering them better service with upgraded choices.

Criticism And Rethinking:

1. Ethics
2. Privacy
3. Crash + Back-up Systems
4. Implementation Difficulties & Technological Inadequacy

When the terms 'open data', 'big data', 'data capture', 'social media' are on the table, it is crucial to take into account the essential matter of ethics and privacy. The legal terms on data sharing and open data usage has a crucial role on the projects such as 'Symbiotic Data Platform'. In this context, to expand the platform in urban scale and public useage; legal advise and consultation for professionals on the specific issue could be a worthwhile feedback on the design-thinking and development stages of the further research Consultation for revisions from urban designers, philosophers and sociologists could be helpful on this concern.

On the other sides, it's very important to regard the unexpected circumstances that could occur, in the scenario. The proposed platform is meant to be a network that could cover up a huge responsibility on a newly constructed urban functionality, and create new demands on quotidian life. In case of an improbable crash in communication services, breakdown of internet



connection, energy interruption or outage, technical problems of the machines and sensors are some aspects that must have a back-up system for decreasing the unwanted losses. This very specific detail could be another research independently by itself; nevertheless, it will be mentioned and will be covered up in the projects design phase with a chapter. Moreover, future work could be focused on specifically on the issues and theories on back up projects.

One of the most discussed point of IoT is the 'cyber security'. The question of 'privacy' getting criticized often, and cannot be underestimated, is. Personal data control is one of the hardest fields to enter, and it is open to discussion since the field is the most critical policy of the Big Data matter. As well as there are developments everyday constantly on smart cities, digital features, communication technologies and so on, on the other hand, hackers and malignant market are also searching for their own benefit out of the developing field. Likely in every human related sector, there are two faces of the case. Personal and/or mass attacks by data thieves are a current problem on this field.

The Big Data is seen as the future power source. On the way of entering the interdisciplinary projects which consists IoT and use open-source databases, the control of shared information and the usage of private input have to be considered and have to be

protected in the possible ways. *"While the IoT applications will be varied and difficult to predict, some clear opportunities will arise for ubiquitous information gathering, context sensing, and control, which will likely be key enabling building blocks. However, some of the real challenges will be in the areas of privacy and security"* (Want, Schilit, & Jenson , 2015). Recently, the privacy and security field is being discussed, the legal restrictions and regulations are applied word-wide. The issue is a global fact, and every entity is aware of the possible outcomes of hacking and manipulation.

As another point of view towards responsive cities is that; the cities got smart by the help of communication and connection, as well as the digital technologies' assistance. But, *"What if the seeds of smart cities' own destruction are already built into their DNA?"* (Townsend, 2013). Even though, the current smart systems and intelligent cities already have are multiple layers of fail-safes and back-up options, still the question of breakdown and the possible crisis is the biggest critical point in the smart city field. "When cellphones went down, there was paralysis and panic," the head of emergency communications in the city of Miyako told the New York Times, regarding the Tsunami Emergency on 2011 (Fackler, 2011). As another standpoint, not only the smart systems, but also the communication network fail could be the reason for the crisis. By today, Internet

communication quality, carrier networks service and wireless technology are in a satisfactory level in order to assist an urban scale system. But, *"The biggest threat to cellular networks in cities, however, is population density. Because wireless carriers try to maximize the profit-making potential of their expensive spectrum licenses, they typically only build out enough infrastructures to connect a fraction of their customers in a given place at the same time"* (Townsend, 2013). As much as the market grows, there would be additional fields to cover up legally, economically, socially and of course technologically.

Another factor, is the case of the unexpected crashes; is to estimate the possibilities of the damage and designing the systems according to minimizing the possible damage. There has to be a strong back-up system, emergency alternatives and also, these systems and technologies have to be updated frequently. This concept could be a further research topic, or even could be handled in the design phase of 'Symbiotic Data Platform' in the subsequent steps of the progress of the future research.

Closing:

In the further research chapter, the following research question is studied; "How to use the 'existing BIM data' and 'constantly

produced real-time data' together; during the operational phase of the building, to upgrade the energy efficiency and enhance sustainability while addressing users' customized and optimized thermal comfort?". Also, the complementary questions are discussed while the following concepts are covered around the 'Responsive Cities' framework; *'Is it possible to achieve Sustainable Urban Development by digital architecture?', and 'Is it possible to design a tool that would upgrade the digital infrastructures of the cities and could create a transaction of mutual benefits between citizens?'*. This last chapter is where the proposal of Symbiotic Data Platform could apply to the city scale, the possibilities of upgrading smart cities to responsive cities is discussed. As a case, the introduction of Symbiotic Data Platform as a city infrastructure is questioned and discussed.

Regarding to the research questions on the further research part, the conclusion could be summarized as; the digital architectural design and interactive environments are creating a new layer on urban fabric. The data layer became one of the vital aspects, to be taken care of. During the very last years, the importance of the big data, (also can be defined as the data layer of the city); is augmented. Raising the concept of responsive cities, by social and technologic aspects are a huge new field with promising horizons.



The transformation of the cities, from smart to responsive, and transformation of citizens through being the knowledge generation of the digital era are unavoidable. To sum up, the built environment and the generation is under a radical and essential regeneration. This entrenched necessity to adapt the 21st century digitalization is crucial.

Symbiotic Data Platform addresses *energy efficiency* while proposing *optimized comfort level* for the user, since sustainability and energy efficiency are two of the most important concerns of current era. Using more efficient systems such as this one, could create a distinctive change. As a standpoint of this thesis, it is believed that a very small change can make a very big difference for the society, economy and environment and culture.

In direct relation with the documentation of results and the discussion of the outcomes of Symbiotic Data Platform + Prototype VII¹⁰²; up-scaling the application area of the project is also useful and fruitful for the citizens of the city, as it is giving efficient and optimized outcomes for the occupants of the building. Symbiotic Data Platform is a beneficial project for

occupants, and it might be developed further to become a digital city infrastructure. Moreover, apart from the developed technology and interface, by using Symbiotic Data Platform actively, a collective cognition, and a responsible manner for socio-economic and environmental concerns emerge.

As knowledge generation, we are in a constant transformation for approaching a greater conscience and cognition, as a consequence our built environment is also getting adapted and regenerated. This project is an example of how the '*new architectural design understanding*' of '*Form + Function + Interaction*' could be applied.

The doctoral research project 'Symbiotic Data Platform', might be a small-scaled contribution to the massive field of architectural design & computing field, yet; it is an substantial step to prove and introduces a promising connection between the existing technologies and real-time information. Within the inference and reflection of this research, greater projects could be developed upon. Among all, by this project, the greater outcome is not the technologic findings, but it is the moral inferring; that is '*the architecture should be sensible and sensitive*', which leads the society to live in '***livable cities with collective values.***'

¹⁰² See Conclusions Chapter for discussion.



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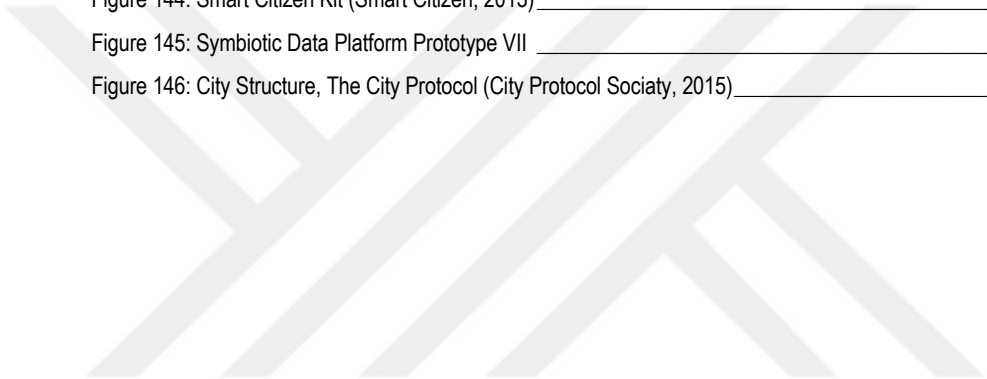
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APPENDIX

Prototype I & II -

Transmitter

```
/*
  Author: Zeynep
  Date : January 3, 2018

  -Transmitter Code
*/
#include <Wire.h>
#include <Adafruit_MLX90614.h>
#include <SoftwareSerial.h>

SoftwareSerial Xbee(10, 11);
Adafruit_MLX90614 mlx = Adafruit_MLX90614();
String data="";
void setup() {
  Serial.begin(9600);
  Xbee.begin(9600);
  Serial.println("Adafruit MLX90614 test");
  mlx.begin();
}

void loop() {
  Serial.print("Ambient = "); Serial.print(mlx.readAmbientTempC());
  Serial.print("\tObject = "); Serial.print(mlx.readObjectTempC());
  Serial.println("\t\tC");
  Serial.print("Ambient = "); Serial.print(mlx.readAmbientTempF());
  Serial.print("\tObject = "); Serial.print(mlx.readObjectTempF());
  Serial.println("\t\tF");

  Serial.println();
  data = String(mlx.readAmbientTempC()) + "," +
  String(mlx.readObjectTempC()) + ",";
  Xbee.println(data);
  delay(500);
}
```

Prototype I & II - Receiver

```
/*
  Author: Zeynep
  Date : Feb 1, 2018

  -Receiver Code

  Software Requirements:
  -----
  -Arduino IDE

  Hardware Requirements:
  -----
  -Arduino Uno, Xbee, Servo motors

  Project Requirements:
  -----
  * Rx will receive data and control servo motors
*/

#include <Servo.h>
#include <SoftwareSerial.h>

SoftwareSerial Xbee(10, 11);

#define hPin 3
#define vPin 5

Servo Heater ;
Servo Vantilator;

String dataString = "";
String data[2] = {"", "" };
int temp1 , temp2 ;

void setup() {

  Serial.begin(9600);
  Xbee.begin(9600);
  Heater.attach(hPin);
  Vantilator.attach(vPin);
}

void loop() {
  while (Xbee.available() > 0) {
    dataString = Xbee.readStringUntil('\n');

    int j = 0 , c = 0;
    for (int i = 0; i < dataString.length() + 1 ; i++) {
      if (dataString.substring(i, i + 1) == ",") {
        data[c] = dataString.substring(j, i);
        j = i + 1;
        c++;
      }
    }
    temp1 = data[0].toInt();
    temp2 = data[1].toInt();
    Serial.print("Ambient = " + String(temp1));
```

SYMBIOTIC DATA PLATFORM

symbiosis & sensitivity

```
Serial.print("C\tObject = " + String(temp2));
Serial.println("C");

if (data[1].toInt() < 36) {
  Serial.println("Heater ON");
  TurnOnHeater();
}
else if (data[1].toInt() > 38) {
  Serial.println("Vantilator ON");
  TurnOnVantilator();
}
else if (data[1].toInt() >= 36 && data[1].toInt() <= 38) {
  Serial.println("Both Off");
  Heater.write(0);
  Vantilator.write(0);
}
}

void TurnOnHeater() {
  Vantilator.write(0);
  for (int angle = 0; angle < 180; angle += 1)
  {
    Heater.write(angle);
    delay(15);
  }
  delay(1000);

  for (int angle = 180; angle >= 1; angle -= 1)
  {
    Heater.write(angle);
    delay(5);
  }
  delay(1000);
}

void TurnOnVantilator() {
  Heater.write(0);
  for (int angle = 0; angle < 180; angle += 1)
  {
    Vantilator.write(angle);
    delay(15);
  }
  delay(1000);

  for (int angle = 180; angle >= 1; angle -= 1)
  {
    Vantilator.write(angle);
    delay(5);
  }
  delay(1000);
}
```

Prototype III – Transmitter

```
/*
  Author: Zeynep
  Date : May 16, 2018
  Software Requirements:
  -----
  -Arduino IDE
  -Wire library
  -SparkFunMLX90614 library
  -SoftwareSerial library
  Hardware Requirements:
  -----
  -Flora Lilypad usb
  -Xbee
  -Adafruit GPS + Button, MLX90614
  Project Requires:
  -----
  * Read the temperature data
  * Read the GPS data
  * If the user in the range of house send the temperature
  data to the receiver
  * Update the GPS data by press Update button
*/

#include<SoftwareSerial.h>
#include <Adafruit_MLX90614.h>
#include <Adafruit_GPS.h>
#include <Wire.h>

#define rxPin 10
#define txPin 11
#define GPSECHO true
#define update 9

Adafruit_MLX90614 mlx = Adafruit_MLX90614();
SoftwareSerial Xbee(rxPin, txPin);
SoftwareSerial mySerial(A2, A3);
Adafruit_GPS GPS(&mySerial);

String data = "";
uint32_t timer = millis(), timer1;
boolean usingInterrupt = false;
void useInterrupt(boolean);
float lat = 0, lng = 0, Max_lat, Min_lat, Max_lng, Min_lng;

SIGNAL(TIMERO_COMPA_vect) {
  char c = GPS.read();
  #ifdef UDR0
    if (GPSECHO)
      if (c) UDR0 = c;
  #endif
}

void useInterrupt(boolean v) {
  if (v) {
    OCR0A = 0xAF;
    TIMSK0 |= _BV(OCIE0A);
    usingInterrupt = true;
  } else {
    TIMSK0 &= ~_BV(OCIE0A);
    usingInterrupt = false;
  }
}

void setup() {
  mlx.begin();
  Serial.begin(9600);
  GPS.begin(9600);
  Xbee.begin(9600);
  GPS.sendCommand(PMTK_SET_NMEA_OUTPUT_RMCGGA);
  GPS.sendCommand(PMTK_SET_NMEA_UPDATE_1HZ);
  GPS.sendCommand(PGCMD_ANTENNA);
}
```



```
useInterrupt(true);
delay(1000);
mySerial.println(PMTK_Q_RELEASE);
pinMode(update , INPUT_PULLUP);
}

void loop() {

  if (! usingInterrupt) {
    char c = GPS.read();
    if (GPSECHO)
      if (c) Serial.print(c);
  }
  if (GPS.newNMEAReceived()) {
    if (!GPS.parse(GPS.lastNMEA()))
      return;
  }

  if (digitalRead(update) == LOW && millis() - timer1 > 150) {
    lat = GPS.latitude;
    lng = GPS.longitude;
    Max_lat = lat + 5;
    Min_lat = lat - 5;
    Max_lng = lng + 5;
    Min_lng = lng - 5;
    timer1 = millis();
  }
  if ((GPS.latitude >= Min_lat && GPS.latitude <= Max_lat) &&
(GPS.longitude >= Min_lng && GPS.longitude <= Max_lng)) {
    data = String(mlx.readAmbientTempC()) + "," +
String(mlx.readObjectTempC()) + ",";
    Xbee.println(data);
  }
}
```

Prototype III – Receiver

```
/*
  Author: Zeynep Birgonul
  Date : April 23, 2019

  -Receiver Code

  Software Requirements:
  -----
  -Arduino IDE

  Hardware Requirements:
  -----
  -Arduino Uno, Xbee, Servo motors

  Project Requirments:
  -----
  Rx will receive data and control servo motors
  Human interaction with thermal sensor / body temperature
  Thermal analysis by BIM input, user body temperature and Real-time
  data.
*/

#include <Servo.h>
#include <SoftwareSerial.h>
#include <LinkedList.h>

//SoftwareSerial Xbee(8,9);

#define hPin 3
#define vPin 5

/*
 * Define new type of data to model a point with latitude and longitude
 */
struct Coord{
  String lat;
  String lng;
};

/*
 * Define new type of data structure to model a single detail of a
room (wall, window, ecc...):
 * r_value -> R value of object
 * u_value -> U value of object
 * description -> Name of the object
 */
struct Detail {
  float r_value;
  float u_value;
  float area;
  String description;
};

/*
 * Define new type of data structure to model a room:
 * value -> value of room
 * threshold -> 0.5 value it could be unique for each room
 * name -> Name of the room
 * details -> A list of object Detail (wall, window, ceiling, ecc...)
 * coord_A, coord_B, coord_C, coord_D -> are latitude and longitude
about the 4 corners of the room (usefull for future release)
 */
struct Room {
  float value;
  float threshold;
  String name;
  LinkedList<Detail> *details;
  Coord coord_A;
  Coord coord_B;
  Coord coord_C;
```


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```
Coord coord_D;
float altitude;
};

LinkedList<Room> *singleBIM = new LinkedList<Room>();

Servo Heater ;
Servo Ventilator;

String dataString = "";
String data[2] = {"", "" };
int temp1 , temp2 ;

void setup() {

    Serial.begin(9600);

    // BluetoothHC05.begin(9600);
    Heater.attach(hPin);
    Ventilator.attach(vPin);
    SetupStruct_1();
    SetupStruct_2();
    SetupStruct_3();
    SetupStruct_4();
    SetupStruct_5();
    SetupStruct_6();
    SetupStruct_7();
}

void loop() {

    Serial.print(singleBIM->size());

    for(int k = 0; k < singleBIM->size(); k++){
        Serial.print("\tRoom: " + singleBIM->get(k).name);
        Serial.print("\tValue: " + String(singleBIM->get(k).value));
        Serial.println("\tThreshold: " + String(singleBIM->get(k).threshold));
    }

    /*
    while (Xbee.available() > 0) {
        dataString = Xbee.readStringUntil('\n');

        int j = 0 , c = 0;
        Serial.print("/t dataRead: " + String(dataString));
        for (int i = 0; i < dataString.length() + 1 ; i++) {
            if (dataString.substring(i, i + 1) == ",") {
                data[c] = dataString.substring(j, i);
                j = i + 1;
                c++;
            }
        }
        temp1 = data[0].toInt();
        Serial.print("\t temp1: ");
        Serial.println(String(temp1));
        temp2 = data[1].toInt();
        Serial.print("\t temp2: ");
        Serial.println(String(temp2));
        bool u = false;
        int h = 0;
        while((h < singleBIM->size())&&(!u)){
            if((singleBIM->get(h).value < singleBIM->get(h).threshold)){
                u = true;
            }
            h++;
        }
        if((u) && (data[1].toInt() < 25)){
            Serial.println("Heater ON");
            TurnOnHeater();
        }
    }
    */
}
```

```
        }else if((u) && (data[1].toInt() > 38)){
            Serial.println("Ventilator ON");
            TurnOnVentilator();
        }else if((data[1].toInt() >= 25) && (data[1].toInt() <= 38)){
            Serial.println("Both Off");
            Heater.write(0);
            Ventilator.write(0);
        }
    }
}

void TurnOnHeater() {
    Ventilator.write(0);
    for (int angle = 0; angle < 180; angle += 1)
    {
        Heater.write(angle);
        delay(15);
    }
    delay(1000);

    for (int angle = 180; angle >= 1; angle -= 1)
    {
        Heater.write(angle);
        delay(5);
    }
    delay(1000);
}

void TurnOnVentilator() {
    Heater.write(0);
    for (int angle = 0; angle < 180; angle += 1)
    {
        Ventilator.write(angle);
        delay(15);
    }
    delay(1000);

    for (int angle = 180; angle >= 1; angle -= 1)
    {
        Ventilator.write(angle);
        delay(5);
    }
    delay(1000);
}

void SetupStruct_1(){
    //default config
    struct Coord nullCoord;
    nullCoord.lat = "";
    nullCoord.lng = "";

    struct Detail floor;
    floor.u_value = 4.981;
    floor.r_value = 0.04;
    floor.area = 64;
    floor.description = "floor";

    struct Detail wall_ext;
    wall_ext.u_value = 4.3333;
    wall_ext.r_value = 0.2308;
    wall_ext.area = 58;
    wall_ext.description = "wall exterior";

    struct Detail wall_int;
    wall_int.u_value = 0.2682;
    wall_int.r_value = 3.7292;
    wall_int.area = 36.8;
    wall_int.description = "wall interior";
}
```



```
struct Detail ceiling;
ceiling.u_value = 3.5626;
ceiling.r_value = 0.2827;
ceiling.area = 63;
ceiling.description = "ceiling";

struct Detail door_ext;
door_ext.u_value = 6.8703;
door_ext.r_value = 0.1456;
door_ext.area = 7.04;
door_ext.description = "door exterior";

struct Detail door_int;
door_int.u_value = 5.5617;
door_int.r_value = 0.1798;
door_int.area = 3.52;
door_int.description = "door interior";

struct Detail window;
window.u_value = 3.6886;
window.r_value = 0.2711;
window.area = 9.48;
window.description = "window";

struct Room living;
living.threshold = 0.5;
living.name = "LivingRoom";
living.details = new LinkedList<Detail>();
living.details->add(0, floor);
living.details->add(1, wall_ext);
living.details->add(2, wall_int);
living.details->add(3, ceiling);
living.details->add(4, door_ext);
living.details->add(5, door_int);
living.details->add(6, window);
living.coord_A = living.coord_B = living.coord_C = living.coord_D =
nullCoord;
living.altitude = 0;
living.value = calcValue(living);
singleBIM->add(living);
}

float calcValue(Room living){
    float result = 0;
    int h = 0;
    while(h < living.details->size()){
        result = result + (living.details->get(h).u_value *
living.details->get(h).area);
        h++;
    }
    return (result);
}

void SetupStruct_2(){
    //default config
    struct Coord nullCoord;
    nullCoord.lat = "";
    nullCoord.lng = "";

    struct Detail floor;
    floor.u_value = 4.981;
    floor.r_value = 0.04;
    floor.area = 34;
    floor.description = "floor";

    struct Detail wall_ext;
    wall_ext.u_value = 4.3333;
    wall_ext.r_value = 0.2308;
    wall_ext.area = 48.4;
    wall_ext.description = "wall exterior";
```

```
struct Detail wall_int;
wall_int.u_value = 0.2682;
wall_int.r_value = 3.7292;
wall_int.area = 27.2;
wall_int.description = "wall interior";

struct Detail ceiling;
ceiling.u_value = 3.5626;
ceiling.r_value = 0.2827;
ceiling.area = 34;
ceiling.description = "ceiling";

struct Detail door_ext;
door_ext.u_value = 6.8703;
door_ext.r_value = 0.1456;
door_ext.area = 3.52;
door_ext.description = "door exterior";

struct Detail window;
window.u_value = 3.6886;
window.r_value = 0.2711;
window.area = 9.48;
window.description = "window";

struct Room kitchen;
kitchen.threshold = 0.5;
kitchen.name = "Kitchen";
kitchen.details = new LinkedList<Detail>();
kitchen.details->add(0, floor);
kitchen.details->add(1, wall_ext);
kitchen.details->add(2, wall_int);
kitchen.details->add(3, ceiling);
kitchen.details->add(4, door_ext);
kitchen.details->add(5, window);
kitchen.coord_A = kitchen.coord_B = kitchen.coord_C = kitchen.coord_D
= nullCoord;
kitchen.altitude = 0;
kitchen.value = calcValue(kitchen);
singleBIM->add(kitchen);
}

void SetupStruct_3(){
    //default config
    struct Coord nullCoord;
    nullCoord.lat = "";
    nullCoord.lng = "";

    struct Detail floor;
    floor.u_value = 4.981;
    floor.r_value = 0.04;
    floor.area = 28;
    floor.description = "floor";

    struct Detail wall_ext;
    wall_ext.u_value = 4.3333;
    wall_ext.r_value = 0.2308;
    wall_ext.area = 28.3;
    wall_ext.description = "wall exterior";

    struct Detail wall_int;
    wall_int.u_value = 0.2682;
    wall_int.r_value = 3.7292;
    wall_int.area = 57.8;
    wall_int.description = "wall interior";

    struct Detail ceiling;
    ceiling.u_value = 3.5626;
    ceiling.r_value = 0.2827;
    ceiling.area = 28;
    ceiling.description = "ceiling";
```

SYMBIOTIC DATA PLATFORM

resilibility & resigitivity

```
struct Detail door_int;
door_int.u_value = 3.7021;
door_int.r_value = 0.2701;
door_int.area = 18.9;
door_int.description = "door interior";

struct Detail window;
window.u_value = 3.6886;
window.r_value = 0.2711;
window.area = 9.48;
window.description = "window";

struct Room bedroom;
bedroom.threshold = 0.5;
bedroom.name = "bedroom";
bedroom.details = new LinkedList<Detail>();
bedroom.details->add(0, floor);
bedroom.details->add(1, wall_ext);
bedroom.details->add(2, wall_int);
bedroom.details->add(3, ceiling);
bedroom.details->add(4, door_int);
bedroom.details->add(5, window);
bedroom.coord_A = bedroom.coord_B = bedroom.coord_C = bedroom.coord_D
= nullCoord;
bedroom.altitude = 0;
bedroom.value = calcValue(bedroom);
singleBIM->add(bedroom);
}

void SetupStruct_4(){
    //default config
    struct Coord nullCoord;
    nullCoord.lat = "";
    nullCoord.lng = "";

    struct Detail floor;
    floor.u_value = 4.981;
    floor.r_value = 0.04;
    floor.area = 28;
    floor.description = "floor";

    struct Detail wall_ext;
    wall_ext.u_value = 4.3333;
    wall_ext.r_value = 0.2308;
    wall_ext.area = 28.3;
    wall_ext.description = "wall exterior";

    struct Detail wall_int;
    wall_int.u_value = 0.2682;
    wall_int.r_value = 3.7292;
    wall_int.area = 57.8;
    wall_int.description = "wall interior";

    struct Detail ceiling;
    ceiling.u_value = 3.5626;
    ceiling.r_value = 0.2827;
    ceiling.area = 28;
    ceiling.description = "ceiling";

    struct Detail door_int;
    door_int.u_value = 3.7021;
    door_int.r_value = 0.2701;
    door_int.area = 18.9;
    door_int.description = "door interior";

    struct Detail window;
    window.u_value = 3.6886;
    window.r_value = 0.2711;
    window.area = 9.48;
    window.description = "window";
```

```
struct Room room1;
room1.threshold = 0.5;
room1.name = "room1";
room1.details = new LinkedList<Detail>();
room1.details->add(0, floor);
room1.details->add(1, wall_ext);
room1.details->add(2, wall_int);
room1.details->add(3, ceiling);
room1.details->add(4, door_int);
room1.details->add(5, window);
room1.coord_A = room1.coord_B = room1.coord_C = room1.coord_D =
nullCoord;
room1.altitude = 0;
room1.value = calcValue(room1);
singleBIM->add(room1);
}

void SetupStruct_5(){
    //default config
    struct Coord nullCoord;
    nullCoord.lat = "";
    nullCoord.lng = "";

    struct Detail floor;
    floor.u_value = 4.981;
    floor.r_value = 0.04;
    floor.area = 12;
    floor.description = "floor";

    struct Detail wall_ext;
    wall_ext.u_value = 4.3333;
    wall_ext.r_value = 0.2308;
    wall_ext.area = 14.3;
    wall_ext.description = "wall exterior";

    struct Detail wall_int;
    wall_int.u_value = 0.2682;
    wall_int.r_value = 3.7292;
    wall_int.area = 38.8;
    wall_int.description = "wall interior";

    struct Detail ceiling;
    ceiling.u_value = 3.5626;
    ceiling.r_value = 0.2827;
    ceiling.area = 12;
    ceiling.description = "ceiling";

    struct Detail door_int;
    door_int.u_value = 3.7021;
    door_int.r_value = 0.2701;
    door_int.area = 18.9;
    door_int.description = "door interior";

    struct Detail window;
    window.u_value = 3.6886;
    window.r_value = 0.2711;
    window.area = 12;
    window.description = "window";

    struct Room room2;
    room2.threshold = 0.5;
    room2.name = "room2";
    room2.details = new LinkedList<Detail>();
    room2.details->add(0, floor);
    room2.details->add(1, wall_ext);
    room2.details->add(2, wall_int);
    room2.details->add(3, ceiling);
    room2.details->add(4, door_int);
    room2.details->add(5, window);
    room2.coord_A = room2.coord_B = room2.coord_C = room2.coord_D =
nullCoord;
```



```
room2.altitude = 0;
room2.value = calcValue(room2);
singleBIM->add(room2);
}

void SetupStruct_6(){
//default config
struct Coord nullCoord;
nullCoord.lat = "";
nullCoord.lng = "";

struct Detail floor;
floor.u_value = 4.981;
floor.r_value = 0.04;
floor.area = 17;
floor.description = "floor";

struct Detail wall_ext;
wall_ext.u_value = 4.3333;
wall_ext.r_value = 0.2308;
wall_ext.area = 31.4;
wall_ext.description = "wall exterior";

struct Detail wall_int;
wall_int.u_value = 0.2682;
wall_int.r_value = 3.7292;
wall_int.area = 31.4;
wall_int.description = "wall interior";

struct Detail ceiling;
ceiling.u_value = 3.5626;
ceiling.r_value = 0.2827;
ceiling.area = 17;
ceiling.description = "ceiling";

struct Detail door_ext;
door_ext.u_value = 5.5617;
door_ext.r_value = 0.1798;
door_ext.area = 18.9;
door_ext.description = "door exterior";

struct Detail door_int;
door_int.u_value = 3.7021;
door_int.r_value = 0.2701;
door_int.area = 18.9;
door_int.description = "door interior";

struct Room bathroom;
bathroom.threshold = 0.5;
bathroom.name = "bathroom";
bathroom.details = new LinkedList<Detail>();
bathroom.details->add(0, floor);
bathroom.details->add(1, wall_ext);
bathroom.details->add(2, wall_int);
bathroom.details->add(3, ceiling);
bathroom.details->add(4, door_ext);
bathroom.details->add(5, door_int);
bathroom.coord_A = bathroom.coord_B = bathroom.coord_C =
bathroom.coord_D = nullCoord;
bathroom.altitude = 0;
bathroom.value = calcValue(bathroom);
singleBIM->add(bathroom);
}
```

```
void SetupStruct_7(){
//default config
struct Coord nullCoord;
nullCoord.lat = "";
nullCoord.lng = "";

struct Detail floor;
floor.u_value = 4.981;
```

```
floor.r_value = 0.04;
floor.area = 115.5;
floor.description = "floor";
```

```
struct Detail wall_int;
wall_int.u_value = 0.2682;
wall_int.r_value = 3.7292;
wall_int.area = 109.4;
wall_int.description = "wall interior";
```

```
struct Detail ceiling;
ceiling.u_value = 3.5626;
ceiling.r_value = 0.2827;
ceiling.area = 115.5;
ceiling.description = "ceiling";
```

```
struct Detail door_ext;
door_ext.u_value = 3.7021;
door_ext.r_value = 0.2701;
door_ext.area = 20;
door_ext.description = "door entrance";
```

```
struct Detail door_ext;
door_ext.u_value = 5.5617;
door_ext.r_value = 0.1798;
door_ext.area = 18.9;
door_ext.description = "door exterior";
```

```
struct Detail door_int;
door_int.u_value = 3.7021;
door_int.r_value = 0.2701;
door_int.area = 18.9;
door_int.description = "door interior";
```

```
struct Room corridor;
corridor.threshold = 0.5;
corridor.name = "corridor";
corridor.details = new LinkedList<Detail>();
corridor.details->add(0, floor);
corridor.details->add(1, wall_int);
corridor.details->add(2, ceiling);
corridor.details->add(3, door_ext);
corridor.details->add(4, door_ext);
corridor.details->add(5, door_int);
corridor.coord_A = corridor.coord_B = corridor.coord_C =
corridor.coord_D = nullCoord;
corridor.altitude = 0;
corridor.value = calcValue(corridor);
singleBIM->add(corridor);
}
```

SYMBIOTIC DATA PLATFORM

symbiosis & sensitivity

Prototype IV – Transmitter

```
/*
  Author: Zeynep
  Date : September 27, 2018

  -Transmitter Code

*/

#include <Wire.h>
#include <Adafruit_MLX90614.h>
#include<SoftwareSerial.h>

SoftwareSerial BluetoothHC05 (8,9);
Adafruit_MLX90614 mlx = Adafruit_MLX90614();
String data="";

void setup() {
  Serial.begin(9600);
  BluetoothHC05.begin(9600);
  Serial.println("Adafruit MLX90614 test");
  mlx.begin();
}

void loop() {
  Serial.print("Ambient = "); Serial.print(mlx.readAmbientTempC());
  Serial.print("\tObject = "); Serial.print(mlx.readObjectTempC());
  Serial.println("\tC");

  Serial.println();
  data = String(mlx.readAmbientTempC()) + "," +
  String(mlx.readObjectTempC()) + ",";
  BluetoothHC05.println(data);
  delay(500);
}
```

Prototype IV – Receiver

```
/*
  Author: Zeynep
  Date : October 18,2018

  -Receiver Code

  Software Requirements:
  -----
  -Arduino IDE

  Hardware Requirements:
  -----
  -Arduino Uno, Xbee, Servo motors

  Project Requirents:
  -----
  Rx will receive data and control servo motors
  Human interaction with thermal sensor / body temperature
  Thermal analysis by BIM input, user body temperature and Real-time
  data.

*/

#include <Servo.h>
#include <SoftwareSerial.h>
#include <LinkedList.h>

//SoftwareSerial BluetoothHC05(0,1);

#define hPin 3
#define vPin 5

/*
 * Define new type of data to model a point with latitude and longitude
 */
struct Coord{
  String lat;
  String lng;
};

/*
 * Define new type of data structure to model a single detail of a
room (wall, window, ecc...):
 * r_value -> R value of object
 * u_value -> U value of object
 * description -> Name of the object
 */
struct Detail {
  float r_value;
  float u_value;
  float area;
  String description;
};

/*
 * Define new type of data structure to model a room:
 * value -> value of room
 * threshold -> 0.5 value it could be unique for each room
 * name -> Name of the room
 * details -> A list of object Detail (wall, window, ceiling, ecc...)
 * coord_A, coord_B, coord_C, coord_D -> are latitude and longitude
about the 4 corners of the room (usefull for future release)
 */
struct Room {
  float value;
  float threshold;
  String name;
  LinkedList<Detail> *details;
  Coord coord_A;
  Coord coord_B;
```



```
Coord coord_C;
Coord coord_D;
float altitude;
};

LinkedList<Room> *singleBIM = new LinkedList<Room>();

Servo Heater ;
Servo Vantilator;

String dataString = "";
String data[2] = {"", "" };
int temp1 , temp2 ;

void setup() {

    Serial.begin(9600);

    // BluetoothHC05.begin(9600);
    Heater.attach(hPin);
    Vantilator.attach(vPin);
    SetupStruct_1();
    SetupStruct_2();
    SetupStruct_3();
    SetupStruct_4();
    SetupStruct_5();
    SetupStruct_6();
    SetupStruct_7();
}

void loop() {

    Serial.print(singleBIM->size());

    for(int k = 0; k < singleBIM->size(); k++){
        Serial.print("\tRoom: " + singleBIM->get(k).name);
        Serial.print("\tValue: " + String(singleBIM->get(k).value));
        Serial.println("\tThreshold: " + String(singleBIM->get(k).threshold));
    }
    /*
    while (BluetoothHC05.available() > 0) {
        dataString = BluetoothHC05.readStringUntil('\n');

        int j = 0 , c = 0;
        Serial.print("/t dataRead: " + String(dataString));
        for (int i = 0; i < dataString.length() + 1 ; i++) {
            if (dataString.substring(i, i + 1) == ",") {
                data[c] = dataString.substring(j, i);
                j = i + 1;
                c++;
            }
        }
        temp1 = data[0].toInt();
        Serial.print("\t temp1: ");
        Serial.println(String(temp1));
        temp2 = data[1].toInt();
        Serial.print("\t temp2: ");
        Serial.println(String(temp2));
        bool u = false;
        int h = 0;
        while((h < singleBIM->size())&&(!u)){
            if((singleBIM->get(h).value < singleBIM->get(h).threshold)){
                u = true;
            }
            h++;
        }
        if((u) && (data[1].toInt() < 25)){
            Serial.println("Heater ON");
            TurnOnHeater();
        }else if((u) && (data[1].toInt() > 38)){
            Serial.println("Vantilator ON");
        }
    }
    */
}
```

```
TurnOnVantilator();
}else if((data[1].toInt() >= 25) && (data[1].toInt() <= 38)){
    Serial.println("Both Off");
    Heater.write(0);
    Vantilator.write(0);
}
}
}

void TurnOnHeater() {
    Vantilator.write(0);
    for (int angle = 0; angle < 180; angle += 1)
    {
        Heater.write(angle);
        delay(15);
    }
    delay(1000);

    for (int angle = 180; angle >= 1; angle -= 1)
    {
        Heater.write(angle);
        delay(5);
    }
    delay(1000);
}

void TurnOnVantilator() {
    Heater.write(0);
    for (int angle = 0; angle < 180; angle += 1)
    {
        Vantilator.write(angle);
        delay(15);
    }
    delay(1000);

    for (int angle = 180; angle >= 1; angle -= 1)
    {
        Vantilator.write(angle);
        delay(5);
    }
    delay(1000);
}

void SetupStruct_1(){

    //default config
    struct Coord nullCoord;
    nullCoord.lat = "";
    nullCoord.lng = "";

    struct Detail floor;
    floor.u_value = 5.2300;
    floor.r_value = 0.1912;
    floor.area = 52;
    floor.description = "floor";

    struct Detail wall_ext;
    wall_ext.u_value = 4.6429;
    wall_ext.r_value = 0.3451;
    wall_ext.area = 58;
    wall_ext.description = "wall exterior";

    struct Detail wall_int;
    wall_int.u_value = 4.6429;
    wall_int.r_value = 0.2154;
    wall_int.area = 36.8;
    wall_int.description = "wall interior";

    struct Detail ceiling;
    ceiling.u_value = 3.5626;
    ceiling.r_value = 0.2789;
    ceiling.area = 52;
}
```

SYMBIOTIC DATA PLATFORM

symbiosis & sensitivity

```
ceiling.description = "ceiling";

struct Detail door_ext;
door_ext.u_value = 6.8703;
door_ext.r_value = 0.1456;
door_ext.area = 7.04;
door_ext.description = "door exterior";

struct Detail door_int;
door_int.u_value = 5.5617;
door_int.r_value = 0.1798;
door_int.area = 3.52;
door_int.description = "door interior";

struct Detail window;
window.u_value = 3.6886;
window.r_value = 0.2711;
window.area = 9.48;
window.description = "window";

struct Room living;
living.threshold = 0.5;
living.name = "LivingRoom";
living.details = new LinkedList<Detail>();
living.details->add(0, floor);
living.details->add(1, wall_ext);
living.details->add(2, wall_int);
living.details->add(3, ceiling);
living.details->add(4, door_ext);
living.details->add(5, door_int);
living.details->add(6, window);
living.coord_A = living.coord_B = living.coord_C = living.coord_D =
nullCoord;
living.altitude = 0;
living.value = calcValue(living);
singleBIM->add(living);
}

float calcValue(Room living){
    float result = 0;
    int h = 0;
    while(h < living.details->size()){
        result = result + (living.details->get(h).u_value *
living.details->get(h).area);
        h++;
    }
    return (result);
}

void SetupStruct_2(){
    //default config
    struct Coord nullCoord;
    nullCoord.lat = "";
    nullCoord.lng = "";

    struct Detail floor;
    floor.u_value = 4.981;
    floor.r_value = 0.04;
    floor.area = 34;
    floor.description = "floor";

    struct Detail wall_ext;
    wall_ext.u_value = 4.3333;
    wall_ext.r_value = 0.2308;
    wall_ext.area = 48.4;
    wall_ext.description = "wall exterior";
    struct Detail wall_int;
    wall_int.u_value = 0.2682;
    wall_int.r_value = 3.7292;
    wall_int.area = 27.2;
```

```
wall_int.description = "wall interior";

struct Detail ceiling;
ceiling.u_value = 3.5626;
ceiling.r_value = 0.2827;
ceiling.area = 34;
ceiling.description = "ceiling";

struct Detail door_ext;
door_ext.u_value = 6.8703;
door_ext.r_value = 0.1456;
door_ext.area = 3.52;
door_ext.description = "door exterior";

struct Detail window;
window.u_value = 3.6886;
window.r_value = 0.2711;
window.area = 9.48;
window.description = "window";

struct Room kitchen;
kitchen.threshold = 0.5;
kitchen.name = "Kitchen";
kitchen.details = new LinkedList<Detail>();
kitchen.details->add(0, floor);
kitchen.details->add(1, wall_ext);
kitchen.details->add(2, wall_int);
kitchen.details->add(3, ceiling);
kitchen.details->add(4, door_ext);
kitchen.details->add(5, window);
kitchen.coord_A = kitchen.coord_B = kitchen.coord_C = kitchen.coord_D
= nullCoord;
kitchen.altitude = 0;
kitchen.value = calcValue(kitchen);
singleBIM->add(kitchen);
}

void SetupStruct_3(){
    //default config
    struct Coord nullCoord;
    nullCoord.lat = "";
    nullCoord.lng = "";

    struct Detail floor;
    floor.u_value = 4.981;
    floor.r_value = 0.04;
    floor.area = 28;
    floor.description = "floor";

    struct Detail wall_ext;
    wall_ext.u_value = 4.3333;
    wall_ext.r_value = 0.2308;
    wall_ext.area = 28.3;
    wall_ext.description = "wall exterior";

    struct Detail wall_int;
    wall_int.u_value = 0.2682;
    wall_int.r_value = 3.7292;
    wall_int.area = 57.8;
    wall_int.description = "wall interior";

    struct Detail ceiling;
    ceiling.u_value = 3.5626;
    ceiling.r_value = 0.2827;
    ceiling.area = 28;
    ceiling.description = "ceiling";

    struct Detail door_int;
    door_int.u_value = 3.7021;
    door_int.r_value = 0.2701;
    door_int.area = 18.9;
```




```

door_int.description = "door interior";

struct Detail window;
window.u_value = 3.6886;
window.r_value = 0.2711;
window.area = 9.48;
window.description = "window";

struct Room bedroom;
bedroom.threshold = 0.5;
bedroom.name = "bedroom";
bedroom.details = new LinkedList<Detail>();
bedroom.details->add(0, floor);
bedroom.details->add(1, wall_ext);
bedroom.details->add(2, wall_int);
bedroom.details->add(3, ceiling);
bedroom.details->add(4, door_int);
bedroom.details->add(5, window);
bedroom.coord_A = bedroom.coord_B = bedroom.coord_C = bedroom.coord_D
= nullCoord;
bedroom.altitude = 0;
bedroom.value = calcValue(bedroom);
singleBIM->add(bedroom);
}

void SetupStruct_4(){
    //default config
    struct Coord nullCoord;
    nullCoord.lat = "";
    nullCoord.lng = "";

    struct Detail floor;
    floor.u_value = 4.981;
    floor.r_value = 0.04;
    floor.area = 28;
    floor.description = "floor";

    struct Detail wall_ext;
    wall_ext.u_value = 4.3333;
    wall_ext.r_value = 0.2308;
    wall_ext.area = 28.3;
    wall_ext.description = "wall exterior";

    struct Detail wall_int;
    wall_int.u_value = 0.2682;
    wall_int.r_value = 3.7292;
    wall_int.area = 57.8;
    wall_int.description = "wall interior";

    struct Detail ceiling;
    ceiling.u_value = 3.5626;
    ceiling.r_value = 0.2827;
    ceiling.area = 28;
    ceiling.description = "ceiling";

    struct Detail door_int;
    door_int.u_value = 3.7021;
    door_int.r_value = 0.2701;
    door_int.area = 18.9;
    door_int.description = "door interior";

    struct Detail window;
    window.u_value = 3.6886;
    window.r_value = 0.2711;
    window.area = 9.48;
    window.description = "window";

    struct Room room1;
    room1.threshold = 0.5;
    room1.name = "room1";
    room1.details = new LinkedList<Detail>();

```

```

room1.details->add(0, floor);
room1.details->add(1, wall_ext);
room1.details->add(2, wall_int);
room1.details->add(3, ceiling);
room1.details->add(4, door_int);
room1.details->add(5, window);
room1.coord_A = room1.coord_B = room1.coord_C = room1.coord_D =
nullCoord;
room1.altitude = 0;
room1.value = calcValue(room1);
singleBIM->add(room1);
}

void SetupStruct_5(){
    //default config
    struct Coord nullCoord;
    nullCoord.lat = "";
    nullCoord.lng = "";

    struct Detail floor;
    floor.u_value = 4.981;
    floor.r_value = 0.04;
    floor.area = 12;
    floor.description = "floor";

    struct Detail wall_ext;
    wall_ext.u_value = 4.3333;
    wall_ext.r_value = 0.2308;
    wall_ext.area = 14.3;
    wall_ext.description = "wall exterior";

    struct Detail wall_int;
    wall_int.u_value = 0.2682;
    wall_int.r_value = 3.7292;
    wall_int.area = 38.8;
    wall_int.description = "wall interior";

    struct Detail ceiling;
    ceiling.u_value = 3.5626;
    ceiling.r_value = 0.2827;
    ceiling.area = 12;
    ceiling.description = "ceiling";

    struct Detail door_int;
    door_int.u_value = 3.7021;
    door_int.r_value = 0.2701;
    door_int.area = 18.9;
    door_int.description = "door interior";

    struct Detail window;
    window.u_value = 3.6886;
    window.r_value = 0.2711;
    window.area = 12;
    window.description = "window";

    struct Room room2;
    room2.threshold = 0.5;
    room2.name = "room2";
    room2.details = new LinkedList<Detail>();
    room2.details->add(0, floor);
    room2.details->add(1, wall_ext);
    room2.details->add(2, wall_int);
    room2.details->add(3, ceiling);
    room2.details->add(4, door_int);
    room2.details->add(5, window);
    room2.coord_A = room2.coord_B = room2.coord_C = room2.coord_D =
nullCoord;
    room2.altitude = 0;
    room2.value = calcValue(room2);
    singleBIM->add(room2);
}

```

SYMBIOTIC DATA PLATFORM

usability & sensitivity

```
void SetupStruct_6(){
//default config
struct Coord nullCoord;
nullCoord.lat = "";
nullCoord.lng = "";

struct Detail floor;
floor.u_value = 4.981;
floor.r_value = 0.04;
floor.area = 17;
floor.description = "floor";

struct Detail wall_ext;
wall_ext.u_value = 4.3333;
wall_ext.r_value = 0.2308;
wall_ext.area = 31.4;
wall_ext.description = "wall exterior";

struct Detail wall_int;
wall_int.u_value = 0.2682;
wall_int.r_value = 3.7292;
wall_int.area = 31.4;
wall_int.description = "wall interior";

struct Detail ceiling;
ceiling.u_value = 3.5626;
ceiling.r_value = 0.2827;
ceiling.area = 17;
ceiling.description = "ceiling";

struct Detail door_ext;
door_ext.u_value = 5.5617;
door_ext.r_value = 0.1798;
door_ext.area = 18.9;
door_ext.description = "door exterior";

struct Detail door_int;
door_int.u_value = 3.7021;
door_int.r_value = 0.2701;
door_int.area = 18.9;
door_int.description = "door interior";

struct Room bathroom;
bathroom.threshold = 0.5;
bathroom.name = "bathroom";
bathroom.details = new LinkedList<Detail>();
bathroom.details->add(0, floor);
bathroom.details->add(1, wall_ext);
bathroom.details->add(2, wall_int);
bathroom.details->add(3, ceiling);
bathroom.details->add(4, door_ext);
bathroom.details->add(5, door_int);
bathroom.coord_A = bathroom.coord_B = bathroom.coord_C =
bathroom.coord_D = nullCoord;
bathroom.altitude = 0;
bathroom.value = calcValue(bathroom);
singleBIM->add(bathroom);
}

void SetupStruct_7(){
//default config
struct Coord nullCoord;
nullCoord.lat = "";
nullCoord.lng = "";

struct Detail floor;
floor.u_value = 4.981;
floor.r_value = 0.04;
floor.area = 115.5;
floor.description = "floor";

struct Detail wall_int;
```

```
wall_int.u_value = 0.2682;
wall_int.r_value = 3.7292;
wall_int.area = 109.4;
wall_int.description = "wall interior";

struct Detail ceiling;
ceiling.u_value = 3.5626;
ceiling.r_value = 0.2827;
ceiling.area = 115.5;
ceiling.description = "ceiling";

struct Detail door_ext;
door_ext.u_value = 3.7021;
door_ext.r_value = 0.2701;
door_ext.area = 20;
door_ext.description = "door entrance";

struct Detail door_ext;
door_ext.u_value = 5.5617;
door_ext.r_value = 0.1798;
door_ext.area = 18.9;
door_ext.description = "door exterior";

struct Detail door_int;
door_int.u_value = 3.7021;
door_int.r_value = 0.2701;
door_int.area = 18.9;
door_int.description = "door interior";

struct Room corridor;
corridor.threshold = 0.5;
corridor.name = "corridor";
corridor.details = new LinkedList<Detail>();
corridor.details->add(0, floor);
corridor.details->add(1, wall_int);
corridor.details->add(2, ceiling);
corridor.details->add(3, door_ext);
corridor.details->add(4, door_ext);
corridor.details->add(5, door_int);
corridor.coord_A = corridor.coord_B = corridor.coord_C =
corridor.coord_D = nullCoord;
corridor.altitude = 0;
corridor.value = calcValue(corridor);
singleBIM->add(corridor);
}
```



Prototype V - Transmitter 1

```
/*
  Author: Zeynep
  Date : November 8, 2018

  -Transmitter Code
*/

#define BLYNK_PRINT Serial

#include <ESP8266_Lib.h>
#include <BlynkSimpleShieldEsp8266.h>
#include <SoftwareSerial.h>

#define RX 8
#define TX 9
String longt;
String lati;
SoftwareSerial GSM(RX, TX);
// You should get Auth Token in the Blynk App.
// Go to the Project Settings (nut icon).
char auth[] = "7990df4af669451f9dd4d978bd05581b";

char ssid[] = "Z&X";
char pass[] = "GOODLIFE.35";

#define ESP8266_BAUD 115200

ESP8266 wifi(&Serial);
BlynkTimer timer;

void sendSensor()
{
  if (Serial.available() > 0)
  {
    if (Serial.read() == '1')
    {
      Blynk.virtualWrite(V1, 1);
    }
    if (Serial.read() == '2')
    {
      Blynk.virtualWrite(V2, 3);
    }
    if (Serial.read() == '3')
    {
      Blynk.virtualWrite(V3, 3);
    }
  }
}

void setup()
{
  Serial.begin(115200);
  delay(10);
  GSM.begin(9600);
  Blynk.begin(auth, wifi, ssid, pass);
  timer.setInterval(1000L, sendSensor);
}

void loop()
{
  if (Blynk.connected())
  {
    Blynk.run();
  }
  timer.run();
}
```

Prototype V - Transmitter 2

```
/*
  Author: Zeynep
  Date : November 8, 2018

  - Transmitter Code
*/

/* This is a bare bone library for communicating with SIM800
   It's barebone in that - it only provides basic functions
   while still maintaining strong performance and being memory friendly.
   It currently supports GSM(sending and reading SMS),
   GPRS connectivity(sending and receiving TCP) with Time and
   Location
   This library is writing by Ayo Ayibiowu.
   charlesayibiowu@hotmail.com
   Designed to work with the GSM Sim800l module,
   and possibly other SIMxxx modules(not tested with others)
   This library use AltSoftSerial, and the pins has already be
   defined
   be sure that GND is attached to arduino too.
   The RESET_PIN is not used for this Library, you can leave it un-
   connected
   To Enable Debugging - Go to <BareBoneSim800.h file and change the
   #define DEBUG 0 to #define DEBUG 1

   PINOUT:

   | ARDUINO UNO >>> SIM800L |
   |-----|
   | GND >>> GND |
   | RX 8 >>> TX |
   | TX 9 >>> RX |

   POWER SOURCE 4.2V (MAX) >>> VCC
   Created on: Oct 24, 2017
   Author: Ayo Ayibiowu
   Email: charlesayibiowu@hotmail.com
   Version: v1.0
*/

#include <BareBoneSim800.h>
#include <Wire.h>
#include <Adafruit_MLX90614.h>

BareBoneSim800 sim800("internet"); //to declare the library with an
APN

String location = "";
double athemp;
double othemp;
double trhsld;

Adafruit_MLX90614 mlx = Adafruit_MLX90614();

void setup() {
  Serial.begin(9600);
  sim800.begin();
  while (!Serial);
  delay(8000); // this delay is necessary, it helps the device to be
  ready and connect to a network

  // Serial.println("Should be ready by now");
  // bool deviceAttached = sim800.isAttached();
  // if (deviceAttached)
  //   Serial.println("Device is Attached");
  // else
  //   Serial.println("Not Attached");

  // Testing for Time Reading and Location
```

SYMBIOTIC DATA PLATFORM

symbiosis & sensitivity

```
    delay(100);
    location = sim800.getLocation();
    Serial.println(location);
    sim800.closeHTTP();
    mlx.begin();
}

void loop() {
    athemp = mlx.readAmbientTempC();
    othemp = mlx.readObjectTempC();
    if (athemp <= trhsld && athemp <= trhsld)
    {
        // sicaklik kontrol dongusu: Temperature Control
        // Serial.write(1);
    }

    if (athemp > trhsld && athemp > trhsld)
    {
        // sicaklik kontrol dongusu: Temperature Control
        // Serial.write(2);
    }

    if (location == "coordinates")
    {
        // koordinat kontrol: Coordinates Control
        // Serial.write(3);
    }

    Serial.println(athemp);
    Serial.println(othemp);
    if (mlx.readAmbientTempC())
        if (location )
            sim800.begin();
    delay(8000);
    location = sim800.getLocation();
    Serial.println(location);
    delay(100);
    sim800.closeHTTP();
}
```

Prototype V – Receiver

```
/*
  Author: Zeynep
  Date : November 8, 2018

  -Receiver Code

*/

#include <SPI.h>
#include <SD.h>
#define BLYNK_PRINT Serial
#include <ESP8266_Lib.h>
#include <BlynkSimpleShieldEsp8266.h>
#include <Servo.h>
char auth[] = "7990df4af669451f9dd4d978bd05581b";
double temp;
double atemp;
Servo Vantilator;
Servo Heater;
char ssid[] = "Z&X";
char pass[] = "GOODLIFE.35";
#define EspSerial Serial
#define ESP8266_BAUD 115200

ESP8266 wifi(&EspSerial);
BlynkTimer timer;
String corridor;
double corridor_ther;
String guest;
double guest_ther;
String kitchen;
double kitchen_ther;
String child;
double child_ther;
String saloon;
double saloon_ther;
String dining;
double dining_ther;
String main_co;
double main_co_ther;
String dining2;
double dining2_ther;
String main_co2;
double main_co2_ther;
String terrace;
double terrace_ther;
String terrace2;
double terrace2_ther;
String garden;
double garden_ther;
String entrance;
double entrance_ther;
String bath;
double bath_ther;
String child2;
double child2_ther;
String living;
double living_ther;
String wc;
double wc_ther;
String wc2;
double wc2_ther;
```



```
const int chipSelect = 53;
char ltr;

void setup() {
  Vantilator.attach(3);
  Heater.attach(5);
  Serial.begin(9600);
  while (!Serial) {
    ;
  }

  if (!SD.begin(chipSelect)) {
    Serial.println("Card failed, or not present");
    while (1);
  }
  Serial.println("card initialized.");
  File dataFile = SD.open("datas.txt");

  // if the file is available, write to it:
  if (dataFile) {
    while (dataFile.available()) {
      ltr = dataFile.read();
      corridor += ltr;
      if (ltr == '\n')
      {
        while (dataFile.available()) {
          ltr = dataFile.read();
          guest += ltr;
          if (ltr == '\n')
          {
            while (dataFile.available()) {
              ltr = dataFile.read();
              kitchen += ltr;
              if (ltr == '\n')
              {
                while (dataFile.available()) {
                  ltr = dataFile.read();
                  child += ltr;
                  if (ltr == '\n')
                  {
                    while (dataFile.available()) {
                      ltr = dataFile.read();
                      saloon += ltr;
                      if (ltr == '\n')
                      {
                        while (dataFile.available()) {
                          ltr = dataFile.read();
                          dining += ltr;
                          if (ltr == '\n')
                          {
                            while (dataFile.available()) {
                              ltr = dataFile.read();
                              main_co += ltr;
                              if (ltr == '\n')
                              {
                                while (dataFile.available()) {
                                  ltr = dataFile.read();
                                  dining2 += ltr;
                                  if (ltr == '\n')
                                  {
                                    while (dataFile.available()) {
                                      ltr = dataFile.read();
                                      main_co2 += ltr;
                                      if (ltr == '\n')
                                      {
                                        while (dataFile.available()) {
                                          ltr = dataFile.read();
                                          terrace += ltr;
                                          if (ltr == '\n')
                                          {

```

```
      (dataFile.available()) {
        while (dataFile.available()) {
          dataFile.read();

          (dataFile.available()) {
            dataFile.read();

            (dataFile.available()) {
              dataFile.read();

              (dataFile.available()) {
                dataFile.read();

                '\n')

                (dataFile.available()) {
                  dataFile.read();

                  ltr;

                  == '\n')

                  (dataFile.available()) {
                    dataFile.read();

                    living += ltr;

                    (ltr == '\n')

                    while (dataFile.available()) {
                      ltr = dataFile.read();

                      wc += ltr;

                      if (ltr == '\n')

                      while (dataFile.available()) {
                        ltr = dataFile.read();

                        wc2 += ltr;

                      }

```

```
while
  ltr = dataFile.read();
  terrace2 += ltr;
  if (ltr == '\n')
  {
    while
      ltr =
      garden += ltr;
      if (ltr == '\n')
      {
        while
          ltr =
          entrance += ltr;
          if (ltr == '\n')
          {
            while
              ltr =
              bath += ltr;
              if (ltr ==
              {
                while
                  ltr =
                  child2 +=
                  if (ltr
                  {
                    while
                      ltr =
                      if
                      {
                        while (dataFile.available()) {
                          ltr = dataFile.read();

                          wc += ltr;

                          if (ltr == '\n')

                          while (dataFile.available()) {
                            ltr = dataFile.read();

                            wc2 += ltr;

                          }
                        }
                      }
                    }
                  }
                }
              }
            }
          }
        }
      }
    }
  }
}
```

sensitivity & specificity

```

    delay(1000);
}

void TurnOnVantilator() {
    Heater.write(0);
    for (int angle = 0; angle < 180; angle += 1)
    {
        Vantilator.write(angle);
        delay(15);
    }

    delay(1000);

    for (int angle = 180; angle >= 1; angle -= 1)
    {
        Vantilator.write(angle);
        delay(5);
    }
    delay(1000);
}

BLYNK_WRITE(V1) // V1 is the number of Virtual Pin
{
    if ( double pinValue = param.asInt() == '1' )
    {
        TurnOnHeater();
    }
}

BLYNK_WRITE(V2) // V2 is the number of Virtual Pin
{
    if ( double pinValue = param.asInt() == '2' )
    {
        TurnOnVantilator();
    }
}

BLYNK_WRITE(V3) // V3 is the number of Virtual Pin
{
    if ( double pinValue = param.asInt() == '3' )
    {
        TurnOnHeater();
    }
}

void loop() {
    Blynk.run();
}

```



Prototype VI - Transmitter

```
/*
  Author: Zeynep
  Date : January 15, 2019

  -Transmitter Code
*/

#define BLYNK_PRINT Serial
#include <ESP8266WiFi.h>
#include <BlynkSimpleEsp8266.h>
#include <Wire.h>
#include <Adafruit_MLX90614.h>

#define ESP8266_BAUD 115200

char auth[] = "7990df4af669451f9dd4d978bd05581b";
char ssid[] = "Z&X";
char pass[] = "GOODLIFE.35";

double athemp;
double othemp;
double trhsld;
unsigned long t;
Adafruit_MLX90614 mlx = Adafruit_MLX90614();

void setup() {
  Serial.begin(115200);
  delay(10);
  Blynk.begin(auth, ssid, pass);
  mlx.begin();
}

void loop() {
  Blynk.run();
  if (millis() - t > 10000) {
    athemp = mlx.readAmbientTempC();
    othemp = mlx.readObjectTempC();
    sendData();
    t = millis();
  }
}

void sendData() {
  Blynk.virtualWrite(V0, athemp);
  Blynk.virtualWrite(V1, othemp);
  Serial.println("Ambient temp: "+String(athemp)+" Object temp: "+String(othemp));
}
```

Prototype VI - Receiver

```
/*
  Author: Zeynep
  Date : January 15, 2019

  -Receiver Code
*/

#include <SPI.h>
#include <SD.h>
#define BLYNK_PRINT Serial
#include <ESP8266_Lib.h>
#include <BlynkSimpleShieldEsp8266.h>
#include <Servo.h>
char auth[] = "7990df4af669451f9dd4d978bd05581b";
double temp;
double atemp;
Servo Ventilator;
Servo Heater;
char ssid[] = "Z&X";
char pass[] = "GOODLIFE.35";
#define EspSerial Serial3
#define ESP8266_BAUD 115200

ESP8266 wifi(&EspSerial);
BlynkTimer timer;
String corridor;
double corridor_ther;
String guest;
double guest_ther;
String kitchen;
double kitchen_ther;
String child;
double child_ther;
String saloon;
double saloon_ther;
String dining;
double dining_ther;
String main_co;
double main_co_ther;
String dining2;
double dining2_ther;
String main_co2;
double main_co2_ther;
String terrace;
double terrace_ther;
String terrace2;
double terrace2_ther;
String garden;
double garden_ther;
String entrance;
double entrance_ther;
String bath;
double bath_ther;
String child2;
double child2_ther;
String living;
double living_ther;
String wc;
double wc_ther;
String wc2;
double wc2_ther;
const int chipSelect = 53;
char ltr;
int r[18];
int room[18] = {V2, V3, V4, V5, V6, V7, V8, V9, V10, V11, V12, V13, V14, V15, V16, V17, V18, V19};
double data[18];
float temp_A, temp_0;
unsigned long timerX;
float threshold;
String device;
```


sensitivity & specificity

```
(dataFile.available()) {
    dataFile.read();

    (dataFile.available()) {
        dataFile.read();

        '\n')

        (dataFile.available()) {
            dataFile.read();
            += ltr;
            == '\n')

            (dataFile.available()) {
                = dataFile.read();
                living += ltr;
                (ltr == '\n')

                while (dataFile.available()) {
                    ltr = dataFile.read();
                    wc += ltr;

                    if (ltr == '\n')
                    {
                        while (dataFile.available()) {
                            ltr = dataFile.read();
                            wc2 += ltr;
                        }
                    }
                }
            }
        }
    }
}
```

```
ltr =  
garden += ltr;  
if (ltr == '\n')  
{  
    while  
  
        ltr =  
  
entrance += ltr;  
if (ltr == '\n')  
{  
    while  
  
        ltr =  
  
bath += ltr;  
if (ltr ==  
  
    {  
        while  
  
            ltr =  
  
child2  
  
if (ltr  
  
    {  
        while  
  
            ltr  
  
  
                if  
  
                    {
```



```

    }
    delay(1000);
    for (int angle = 180; angle >= 1; angle -= 1)
    {
        Ventilator.write(angle);
        delay(5);
    }
    delay(1000);
}

void check1() {
    Blynk.syncVirtual(V0);
    Blynk.syncVirtual(V1);
}

BLYNK_WRITE(V0)
{
    temp_A = param.asFloat();
}

BLYNK_WRITE(V1)
{
    temp_0 = param.asFloat();
}

BLYNK_WRITE(V2)
{
    Serial.println("Corridor");
    r[0] = param.asInt();
    for (int i = 1; i < 18; i++) {
        Blynk.virtualWrite(room[i], 0);
        r[i] = 0;
    }
    if (r[0] == 1)
        threshold = corridor_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V3)
{
    r[1] = param.asInt();
    for (int i = 0; i < 18; i++) {
        if (i != 1) {
            Blynk.virtualWrite(room[i], 0);
            r[i] = 0;
        }
    }
    if (r[1] == 1)
        threshold = guest_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V4)
{
    r[2] = param.asInt();
    for (int i = 0; i < 18; i++) {
        if (i != 2) {
            Blynk.virtualWrite(room[i], 0);
            r[i] = 0;
        }
    }
    if (r[2] == 1)
        threshold = kitchen_ther;
    else
        threshold = 0;
}

```

SYMBIOTIC DATA PLATFORM

symbiote & symbiosis

```
BLYNK_WRITE(V5)
{
  r[3] = param.asInt();
  for (int i = 0 ; i < 18 ; i++) {
    if (i != 3) {
      Blynk.virtualWrite(room[i] , 0);
      r[i] = 0;
    }
  }
  if (r[3] == 1)
    threshold = child_ther;
  else
    threshold = 0;
}

BLYNK_WRITE(V6)
{
  r[4] = param.asInt();
  for (int i = 0 ; i < 18 ; i++) {
    if (i != 4) {
      Blynk.virtualWrite(room[i] , 0);
      r[i] = 0;
    }
  }
}

BLYNK_WRITE(V7)
{
  r[5] = param.asInt();
  for (int i = 0 ; i < 18 ; i++) {
    if (i != 5) {
      Blynk.virtualWrite(room[i] , 0);
      r[i] = 0;
    }
  }
  if (r[5] == 1)
    threshold = dining_ther;
  else
    threshold = 0;
}

BLYNK_WRITE(V8)
{
  r[6] = param.asInt();
  for (int i = 0 ; i < 18 ; i++) {
    if (i != 6) {
      Blynk.virtualWrite(room[i] , 0);
      r[i] = 0;
    }
  }
  if (r[6] == 1)
    threshold = main_co_ther;
  else
    threshold = 0;
}

BLYNK_WRITE(V9)
{
  r[7] = param.asInt();
  for (int i = 0 ; i < 18 ; i++) {
    if (i != 7) {
      Blynk.virtualWrite(room[i] , 0);
      r[i] = 0;
    }
  }
  if (r[7] == 1)
    threshold = dining2_ther;
  else
    threshold = 0;
}
```

```
BLYNK_WRITE(V10)
{
  r[8] = param.asInt();
  for (int i = 0 ; i < 18 ; i++) {
    if (i != 8) {
      Blynk.virtualWrite(room[i] , 0);
      r[i] = 0;
    }
  }
  if (r[8] == 1)
    threshold = main_co2_ther;
  else
    threshold = 0;
}

BLYNK_WRITE(V11)
{
  r[9] = param.asInt();
  for (int i = 0 ; i < 18 ; i++) {
    if (i != 9) {
      Blynk.virtualWrite(room[i] , 0);
      r[i] = 0;
    }
  }
  if (r[9] == 1)
    threshold = terrace_ther;
  else
    threshold = 0;

  terrace2_ther = 250.5027192;
  garden_ther = 28.85389628;
  entrance_ther = 52.94717842;
  bath_ther = 696.7140531;
  child2_ther = 59.81022136;
  living_ther = 580.4025029;
  wc_ther = 501.290129;
  wc2_ther = 509.603821;
}

BLYNK_WRITE(V12)
{
  r[10] = param.asInt();
  for (int i = 0 ; i < 18 ; i++) {
    if (i != 10) {
      Blynk.virtualWrite(room[i] , 0);
      r[i] = 0;
    }
  }
  if (r[10] == 1)
    threshold = terrace2_ther;
  else
    threshold = 0;

  garden_ther = 28.85389628;
  entrance_ther = 52.94717842;
  bath_ther = 696.7140531;
  child2_ther = 59.81022136;
  living_ther = 580.4025029;
  wc_ther = 501.290129;
  wc2_ther = 509.603821;
}

BLYNK_WRITE(V13)
{
  r[11] = param.asInt();
  for (int i = 0 ; i < 18 ; i++) {
    if (i != 11) {
      Blynk.virtualWrite(room[i] , 0);
      r[i] = 0;
    }
  }
}
```



```

    if (r[11] == 1)
        threshold = garden_ther;
    else
        threshold = 0;

    entrance_ther = 52.94717842;
    bath_ther = 696.7140531;
    child2_ther = 59.81022136;
    living_ther = 580.4025029;
    wc_ther = 501.290129;
    wc2_ther = 509.603821;
}

BLYNK_WRITE(V14)
{
    r[12] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 12) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }

    if (r[12] == 1)
        threshold = entrance_ther;
    else
        threshold = 0;

    bath_ther = 696.7140531;
    child2_ther = 59.81022136;
    living_ther = 580.4025029;
    wc_ther = 501.290129;
    wc2_ther = 509.603821;
}

BLYNK_WRITE(V15)
{
    r[13] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 13) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }
    if (r[13] == 1)
        threshold = bath_ther;
    else
        threshold = 0;

    child2_ther = 59.81022136;
    living_ther = 580.4025029;
    wc_ther = 501.290129;
    wc2_ther = 509.603821;
}

BLYNK_WRITE(V16)
{
    r[14] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 14) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }
    if (r[14] == 1)
        threshold = child2_ther;
    else
        threshold = 0;

    living_ther = 580.4025029;
    wc_ther = 501.290129;
    wc2_ther = 509.603821;
}

}

BLYNK_WRITE(V17)
{
    r[15] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 15) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }
    if (r[15] == 1)
        threshold = living_ther;
    else
        threshold = 0;

    wc_ther = 501.290129;
    wc2_ther = 509.603821;
}

BLYNK_WRITE(V18)
{
    r[16] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 16) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }

    if (r[16] == 1)
        threshold = wc_ther ;
    else
        threshold = 0;

    wc2_ther = 509.603821;
}

BLYNK_WRITE(V19)
{
    r[17] = param.asInt();
    for (int i = 0 ; i < 17 ; i++) {
        Blynk.virtualWrite(room[i] , 0);
        r[i] = 0;
    }
    if (r[17] == 1)
        threshold = wc2_ther ;
    else
        threshold = 0;
}

void loop() {
    if (millis() - timerX > 3000) {
        check1();
        Serial.println("Temp1: " + String(temp_A) + " temp_0: " +
String(temp_0) + " Room Thermal Value: " + String(threshold) + " Device
Status: " + device);
        timerX = millis();
    }
    if (temp_A > 27 && temp_0 > 27) {
        TurnOnVantilator();
        device = "Vantilator";
    }
    else if (temp_A < 25 && temp_0 < 25) {
        TurnOnHeater();
        device = "Heater";
    }
    else {
        device = "Off";
    }
    Blynk.run();
}

```

SYMBIOTIC DATA PLATFORM

symbiosis & sensitivity

Final Prototype //

Prototype VII - Transmitter

```
/*
  Author: Zeynep
  Date : August 29, 2019

  -Transmitter Code
*/

#define BLYNK_PRINT Serial
#include <ESP8266WiFi.h>
#include <BlynkSimpleEsp8266.h>
#include <Wire.h>
#include <Adafruit_MLX90614.h>
#include <ArduinoJson.h>
#include <WiFiClient.h>

#define ESP8266_BAUD 115200

char auth[] = "7990df4af669451f9dd4d978bd05581b";
char ssid[] = "Z&X";
char pass[] = "GOODLIFE.35";

const char server[] = "api.openweathermap.org";
String nameOfCity = "Barcelona,ES";
String apiKey = "a4487f8f9f8fcb2deaab5883d527f7ec";

String text;
int jsonend = 0;
boolean startJson = false;
int status = WL_IDLE_STATUS;
unsigned long lastConnectionTime = 10 * 60 * 1000;
const unsigned long postInterval = 10 * 60 * 1000;

double athemp;
double othemp;
double trhsld;
unsigned long t;
float temperature0;

WiFiClient client;
Adafruit_MLX90614 mlx = Adafruit_MLX90614();

void setup() {
  Serial.begin(115200);
  delay(10);
  Blynk.begin(auth, ssid, pass);
  mlx.begin();
  text.reserve(2500);
  WiFi.begin(ssid, pass);
  Serial.println("connecting");
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("WiFi Connected");
}

void loop() {
  Blynk.run();
  if (millis() - t > 1000) {
    athemp = mlx.readAmbientTempC();
    othemp = mlx.readObjectTempC();

    sendData();
    t = millis();
  }
}
```

```
}
if (millis() - lastConnectionTime > postInterval) {
  lastConnectionTime = millis();
  makeHttpRequest();
}
}

void sendData() {
  Blynk.virtualWrite(V1, othemp);
  Blynk.virtualWrite(V0, athemp);
  Blynk.virtualWrite(V20, temperature0);

  Serial.println("Ambient: "+String(athemp)+" Object: "+String(othemp)+" Temp: "+String(temperature0));
}

// to request data from OWM
void makeHttpRequest() {
  client.stop();
  if (client.connect(server, 80)) {
    client.println("GET /data/2.5/forecast?q=" + nameOfCity + "&APPID="
+ apiKey + "&mode=json&units=metric&cnt=2 HTTP/1.1");
    client.println("Host: api.openweathermap.org");
    client.println("User-Agent: ArduinoWiFi/1.1");
    client.println("Connection: close");
    client.println();

    unsigned long timeout = millis();
    while (client.available() == 0) {
      if (millis() - timeout > 5000) {
        Serial.println(">>> Client Timeout !");
        client.stop();
        return;
      }
    }

    char c = 0;
    while (client.available()) {
      c = client.read();
      if (c == '{') {
        startJson = true;          // set startJson true to indicate
        json message has started
        jsonend++;
      }
      if (c == '}') {
        jsonend--;
      }
      if (startJson == true) {
        text += c;
      }
      // if jsonend = 0 then we have have received equal number of
      curly braces
      if (jsonend == 0 && startJson == true) {
        parseJson(text.c_str()); // parse c string text in parseJson
        function
        text = "";              // clear text string for the next
        time
        startJson = false;      // set startJson to false to indicate
        that a new message has not yet started
      }
    }
  }
  else {
    Serial.println("connection failed");
    return;
  }
}

void parseJson(const char * jsonString) {
  //StaticJsonBuffer<4000> jsonBuffer;
  const size_t bufferSize = 2 * JSON_ARRAY_SIZE(1) + JSON_ARRAY_SIZE(2)
+ 4 * JSON_OBJECT_SIZE(1) + 3 * JSON_OBJECT_SIZE(2) + 3 *
JSON_OBJECT_SIZE(4) + JSON_OBJECT_SIZE(5) + 2 * JSON_OBJECT_SIZE(7) + 2
* JSON_OBJECT_SIZE(8) + 720;
  DynamicJsonBuffer jsonBuffer(bufferSize);
}
```



```
// FIND FIELDS IN JSON TREE
JsonObject& root = jsonBuffer.parseObject(jsonString);
if (!root.success()) {
  Serial.println("parseObject() failed");
  return;
}
JSONArray& list = root["list"];
JsonObject& nowT = list[0];
JsonObject& later = list[1];

String city = root["city"]["name"];
temperature0 = nowT["main"]["temp"];

}
```

Final Prototype //

Prototype VII - Receiver

```
/*
  Author: Zeynep
  Date : August 30, 2019

  -Receiver Code

  */

#include <SPI.h>
#include <SD.h>
#define BLYNK_PRINT Serial
#include <ESP8266_Lib.h>
#include <BlynkSimpleShieldEsp8266.h>
#include <Servo.h>
char auth[] = "7990df4af669451f9dd4d978bd05581b";
double temp;
double atemp;
Servo Ventilator;
Servo Heater;
char ssid[] = "Z&X";
char pass[] = "GOODLIFE.35";
#define EspSerial Serial3
#define ESP8266_BAUD 115200

#define Value_V 25
#define Value_H 20
#define Time1 15
#define Time2 7
#define Time3 3

ESP8266 wifi(&EspSerial);
BlynkTimer timer;
String corridor;
double corridor_ther;
String guest;
double guest_ther;
String kitchen;
double kitchen_ther;
String child;
double child_ther;
String saloon;
double saloon_ther;
String dining;
double dining_ther;
String main_co;
double main_co_ther;
String dining2;
double dining2_ther;
String main_co2;
double main_co2_ther;
String terrace;
double terrace_ther;
String terrace2;
double terrace2_ther;
String garden;
double garden_ther;
String entrance;
double entrance_ther;
String bath;
double bath_ther;
String child2;
double child2_ther;
String living;
double living_ther;
String wc;
```

SYMBIOTIC DATA PLATFORM

symbiosis & sensitivity

```
double wc_ther;
String wc2;
double wc2_ther;
const int chipSelect = 53;
char ltr;
int r[18];
int room[18] = {V2 , V3 , V4 , V5 , V6 , V7 , V8 , V9 , V10 , V11 ,
V12 , V13 , V14 , V15 , V16 , V17 , V18 , V19};
double data[18];
float temp_A , temp_0 , temperature0;
unsigned long timerX;
float threshold;
String device = "Off";
int start = 0;
unsigned long timer1;

void setup() {
  Ventilator.attach(3);
  Heater.attach(5);
  Serial.begin(9600);

  EspSerial.begin(ESP8266_BAUD);
  delay(10);
  Blynk.begin(auth, wifi, ssid, pass);
  Serial.println("Start");
  corridor_ther = 56.27938296;
  guest_ther = 735.7690305;
  kitchen_ther = 77.63025761;
  child_ther = 438.6802486;
  saloon_ther = 28.85389628;
  dining_ther = 481.9206086;
  main_co_ther = 661.8689535;
  dining2_ther = 93.70281082;
  main_co2_ther = 661.8689535;
  terrace_ther = 272.79737;
  terrace2_ther = 250.5027192;
  garden_ther = 28.85389628;
  entrance_ther = 52.94717842;
  bath_ther = 696.7140531;
  child2_ther = 59.81022136;
  living_ther = 580.4025029;
  wc_ther = 501.290129;
  wc2_ther = 509.603821;
  Blynk.syncVirtual(V0);
  Blynk.syncVirtual(V1);
  Blynk.syncVirtual(V20);
}

void TurnOnHeater() {
  Ventilator.write(0);
  for (int angle = 0; angle < 180; angle += 1)
  {
    Heater.write(angle);
    delay(15);
  }
  delay(1000);

  for (int angle = 180; angle >= 1; angle -= 1)
  {
    Heater.write(angle);
    delay(5);
  }
  delay(1000);
}

void TurnOnVentilator() {
  Heater.write(0);
  for (int angle = 0; angle < 180; angle += 1)
  {
    Ventilator.write(angle);
    delay(15);
  }

  delay(1000);

  for (int angle = 180; angle >= 1; angle -= 1)
  {
    Ventilator.write(angle);
    delay(5);
  }
  delay(1000);
}

void check1() {
  Blynk.syncVirtual(V0);
  Blynk.syncVirtual(V1);
  Blynk.syncVirtual(V20);
}

BLYNK_WRITE(V0)
{
  temp_A = param.asFloat();
}

BLYNK_WRITE(V1)
{
  temp_0 = param.asFloat();
}

BLYNK_WRITE(V20)
{
  temperature0 = param.asFloat();
}

BLYNK_WRITE(V2)
{
  Serial.println("Corridor");
  timer1 = millis();
  r[0] = param.asInt();
  for (int i = 0 ; i < 18 ; i++) {
    if (i != 0) {
      Blynk.virtualWrite(room[i] , 0);
      r[i] = 0;
    }
  }
  if (r[0] == 1)
    threshold = corridor_ther;
  else
    threshold = 0;
}

BLYNK_WRITE(V3)
{
  Serial.println("Guest Room");
  timer1 = millis();
  r[1] = param.asInt();
  for (int i = 0 ; i < 18 ; i++) {
    if (i != 1) {
      Blynk.virtualWrite(room[i] , 0);
      r[i] = 0;
    }
  }
  if (r[1] == 1)
    threshold = guest_ther;
  else
    threshold = 0;
}

BLYNK_WRITE(V4)
{
  Serial.println("Kitchen");
  timer1 = millis();
  r[2] = param.asInt();
  for (int i = 0 ; i < 18 ; i++) {
```




```

    if (i != 2) {
        Blynk.virtualWrite(room[i] , 0);
        r[i] = 0;
    }
}

if (r[2] == 1)
    threshold = kitchen_ther;
else
    threshold = 0;
}

BLYNK_WRITE(V5)
{
    Serial.println("Child Room");
    timer1 = millis();
    r[3] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 3) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }
    if (r[3] == 1)
        threshold = child_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V6)
{
    Serial.println("Saloon");
    timer1 = millis();
    r[4] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 4) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }
    if (r[4] == 1)
        threshold = saloon_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V7)
{
    Serial.println("Dining");
    timer1 = millis();
    r[5] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 5) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }
    if (r[5] == 1)
        threshold = dining_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V8)
{
    Serial.println("Main CO");
    timer1 = millis();
    r[6] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 6) {
            Blynk.virtualWrite(room[i] , 0);

```

```

        r[i] = 0;
    }
}

if (r[6] == 1)
    threshold = main_co_ther;
else
    threshold = 0;
}

BLYNK_WRITE(V9)
{
    Serial.println("Dining 2");
    timer1 = millis();
    r[7] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 7) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }
    if (r[7] == 1)
        threshold = dining2_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V10)
{
    Serial.println("Main CO2");
    timer1 = millis();
    r[8] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 8) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }
    if (r[8] == 1)
        threshold = main_co2_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V11)
{
    Serial.println("Terrace");
    timer1 = millis();
    r[9] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 9) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }
    if (r[9] == 1)
        threshold = terrace_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V12)
{
    Serial.println("Terrace 2");
    timer1 = millis();
    r[10] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 10) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }
}

```

SYMBIOTIC DATA PLATFORM

symbiote & symbiosis

```
    if (r[10] == 1)
        threshold = terrace2_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V13)
{
    Serial.println("Garden");
    timer1 = millis();
    r[11] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 11) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }

    if (r[11] == 1)
        threshold = garden_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V14)
{
    Serial.println("Entrance");
    timer1 = millis();
    r[12] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 12) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }

    if (r[12] == 1)
        threshold = entrance_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V15)
{
    Serial.println("Bath Room");
    timer1 = millis();
    r[13] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 13) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }

    if (r[13] == 1)
        threshold = bath_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V16)
{
    Serial.println("Child 2");
    timer1 = millis();
    r[14] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 14) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }

    if (r[14] == 1)
        threshold = child2_ther;
```

```
    else
        threshold = 0;
}

BLYNK_WRITE(V17)
{
    Serial.println("Living Room");
    timer1 = millis();
    r[15] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 15) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }

    if (r[15] == 1)
        threshold = living_ther;
    else
        threshold = 0;
}

BLYNK_WRITE(V18)
{
    Serial.println("WC");
    timer1 = millis();
    r[16] = param.asInt();
    for (int i = 0 ; i < 18 ; i++) {
        if (i != 16) {
            Blynk.virtualWrite(room[i] , 0);
            r[i] = 0;
        }
    }

    if (r[16] == 1)
        threshold = wc_ther ;
    else
        threshold = 0;
}

BLYNK_WRITE(V19)
{
    Serial.println("WC 2");
    timer1 = millis();
    r[17] = param.asInt();
    for (int i = 0 ; i < 17 ; i++) {
        Blynk.virtualWrite(room[i] , 0);
        r[i] = 0;
    }

    if (r[17] == 1)
        threshold = wc2_ther ;
    else
        threshold = 0;
}

void loop() {

    int average = (temp_A + temp_0 + temperature0 ) / 3;

    if (threshold > 0) {

        if (average > Value_H && average < Value_V) {
            device = "Off";
            start = 0;
        }
        else if ( average > Value_V && (start == 0 || start == 2)) {
            timer1 = millis();
            start = 1;
        }
        else if ( average < Value_H && (start == 0 || start == 1)) {
            timer1 = millis();
            start = 2;
        }
    }
}
```

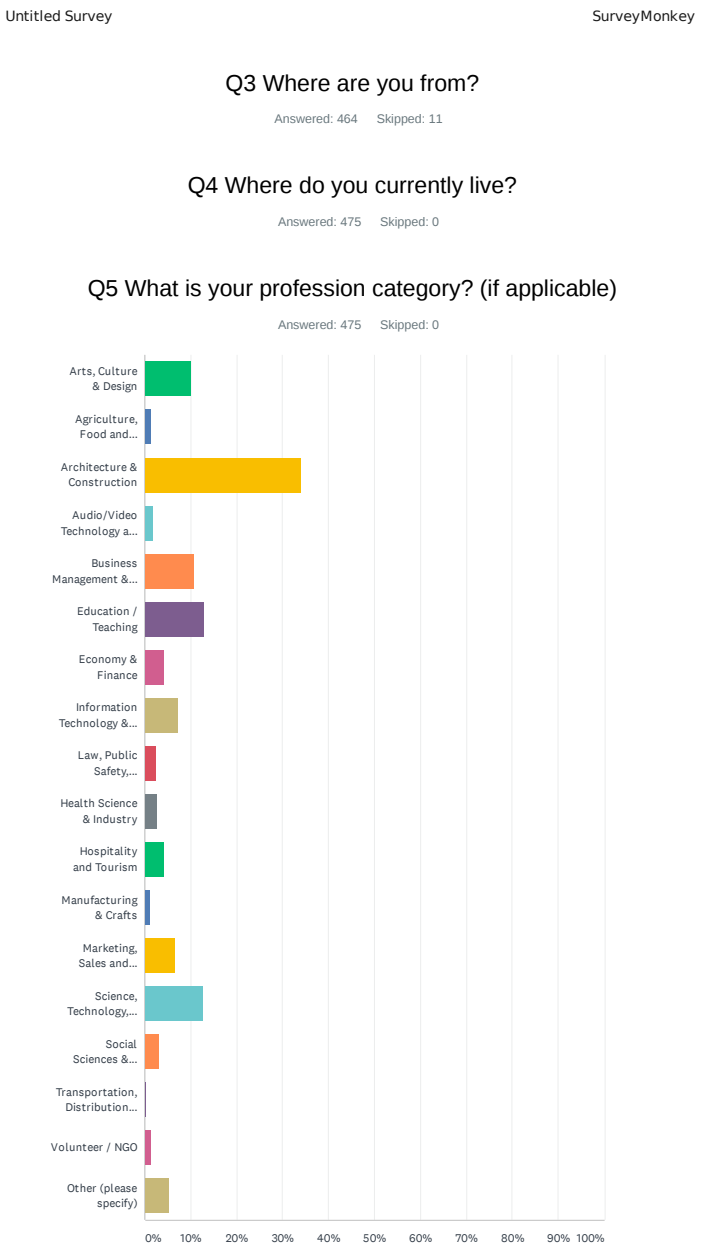
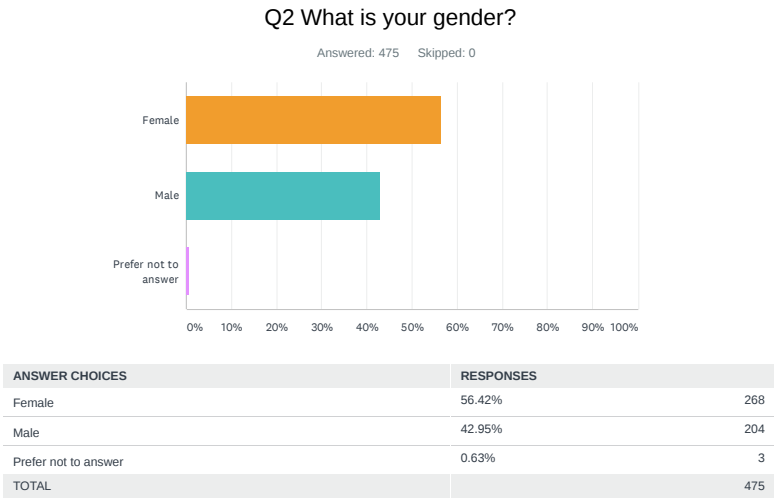
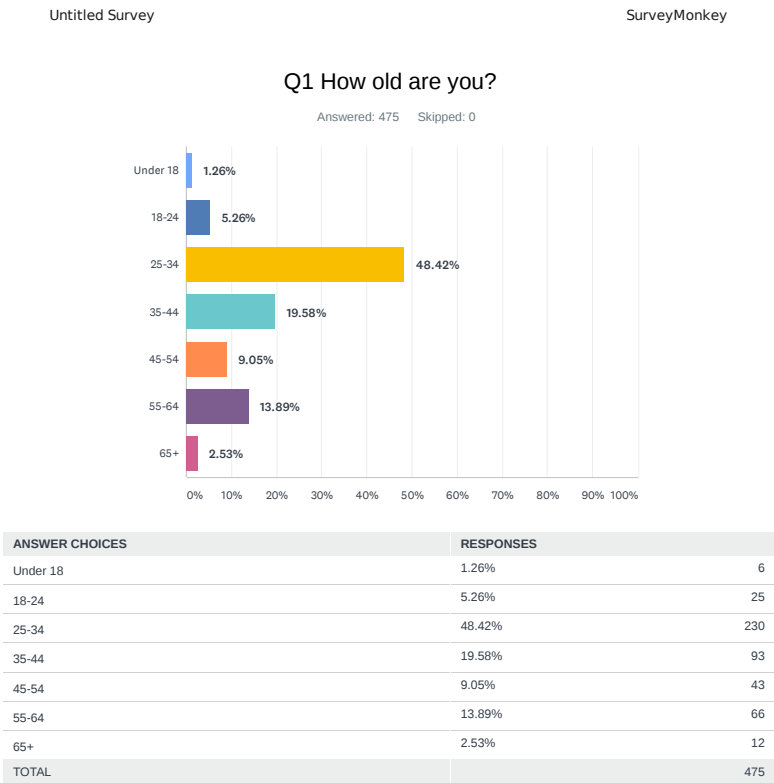


```
    else if (start == 1 && threshold < 350 && millis() - timer1 < Time1
* 60 * 1000) {
    TurnOnVantilator();
    Serial.print(" Duration: " + String( millis() - timer1));
    device = "Vantilator";
    }
    else if (start == 1 && threshold < 500 && millis() - timer1 < Time2
* 60 * 1000) {
    TurnOnVantilator();
    Serial.print(" Duration: " + String( millis() - timer1));
    device = "Vantilator";
    }
    else if (start == 1 && threshold > 500 && millis() - timer1 < Time3
* 60 * 1000) {
    TurnOnVantilator();
    Serial.print(" Duration: " + String( millis() - timer1));
    device = "Vantilator";
    }
    else if (start == 2 && threshold < 350 && millis() - timer1 < Time1
* 60 * 1000) {
    TurnOnHeater();
    Serial.print(" Duration: " + String( millis() - timer1));
    device = "Heater";
    }
    else if (start == 2 && threshold < 500 && millis() - timer1 < Time2
* 60 * 1000) {
    TurnOnHeater();
    Serial.print(" Duration: " + String( millis() - timer1));
    device = "Heater";
    }
    else if (start == 2 && threshold > 500 && millis() - timer1 < Time3
* 60 * 1000) {
    TurnOnHeater();
    Serial.print(" Duration: " + String( millis() - timer1));
    device = "Heater";
    }
    else if (start == 1 && threshold < 350 && millis() - timer1 > Time1
* 60 * 1000) {
    start = 0;
    device = "Off";
    }
    else if (start == 1 && threshold < 500 && millis() - timer1 > Time2
* 60 * 1000) {
    start = 0;
    device = "Off";
    }
    else if (start == 1 && threshold > 500 && millis() - timer1 > Time3
* 60 * 1000) {
    start = 0;
    device = "Off";
    }
    else if (start == 2 && threshold < 350 && millis() - timer1 > Time1
* 60 * 1000) {
    start = 0;
    device = "Off";
    }
    else if (start == 2 && threshold < 500 && millis() - timer1 > Time2
* 60 * 1000) {
    start = 0;
    device = "Off";
    }
    else if (start == 2 && threshold > 500 && millis() - timer1 > Time3
* 60 * 1000) {
    start = 0;
    device = "Off";
    }
    }
    if (millis() - timerX > 3000) {
    check1();
    Serial.println(" Temp1: " + String(temp_A) + " temp_0: " +
String(temp_0) + " Outdoor Temp: " + String(temperature0) + " Average:
    " + String(average) + " Room Thermal Value: " + String(threshold) + "
Device Status: " + device);
    timerX = millis();
    Blynk.run();
    }
}
```

SYMBIOTIC DATA PLATFORM

usability & sensitivity

Survey Data

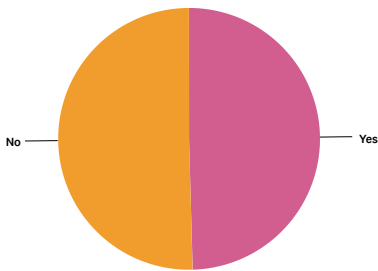




Untitled Survey		SurveyMonkey	
ANSWER CHOICES		RESPONSES	
Arts, Culture & Design		10.11%	48
Agriculture, Food and Natural Resources		1.47%	7
Architecture & Construction		34.11%	162
Audio/Video Technology and Communications		1.89%	9
Business Management & Administration		10.95%	52
Education / Teaching		13.05%	62
Economy & Finance		4.21%	20
Information Technology & Engineering		7.37%	35
Law, Public Safety, Corrections and Security		2.53%	12
Health Science & Industry		2.74%	13
Hospitality and Tourism		4.21%	20
Manufacturing & Crafts		1.26%	6
Marketing, Sales and Service		6.74%	32
Science, Technology, Engineering and Mathematics		12.84%	61
Social Sciences & Humanities		3.16%	15
Transportation, Distribution and Logistics		0.42%	2
Volunteer / NGO		1.47%	7
Other (please specify)		5.26%	25
Total Respondents: 475			

Q6 Have you heard of 'Building Information Modeling'?

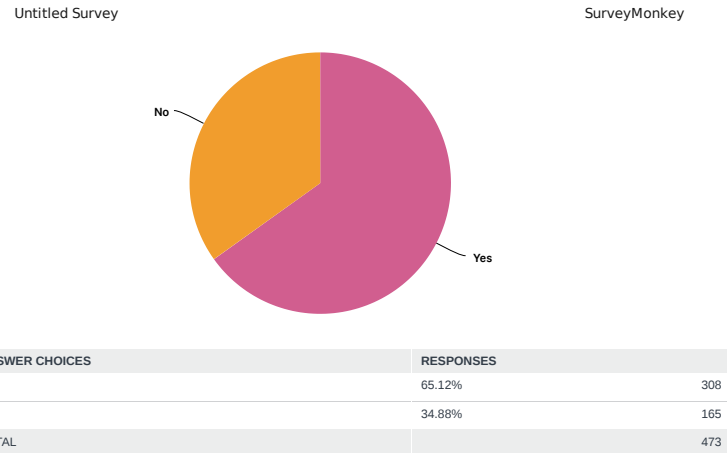
Answered: 470 Skipped: 5



ANSWER CHOICES	RESPONSES	
Yes	49.57%	233
No	50.43%	237
TOTAL	470	

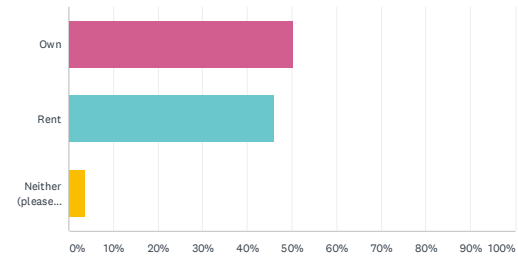
Q7 Have you heard of 'Internet of Things'?

Answered: 473 Skipped: 2



Q8 Do you rent or own the place where you live?

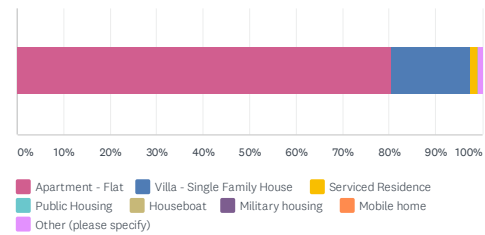
Answered: 463 Skipped: 12



ANSWER CHOICES	RESPONSES	
Own	50.32%	233
Rent	46.00%	213
Neither (please specify)	3.67%	17
TOTAL	463	

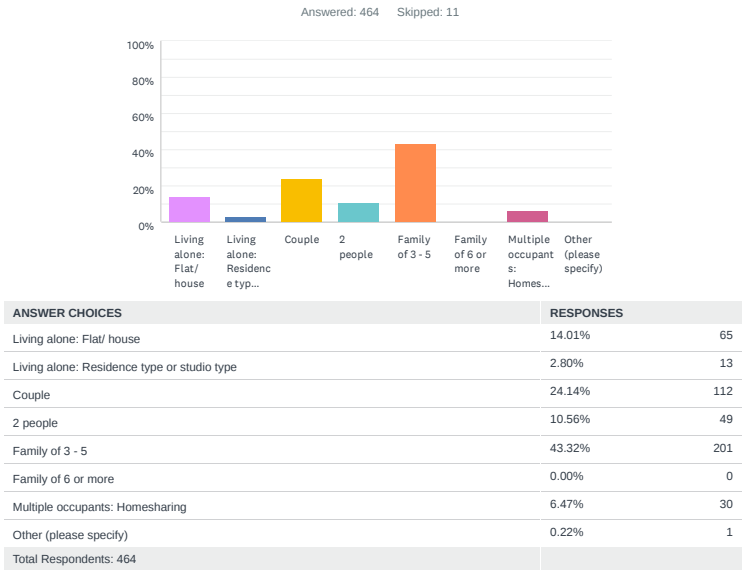
Q9 In which type of housing do you currently live?

Answered: 464 Skipped: 11



Untitled Survey		SurveyMonkey
ANSWER CHOICES	RESPONSES	
Apartment - Flat	80.60%	374
Villa - Single Family House	16.81%	78
Serviced Residence	1.51%	7
Public Housing	0.00%	0
Houseboat	0.22%	1
Military housing	0.00%	0
Mobile home	0.00%	0
Other (please specify)	0.86%	4
TOTAL	464	

Q10 In what type of household do you live?

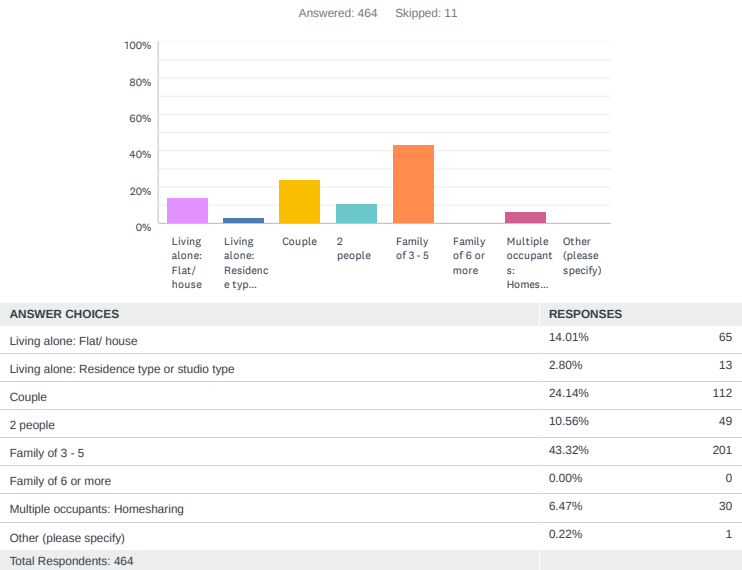


Q11 Are there minors, people with special attention or elderly people in your household? If 'Yes', please specify.

Answered: 464 Skipped: 11

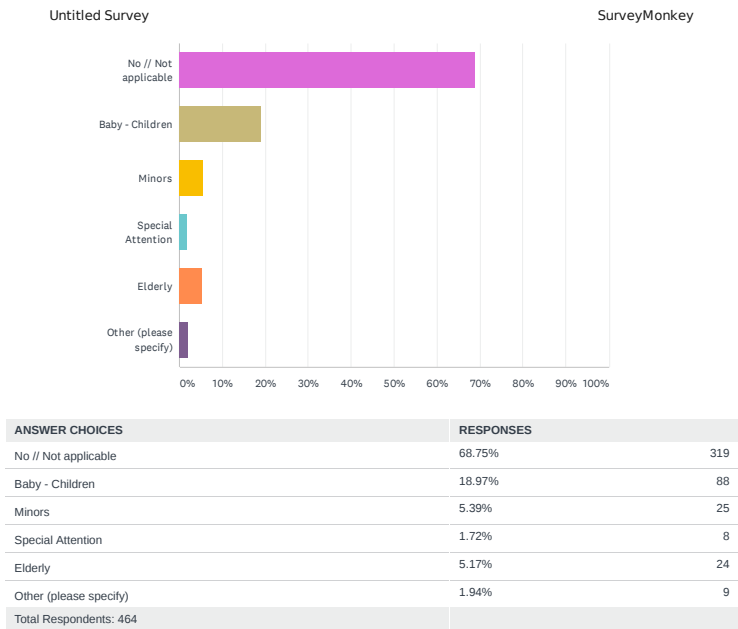
Untitled Survey		SurveyMonkey
ANSWER CHOICES	RESPONSES	
Apartment - Flat	80.60%	374
Villa - Single Family House	16.81%	78
Serviced Residence	1.51%	7
Public Housing	0.00%	0
Houseboat	0.22%	1
Military housing	0.00%	0
Mobile home	0.00%	0
Other (please specify)	0.86%	4
TOTAL	464	

Q10 In what type of household do you live?

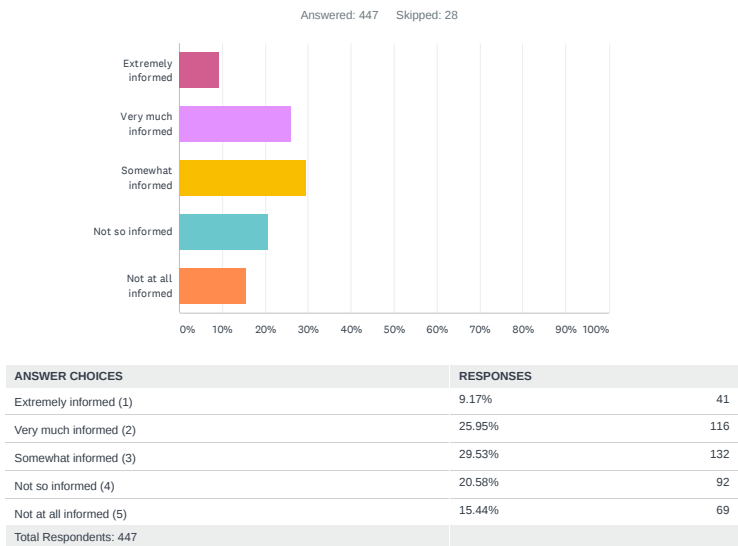


Q11 Are there minors, people with special attention or elderly people in your household? If 'Yes', please specify.

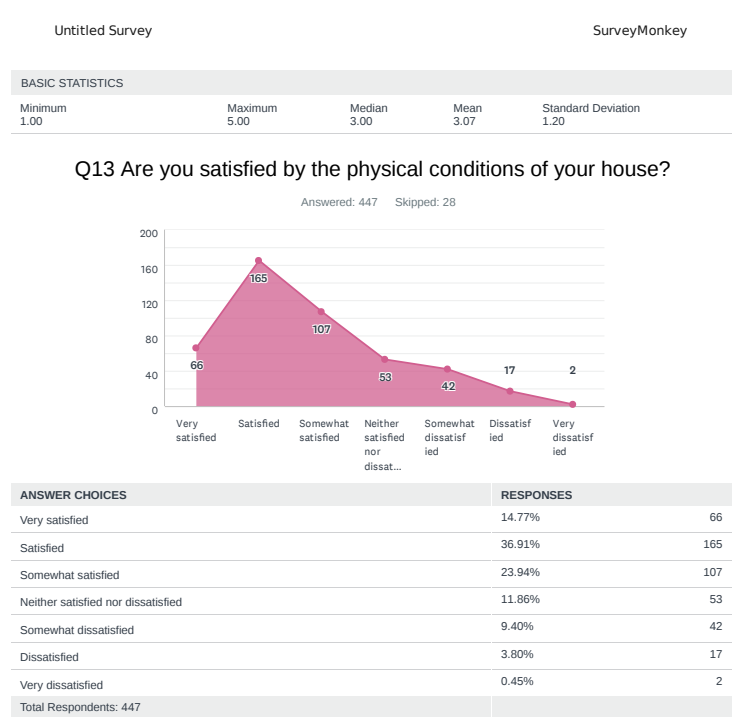
Answered: 464 Skipped: 11



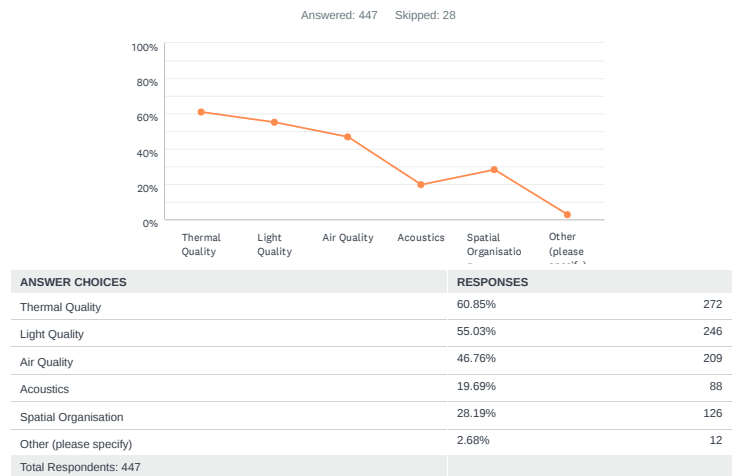
Q12 Are you informed about your houses' structure and material qualities?



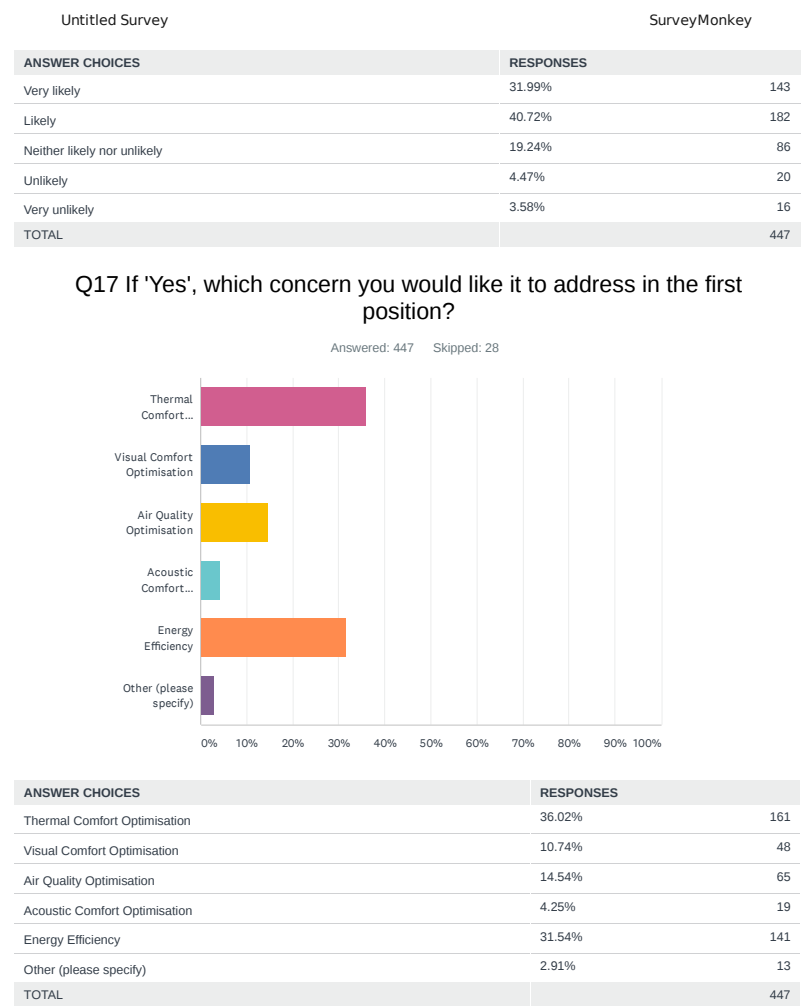
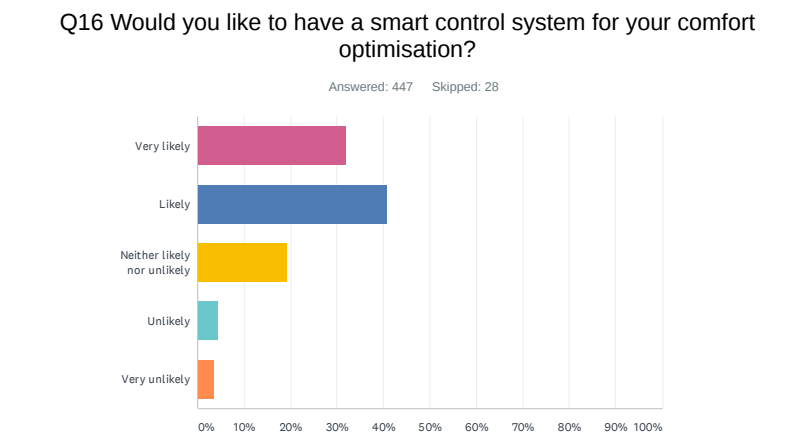
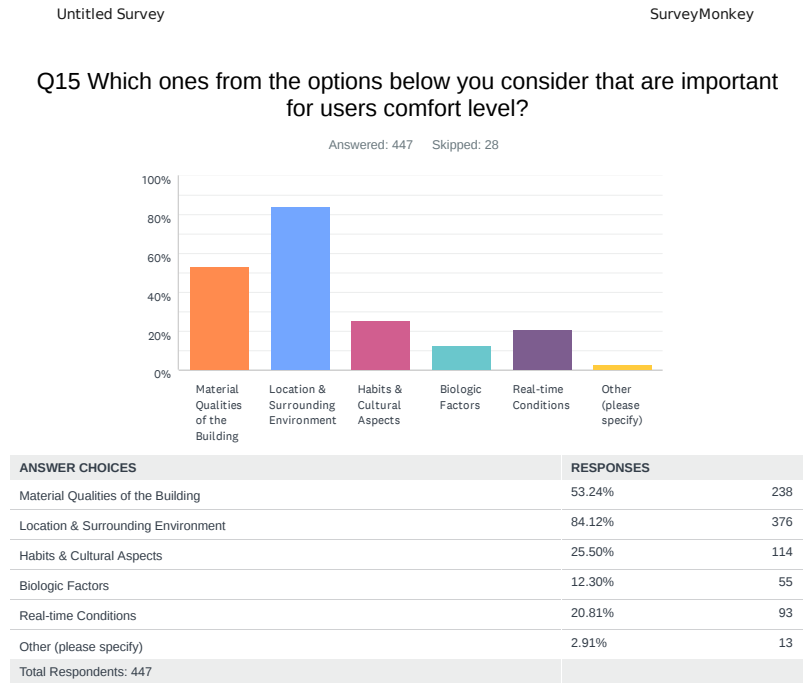
6 / 14



Q14 Which indoor physical condition is more important for your comfort?



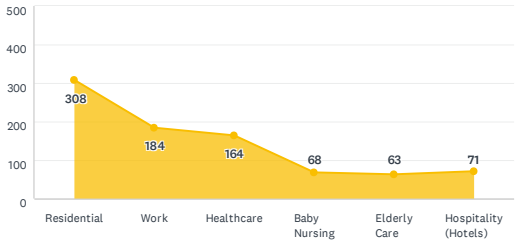
7 / 14





Untitled Survey

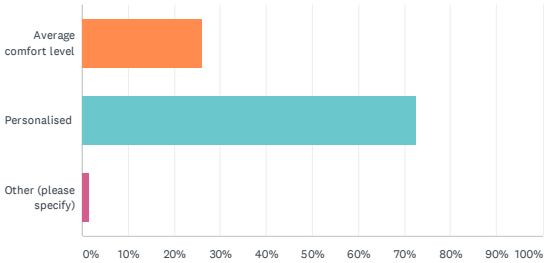
SurveyMonkey



ANSWER CHOICES	RESPONSES	
Residential	71.63%	308
Work	42.79%	184
Healthcare	38.14%	164
Baby Nursing	15.81%	68
Elderly Care	14.65%	63
Hospitality (Hotels)	16.51%	71
Total Respondents: 430		

Q19 Do you think comfort optimisation should take reference from average values or users' personal input?

Answered: 430 Skipped: 45



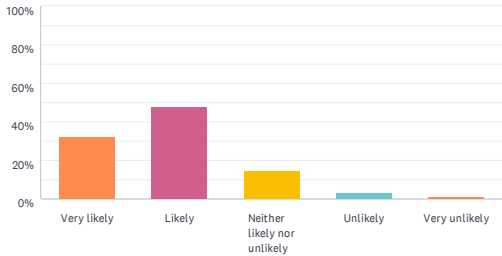
ANSWER CHOICES	RESPONSES	
Average comfort level	26.05%	112
Personalised	72.56%	312
Other (please specify)	1.40%	6
TOTAL		430

Q20 In case of you have minors, people with special attention or elderly people in your household, how likely you would like to manage their comfort level by an automatised platform?

Answered: 430 Skipped: 45

Untitled Survey

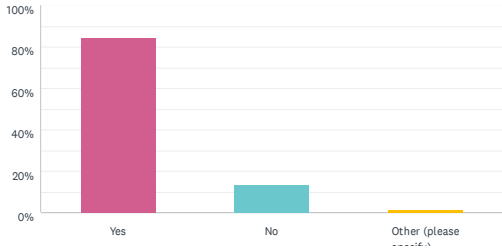
SurveyMonkey



ANSWER CHOICES	RESPONSES	
Very likely	32.56%	140
Likely	48.14%	207
Neither likely nor unlikely	14.88%	64
Unlikely	3.49%	15
Very unlikely	0.93%	4
TOTAL		430

Q21 Do you know about smart home technologies?

Answered: 430 Skipped: 45



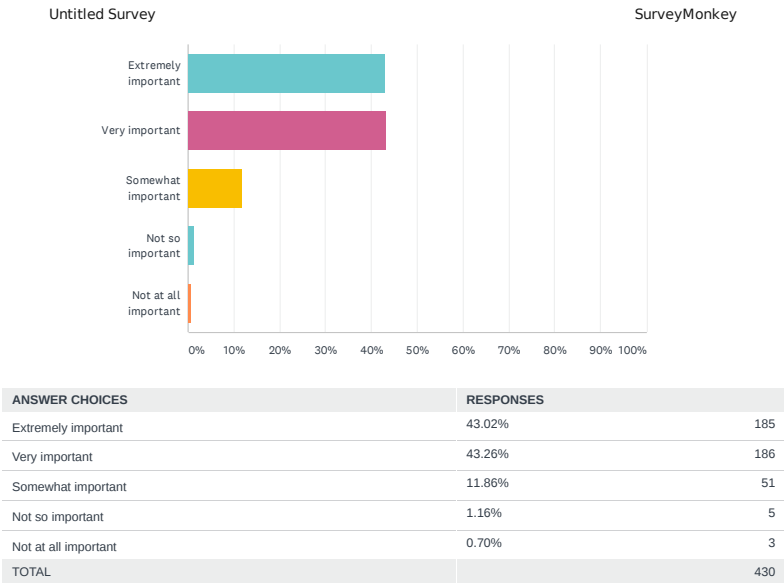
ANSWER CHOICES	RESPONSES	
Yes	84.88%	365
No	13.72%	59
Other (please specify)	1.40%	6
TOTAL		430

Q22 You consider energy consumption, monitoring, and efficiency...

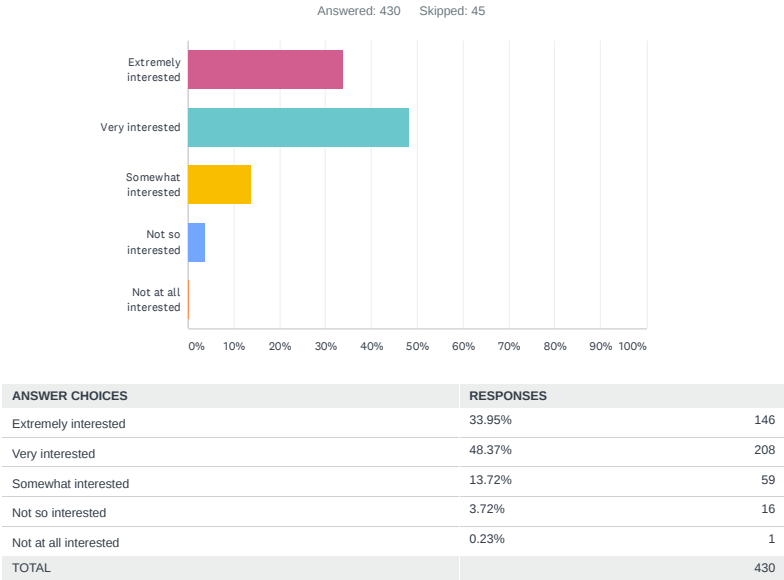
Answered: 430 Skipped: 45

SYMBIOTIC DATA PLATFORM

usability & sensitivity

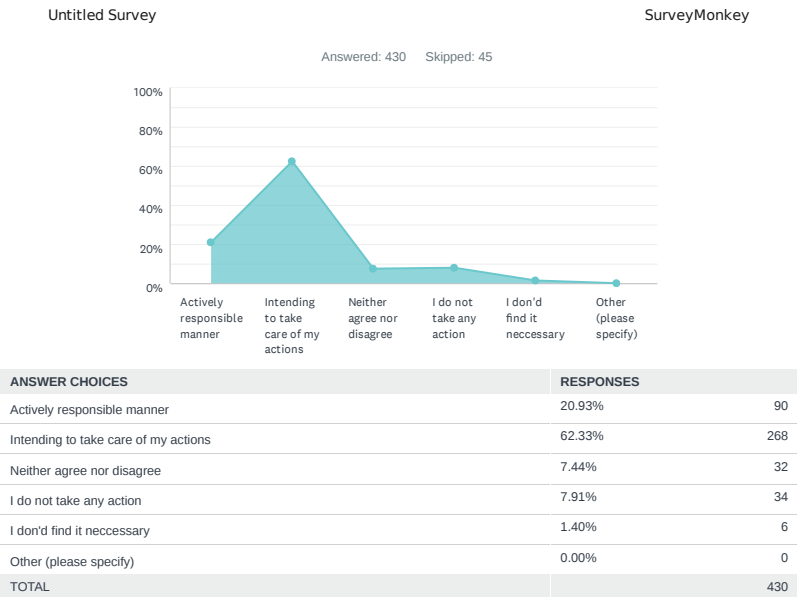


Q23 Would you be interested to see analytics of your energy consumption?

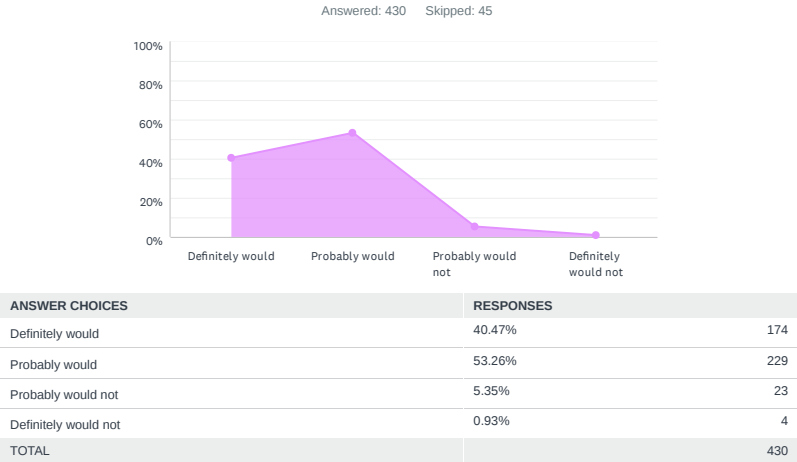


Q24 Do you currently have an action on reducing consumption or energy efficiency?

12 / 14



Q25 If there will be a platform that does comfort optimisation and improves energy efficiency together, how likely would you be using that service?



Q26 How likely would you be for paying such a service?

Answered: 430 Skipped: 45

13 / 14



#	RESPONSES	DATE
1	yes I want, but I don't know how.	2/21/2020 2:57 PM
2	I currently have nest in my home, which I am very happy with. I find I leave it on eco mode most of the time because it is reasonable and a good reminder that the thermal temperature is tolerable.	2/9/2020 7:11 PM
3	Central control system friendly usable	2/6/2020 11:32 PM
4	Xx	2/4/2020 3:00 AM
5	I want to control my expenses in relation to my useage. I don't want to use excess energy.	2/2/2020 2:17 PM
6	online platform where energy consumption data is gathered and a personalized tips/ actions are offered, and energy provider suggestions	2/1/2020 3:23 PM
7	Thermal and light conditions as they come forth as where the most energy waste occurs as far as I'm concerned. Way to go Zeyno.* :)	1/30/2020 5:30 PM
8	Spending little money (State/European Inion supported)	1/30/2020 5:16 PM
9	I don't know	1/30/2020 1:10 AM
10	Being able to consume less energy	1/30/2020 12:09 AM
11	Providing smart solutions.	1/29/2020 6:36 PM
12	Interior lighting and HVAC systems	1/29/2020 2:31 PM
13	A scientifically proven service that targets maximum energy savings and optimum efficiency	1/29/2020 2:28 PM
14	Control of the thermal condition automaticly.	1/29/2020 1:52 PM
15	It is necessary to have smart technologies for optimization and/or energy efficiency but I don't have an idea how it could be.....	1/29/2020 11:33 AM
16	An alarm that works when my threshold value for enegy consumption is exceeded.	1/29/2020 10:43 AM
17	AN AUTOMIZED SERVICE WHICH PERIODICALLY INFORMS THE PERFORMANCE-OUTPUT-BENEFITS (GAINS)	1/29/2020 10:30 AM
18	electric, heating and water consupcion	1/29/2020 10:03 AM
19	Smart home service to take control of everything by an application in my phone	1/29/2020 9:53 AM
20	The balance of price/quality.	1/29/2020 9:41 AM
21	Solar energy service and air quality assurance	1/29/2020 9:33 AM
22	The service that I am able to control and monitor.	1/29/2020 1:31 AM
23	www.arijeothermal.com.tr	1/29/2020 1:28 AM
24	Cheap	1/28/2020 9:04 PM
25	A personalised, cheap and highly efficient system.	1/28/2020 8:56 PM
26	Energy efficiency	1/28/2020 5:03 PM
27	Tips for reducing energy consumption and energy efficieny	1/28/2020 2:55 PM
28	smart monitoring systems attached to energy consumption devices, and mobile sensing	1/28/2020 2:12 PM
29	Energy Tracking System which i already had in my current house	1/28/2020 2:11 PM
30	Smart adaptive sensors for regulating thermal/sound/air/etc. quality of the interior.	1/28/2020 11:17 AM
31	People should be more conscious.They should not waste energy..	1/28/2020 10:42 AM
32	Probably an App	1/28/2020 10:41 AM
33	I have no worries and I have no idea	1/28/2020 10:15 AM
34	Better building design	1/28/2020 10:11 AM
35	Heating Lihgting	1/28/2020 7:27 AM
36	Solar energy	1/28/2020 2:31 AM
37	Society should be informed and accessible	1/27/2020 9:25 PM
38	by an expert company	1/27/2020 9:07 PM
39	I don't have any idea	1/27/2020 8:57 PM
40	Well I would like a system that essentially brings optimisation and effiency without compromising from practicality and user experience. So preferably some tablet with all the information which is listed in a way so that anyone, meaning the average consumer could understand and evaluate the information and act accordingly.	1/27/2020 8:10 PM
41	Personal onely	1/27/2020 8:06 PM
42	Energy production	1/27/2020 6:52 PM
43	I don't know yet	1/27/2020 6:46 PM
44	I don't know	1/27/2020 6:45 PM

SYMBIOTIC DATA PLATFORM

usability & sensitivity

45	Thermal and Air quality	1/27/2020 6:16 PM
46	Sensors and devicew are still so expensive	1/27/2020 5:14 PM
47	An automated platform that will not only adjust temperature levels but also monitors air quality would be good. Also in spaces where multiple people work/live there should be a way to optimize the comfort for majority.	1/27/2020 4:32 PM
48	Full detail about air quality, carbon footprint, energy usage and reduction techniques.	1/27/2020 4:30 PM
49	An alarm system or statistical information regarding my usage of some facilities, if I exceed my own preferred limit or global standards for consumptions would like to know. I would like to know my carbon food print as well.	1/27/2020 4:14 PM
50	Natural Daylight Optimization, Solutions by Amorphous Structure and Additive Manufacturing	1/27/2020 3:55 PM
51	Home visit and test measurementd	1/27/2020 3:13 PM
52	In person or call center	1/27/2020 1:36 PM
53	Having this system built into the thermostat so there is no monthly fee and regulated by the energy company that provides electricity or an online app on your phone. I think these things should be built in and replace the current model of thermostats and electric companies. I think it should be free or cheaper than previous systems so that the public starts becoming more energy efficient and conscience because it's not only better for the environment but better for immediate savings in their electric bill. It is like these new companies that offer plastic free products (for example laundry detergent, it comes in little soap bars that you simply throw into the washer, there is no large plastic container to hold the cleaning contents, therefore saves with environmental waste and cost of transport, cost of supplies. Yet the company charges 10x more for their product than the one that occupies much more space in the delivery truck and needs additional materials to go to the public. This is not helping the consumer choose the smarter more ecologically friendly choice. The ecologically smarter choices should be cheaper so the public is more likely to buy it! Not everyone can afford the more expensive option, even if it's better for the environment.	1/27/2020 1:32 PM
54	Mobile app	1/27/2020 1:07 PM
55	Thanks!	1/27/2020 12:58 PM
56	heating	1/27/2020 12:18 PM
57	Room by room heat control - auto detect occupied rooms and non occupied rooms. Intelligent curtain system to take care of light as you like and working in connection with thermal requirements (non-occupied rooms can get most light and occupied rooms can get desired light). An intelligent follow me music system, playing for occupied rooms, saving energy in non-occupied ones. Fast hot water delivery systems to taps to avoid losing water waiting for the heated water coming. Intelligent room lightings to be turned off when unoccupied. Intelligent garden watering measuring humidity of soil and providing water as necessary. Waste water accommodation for garden watering. Intelligent wifi systems to turn off broadcast when not used like ehen sleeping increasing sleep quality as well. Programmabe comfort lighting systems imitating comfort conditions user desires while watching tv, reading, listening to music or sleeping/waking up.	1/27/2020 12:13 PM
58	A system to optimize lightning, temperature and etc to reduce carbon footprint and also to increase comfort of residents.	1/27/2020 12:10 PM
59	Leed	1/27/2020 12:00 PM
60	Automated system that can optimize certain actions according to behavior of the users of a building	1/27/2020 11:57 AM
61	An automated platform	1/27/2020 11:55 AM
62	A system showing the amount of energy would be useful	1/27/2020 11:43 AM
63	energy usage optimization system and personalized thermal comfort system	1/27/2020 11:28 AM
64	Related service providers.	1/27/2020 11:27 AM
65	a Building Automation System (BAS) or Building Management System (BMS), where the building is equipped with sensors, meters and a user friendly GUI.	1/27/2020 11:23 AM
66	A service that could be reached conveniently even from mpbile phones, advicing user how to follow implementations to increase his or her comfort and increase energy efficiency	1/27/2020 11:10 AM
67	Smart	1/27/2020 10:42 AM
68	Easily accessible personalized service	1/27/2020 10:36 AM
69	Heat insulation, energy source for heating and air conditioning should come from recycled energy, recycling consumed water.	1/27/2020 4:53 AM
70	Light sensors and waste management services	1/27/2020 3:56 AM
71	An app.	1/27/2020 3:06 AM
72	Solar power	1/27/2020 2:45 AM
73	I don't know	1/26/2020 11:41 PM
74	Energy efficiency	1/26/2020 11:27 PM
75	none	1/26/2020 11:24 PM

76	I don't understand much the wording of the question, but I think the energy efficiency /management should be controlled by the own space, with the help of sensors, AI, etc. Or even better by passive means self-regulation.	1/26/2020 10:25 PM
77	Air and lights/visuality related solutions.	1/26/2020 10:20 PM
78	Tek sefer satin alinan device... not monthly yani	1/26/2020 10:04 PM
79	Smart home technologies probably. Good luck! ☺	1/26/2020 10:04 PM
80	Thermal and visual services	1/26/2020 10:02 PM
81	Non procured "After Sale Service"	1/26/2020 9:38 PM
82	Ecology, carbon footprint of energy and buildconstruction, environment	1/26/2020 9:21 PM
83	LED Ligthning usage, Thermal Insulation, Solar Panels	1/26/2020 9:15 PM
84	A Counseling and application service.	1/26/2020 9:02 PM
85	Quality of light	1/26/2020 8:32 PM
86	not sure, living in energy-efficient buildings maybe	1/26/2020 8:24 PM
87	In-home installed device that could also be monitored through a cellphone app.	1/26/2020 8:00 PM
88	Health Economy	1/26/2020 7:59 PM
89		1/26/2020 7:54 PM
90	No idea	1/26/2020 7:31 PM
91	Not sure until I see what could apply to my apartment.	1/26/2020 7:20 PM
92	balanced heating (or cooling) system	1/26/2020 7:18 PM
93	Personal service	1/26/2020 6:56 PM
94	air quality and termal	1/26/2020 6:53 PM
95	Smart house system that could be controlled from smart phones	1/26/2020 6:50 PM
96	.	1/26/2020 6:47 PM
97	A service that would clearly break down energy consumption cost and identify how to save energy.	1/26/2020 6:45 PM
98	AI powered self managing system	1/26/2020 6:37 PM
99	All confirmed conditions	1/26/2020 6:33 PM
100	to have basic understanding in all aspects of being more effective, efficient and sustainable and help, care the welfare of individual households and environmental concerns.	1/26/2020 6:08 PM
101	Energy efficiency first	1/26/2020 5:54 PM

